Photosynthesis in Higher Plants

OBJECTIVE TYPE QUESTIONS

Multiple Choice Questions (MCQs)

1. Who provided the evidence that glucose is formed during photosynthesis and is then stored in the form of starch?
(a) Sachs (b) Engelmann
(c) Van Niel (d) Blackman

2. Photosynthesis is important because
(a) it is the primary source of food on earth
(b) it is responsible for release of O_2 into the atmosphere by green plants
(c) it is responsible for release of water vapour into the atmosphere
(d) both (a) and (b).

3. A student sets up an experiment on photosynthesis as follows:
He takes soda water in glass tumbler and adds chlorophyll extract into the contents and keeps the tumbler exposed to sunlight hoping that he has provided necessary ingredients for photosynthesis to proceed (*viz*., CO_2, H_2O, chlorophyll and light). What do you think will happen after a few hours of exposure of light?
(a) Photosynthesis will take place and glucose will be produced.
(b) Photosynthesis will take place and starch will be produced which will turn the mixture turbid.
(c) Photosynthesis will not take place because CO_2 dissolved in soda water escapes into the atmosphere.
(d) Photosynthesis will not take place because intact chloroplasts are needed for the process.

4. Which of these is a type of phycobilin pigments?
(a) Phycocyanin (b) Allophycocyanin
(c) Phycoerythrin (d) All of these

5. In a plant cell, which of the following pigments is principle pigment of photosynthesis?
(a) Chlorophyll *a* (b) Chlorophyll *b*
(c) Chlorophyll *d* (d) Carotenoids

6. Red colour of tomatoes and carrots is due to the presence of a type of carotene pigment
(a) lutein (b) lycopene
(c) fucoxanthin (d) phycoerythrin.

7. During photocatalytic splitting of water, liberation of O_2 requires
(a) Mn^{2+} (b) Cl^-
(c) Ca^{2+} (d) all of these.

8. DCMU inhibits
(a) PS II
(b) PS I
(c) chloroplast synthesis
(d) oxidative phosphorylation.

9. Photolysis of two water molecules yield
(a) 2 electrons and 4 protons
(b) 4 electrons and 4 protons
(c) 4 electrons and 2 protons
(d) 2 electrons and 2 protons.

10. Which one of the following statements about the events of non-cyclic photophosphorylation is not correct?
(a) Photolysis of water takes place.
(b) Only one photosystem participates.
(c) ATP and NADPH are produced.
(d) O_2 is released.

11. Non-cyclic photophosphorylation is also known as
(a) photolysis (b) photorespiration
(c) Z-scheme (d) biosynthetic phase.

12. Which of the following contains copper?
(a) Quinone (b) Plastoquinone
(c) Plastocyanin (d) Cyt b_5

13. In PS II, active chlorophyll is
(a) P_{680} (b) P_{700}
(c) P_{673} (d) P_{720}.

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

15. During dark reaction the three carbon atoms of 3-PGA are derived from
(a) RuBP only (b) CO_2 only
(c) RuBP + CO_2 (d) RuBP + CO_2 + PEP.

16. Calvin cycle has three stages.
1. Reduction during which carbohydrate is formed at the expense of photochemically made ATP and NADPH.
2. Regeneration during which carbon dioxide acceptor 1, 5-RuBP is formed.
3. Carboxylation during which CO_2 combines with 1,5 RuBP.

Identify the correct sequence.
(a) 3, 1, 2 (b) 3, 2, 1
(c) 1, 2, 3 (d) 2, 1, 3

17. The carbon dioxide acceptor in Calvin cycle/ C_3 plants is
(a) Phosphoenol pyruvate (PEP)
(b) Ribulose-1, 5-biphosphate (RuBP)
(c) Phosphoglyceric acid (PGA)
(d) Ribulose monophosphate (RMP).

18. CAM plants do not show photorespiration due to
(a) keeping stomata open during day time
(b) using PEP carboxylase
(c) fixing CO_2 into organic acid in night and releasing CO_2 during day
(d) performing Calvin cycle at night.

19. Carbon in carbon dioxide is radioactively labelled. The product in which radioactive carbon can be traced in C_3 plants is
(a) PEP (b) RuBP
(c) PGAL (d) PGA.

20. Glucose synthesis occurs during which stage of C_3 cycle?
(a) Carboxylation (b) Oxygenation
(c) Reduction (d) Regeneration

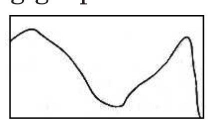
21. Law of limiting factor is
(a) law of maximum (b) law of minimum
(c) law of optimum (d) all of these.

22. A point at which illuminated plant parts stop absorbing CO_2 from their environment, is known as
(a) CO_2 compensation point
(b) CO_2 saturation point
(c) CO_2 optimum point
(d) CO_2 limiting point.

23. Plant factors affecting photosynthesis include
(a) number, age, size and orientation of leaves, mesophyll cells and chloroplast, internal CO_2 conc., the amount of chlorophyll
(b) nature of leaves, size of mesophyll cells and light only
(c) mesophyll cells and temperature only
(d) quantity of chlorophyll, size of leaves only.

24. Thylakoids possess photosynthetic complexes called
(a) photosystem I and II
(b) cyt $b_6 f$ complex
(c) ATP synthetase
(d) all of these.

25. The following graph shows the



(a) absorption spectrum of chlorophyll *a*
(b) absorption spectrum of chlorophyll *b*
(c) action spectrum of photosynthesis
(d) both (a) and (b).

26. Which of the following is correct about chlorophyll *a* and *b* in the leaves of higher plants?
(a) Both are present in equal proportion.
(b) Chlorophyll *a* is more than chlorophyll *b*.
(c) Chlorophyll *a* is less than chlorophyll *b*.
(d) Chlorophyll *b* is ten times more than chlorophyll *a*.

27. Which of the following best represents Hill reaction?
(a) Photolysis of water
(b) Photolysis of water releasing oxygen
(c) Photolysis of water in light resulting in reduction of NADP and release of oxygen
(d) Photolysis of water and release of hydrogen

28. Which one of the following is false about the activities associated with PS-I and PS-II in non-cyclic photophosphorylation?

(a) Water is oxidised in PS-II, but not PS-I.

(b) Photons (light) are needed to activate both PS I and PS-II.

(c) Photolysis of water, formation of ATP and NADPH occur.

(d) Production of NADPH + H^+ is associated with PS-II, not with PS-I.

29. Basic feature of Kranz anatomy of C_4 plants is

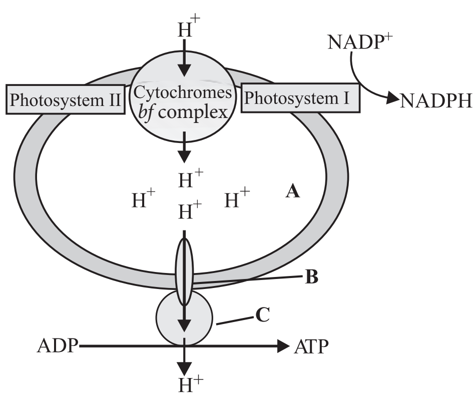
(a) chloroplasts in mesophyll cells are granal whereas in bundle-sheath they are agranal, that favours light reaction and carbon reactions separately.

(b) presence of granal chloroplasts in mesophyll and epidermal cells

(c) presence of typical granal chloroplasts in bundle sheath cells and rudimentary chloroplasts in mesophyll cells

(d) presence of rudimentary chloroplasts in bundle sheath cells and typical granal chloroplasts in mesophyll cells.

30. Identify the parts marked as A , B and C in the given figure showing ATP synthesis through chemiosmosis.



	A	B	C
(a)	Thylakoid lumen	F_0	F_1
(b)	Thylakoid lumen	F_1	F_0
(c)	Chloroplast lumen	F_0	F_1
(d)	Chloroplast lumen	F_1	F_0

31. Read the given statements and select the correct option.

Statement 1 : 6 molecules of CO_2, 12 molecules of NADPH$^+$ + H^+ and 18 ATP are used to form one hexose molecule.

Statement 2 : In light reaction formation of ATP and NADPH take place.

(a) Both the statements are true and statement 2 is a correct explanation for statement 1.

(b) Both the statements are true but statement 2 is not a correct explanation for statement 1.

(c) Statement 1 is true but statement 2 is false.

(d) Both the statements are false.

32. Which of the following is mismatched?

(a) Photosystem I – Uses the P_{700} molecule in its photocenter.

(b) Antenna complex – Contains hundreds of pigment molecules.

(c) PGA – 3-carbon compound.

(d) Dark reaction – Takes place in the grana of the chloroplast.

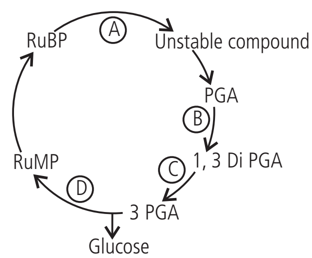
33. The Z scheme of photophosphorylation follows the following sequence:

PS II $\xrightarrow[A]{}$ e^- acceptor $\xrightarrow[B]{}$ ETS $\xrightarrow[B]{}$ PS I $\xrightarrow[C]{}$ e^-acceptor $\xrightarrow[D]{}$ NADP$^+$

Which of the following options is correct for A, B, C, D transfer of electrons?

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

34. In a condensed schematic representation of dark reaction of photosynthesis given below, steps are indicated by alphabets. Select the option where the alphabets are correctly identified.



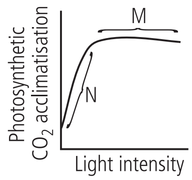
(a) A = CO_2 fixation, B = Reduction, C = Phosphorylation, D = Regeneration

(b) A = Regeneration, B = CO_2 fixation, C = Reduction, D = Phosphorylation

(c) A = CO_2 fixation, B = Phosphorylation, C = Reduction, D = Regeneration

(d) A = CO_2 fixation, B = Phosphorylation, C = Regeneration, D = Reduction

35. A typical light response curve of photosynthesis is shown. The limiting factor/s for photosynthesis at M and N is/are



(a) temperature and CO_2 respectively
(b) CO_2 and light respectively
(c) only CO_2
(d) light and CO_2 respectively.

36. Warburg effect refers to
(a) decreased photosynthetic rate at very high O_2 concentration
(b) increased photosynthetic rate at very high O_2 concentration
(c) decreased photosynthetic rate at very low O_2 concentration
(d) increased photosynthetic rate at very low O_2 concentration.

37. Read the following statements and find out the incorrect one.
(a) Second step of Calvin cycle (*i.e.*, reduction) involve utilisation of 2 molecules of ATP for reduction and 2 of NADPH for phosphorylation per CO_2 molecule fixed.
(b) The regeneration step requires one ATP for phosphorylation to form RuBP.
(c) It is probably to meet the differences in number of ATP and NADPH used in dark reaction that the cyclic phosphorylation takes place.
(d) Plants that are adapted to dry tropical regions have the C_4 pathway.

38. During light reaction, as electrons move through photosystems, protons are transported across the membrane. This happens because of
(a) the primary acceptor of e^- (located towards the outer surface of the membrane) transfers its electron not to an e^- carrier but to H^+ carrier
(b) the primary acceptor of e– transfers only its e^- to e^- carrier
(c) the primary acceptor of e^- transfers only H^+ to the next carrier
(d) NADP-reductase is present in grana.

39. The reactions of Calvin cycle are not directly dependent on light, but they usually do not occur at night. Why?
(a) Night is often too cold for these reactions to occur.
(b) CO_2 concentration in night is too high for these reactions to occurs.
(c) Plants usually open their stomata at night.
(d) Calvin cycle is dependent on the products of light reaction.

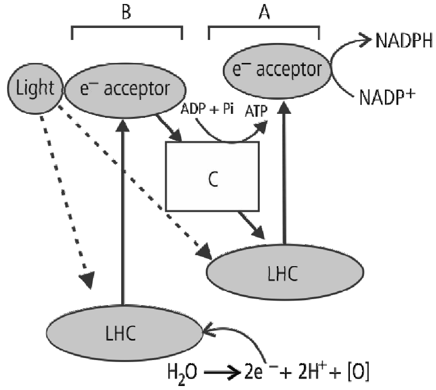
40. Match the following and choose the correct combination from the option given.

	Column I		Column II
A.	Thylakoid of chloroplast	(i)	Kreb's cycle
B.	Stroma of chloroplast	(ii)	Light reaction
C.	Cytoplasm	(iii)	Dark reaction
D.	Mitochondrial matrix	(iv)	Glycolysis

(a) A-(iv), B-(iii), C-(ii), D-(i)
(b) A-(i), B-(ii), C-(iv), D-(iii)
(c) A-(iv), B-(i), C-(iii), D-(ii)
(d) A-(ii), B-(iii), C-(iv), D-(i)

Case Based MCQs

Case I : Study the given schematic diagram and answer the questions from 41 to 45 given below.



41. What do 'B' represents in the given figure?
(a) Photosystem I
(b) Electron transport system
(c) Photosystem II
(d) None of these

42. Electrons lost by PS II are regained from
(a) O_2 (b) CO_2
(c) H_2O (d) none of these.

43. Raw materials required for light reactions are
(a) ADP, ATP and H_2O
(b) ADP, H_2O and NADP
(c) ADP and $NADPH_2$
(d) ATP and NADP.

44. Main substance involved in transfer of electrons in photosynthesis is
(a) phytochrome (b) cytochrome
(c) FAD (d) both (a) and (b).

45. Consider the following.
1. Cytochrome b_6 2. Cytochrome f
3. Plastocyanin 4. Plastoquinone
What is the sequence of these photo-induced electron carries between B to A in photosynthesis?
(a) 4, 1, 2, 3 (b) 3, 4, 1, 2
(c) 1, 2, 3, 4 (d) 3, 2, 4, 1

Case II : Read the following passage and answer questions from 46 to 50 given below:
Photosynthetic reactions which are dependent on the products of light reaction are called biosynthetic phase or dark reactions. There are two main pathways - Calvin cycle and C_4 (dicarboxylic acid) cycle in which assimilatory power (ATP and NADPH) produced during photochemical phase is used in fixation and reduction of carbon dioxide.

46. In C_3 cycle, ATP and NADH required for production of one glucose respectively are
(a) 12 and 18 (b) 18 and 12
(c) 2 and 3 (d) 3 and 2.

47. Which one of following is a special feature of C_4 plants?
(a) They tolerate high temperature.
(b) They have lesser productivity of biomass.
(c) They show less response to high light intensity.
(d) Both (b) and (c)

48. Bundle sheath cells in C_4 plants have
(a) thick walls, large intercellular spaces, large number of chloroplasts
(b) thin walls, no intercellular spaces, large number of chloroplasts
(c) thin walls, large intercellular spaces, no chloroplasts
(d) thick walls, no intercellular spaces, large number of chloroplasts.

49. Where do Calvin pathway takes place in C_3 and C_4 plants?
(a) It takes place in mesophyll cells of both C_3 and C_4 plants.
(b) If takes place is mesophyll cells of C_3 plant and bundle sheath cells of C_4 plant.
(c) Bundle sheath cells of C_3 plant and mesophyll cells of C_4 plant.
(d) It takes place in bundle sheath cells of C_3 and C_4 plants.

50. Read the given statements and answer the follwing questions.
Statement 1 : In C_4 plants, OAA is formed in mesophyll cells.
Statement 2 : Mesophyll cells of C_4 plants have enzyme PEP case but lack RuBisCO.
(a) Both statements 1 and 2 are true.
(b) Statement 1 is true but statement 2 is false.
(c) Statement 1 is false but statement 2 is true.
(d) Both statements 1 and 2 are false.

Assertion & Reasoning Based MCQs

For question numbers 51-60, two statements are given-one labelled Assertion and the other labelled Reason. Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.
(a) Both assertion and reason are true and reason is the correct explanation of assertion.
(b) Both assertion and reason are true but reason is not the correct explanation of assertion.
(c) Assertion is true but reason is false.
(d) Assertion is false but reason is true.

51. Assertion : Plastoquinones act as link between two photosystems.
Reason : The donor of electrons for both photosystems is water.

52. Assertion : Quantum conversion occurs during light reaction.
Reason : Light reaction generates energy-rich compounds.

53. Assertion : A plant growing in complete dark will show only dark reactions.
Reason : Dark reaction produces assimilatory power.

54. Assertion : Plants showing Calvin-Benson pathway are called C_3 plants.
Reason : Plants showing Hatch-Slack pathway are called C_4 plants.

55. Assertion : Plants utilising first RuBP in CO_2-fixations are called C_3 plants.
Reason : Plants utilising first PEP in CO_2-fixations are called C_4 plants.

56. Assertion : Plants possessing C_4-pathway of carbon fixation have a higher net primary productivity than the C_3-pathway possessing plants.
Reason : C_4 plants are more efficient in picking up CO_2 even when it is found in low concentrations.

57. Assertion : Action spectrum of photosynthesis compares well with the absorption spectrum.
Reason : Chlorophyll *a* is the only pigment which can absorb and convert light energy into chemical energy.

58. Assertion : Cyclic photophosphorylation synthesises ATP.
Reason : ATP synthesis in cyclic photophosphorylation is associated with NADPH formation.

59. Assertion : In photorespiration, exchange of gases is independent of light.
Reason : In photosynthesis, the electrons flow from H_2O to NADPH.

60. Assertion : CAM plants lack structural compartmentation of leaf, as found in C_4 plants.
Reason : Stomata of CAM plants are open during the day.

SUBJECTIVE TYPE QUESTIONS

Very Short Answer Type Questions (VSA)

1. Whose hypothesis revealed that plant purifies air while burning candles fouls it?

2. Where do the electrons move from the electron acceptor of PS-II in the Z-scheme?

3. Succulents are known to keep their stomata closed during the day to check transpiration. How do they meet their photosynthetic CO_2 requirements?

4. What would happen to the rate of photosynthesis in C_3 plants if CO_2 concentration level almost doubles from its present level in the atmosphere?

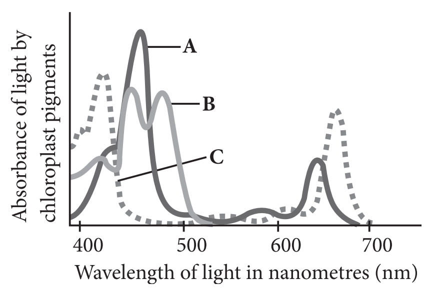
5. Why photosynthesis is an oxidation reduction process?

6. Which range of wavelength (in nm) is called photosynthetically active radiation (PAR)?

7. **(i)** NADP reductase enzyme is located on_______ .
(ii) Breakdown of proton gradient leads to release of_______ .

8. Why is the development of proton gradient across the thylakoid membrane essential for photosynthesis?

9. Identify different pigments A to C in the given graph.



10. How many turns of Calvin cycle are required to generate one molecule of glucose?

Short Answer Type Questions (SA-I)

11. Name the necessary components of the electron transport that process in the light reaction of photosynthesis.

12. What is photorespiration?

13. ATPase enzyme consists of two parts. What are those parts? How are they arranged in the thylakoid membrane and in which part of an enzyme the conformational change occur?

14. **(i)** How many molecules of ATP and NADPH are required to fix one molecule of CO_2?
(ii) Where in the chloroplast does dark reaction occurs?

15. Fill in the blanks at A, B, C, D, E and F and complete the C_4 pathway/Hatch-Slack pathway.

Atmospheric CO_2 enters (A)

↓

CO_2 is accepted by (B) and forms compound (C)

↓

(C) enters into (D) and splits into CO_2 and (E)

↓

CO_2 enters Calvin cycle and 3C acid (F) formed

16. Cyanobacteria and some other photosynthetic bacteria do not have chloroplasts. How do they conduct photosynthesis?

17. Suppose there are plants having high concentration of chlorophyll-*b*, but lack chlorophyll-*a*, will they carry out photosynthesis? Why or why not?

18. Dark reactions are dependent on light yet are called dark reactions. Justify.

19. Why is the lumen of thylakoids acidic while, the stroma is alkaline in nature?

20. How does water stress affect/decrease the rate of photosynthesis?

Short Answer Type Questions (SA-II)

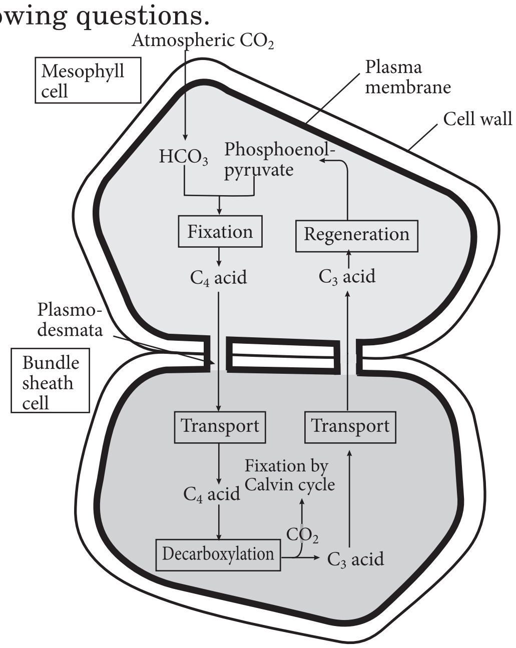
21. Explain the reasons of following.
(i) Photosynthesis can occur in absence of light.
(ii) Even non-green leaves can make the food.
(iii) Photosynthesis can occur under water.

22. How cyclic photophosphorylation is different from non-cyclic photophosphorylation?

23. Differentiate between absorption and action spectrum.

24. Which organism was used by Engelmann in his experiment? What was his experiment?

25. Refer to the given diagram and answer the following questions.

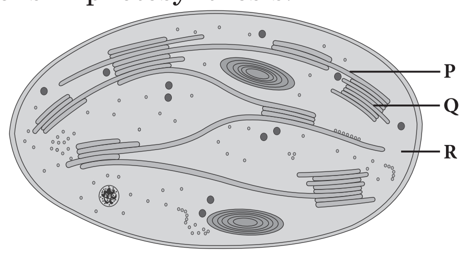


(a) Which group of plants exhibits this type of carbon fixation?
(b) What is the first product of this fixation cycle?
(c) Which enzyme is there in bundle sheath cells and mesophyll cells?

26. A cyclic process is occurring in C_3 plant, which is light dependent and needs O_2. This process doesn't produce energy rather it consumes energy.
(a) Name the given process.
(b) Is it essential for survival?
(c) What are the end products of this process? Where does it occur?

27. How temperature affects the photosynthesis in C_3 and C_4 plants?

28. There is a clear division of labour within the chloroplast. Identify P, Q and R in the given structure of chloroplast and state their specific functions in photosynthesis.



29. What is Emerson enhancement effect?

30. Why photorespiration is absent in C_4 plants?

31. (a) Why does the rate of photosynthesis in plants decrease at higher temperatures?
(b) A plant is provided with all the neccessities required for photosynthesis, i.e., water, CO_2. To provide the light, the plant is kept in moonlight. Will this plant perform photosynthesis? Explain.

32. Represent systematically the process of ATP synthesis through chemiosmosis in chloroplast.

33. List the differences between C_3 and C_4 pathways of dark reaction.

34. **(a)** Which pathway prevents photorespiration in plants? Explain it.
(b) What is the role of RuBisCO?

Long Answer Type Questions (LA)

35. Give a detailed account on factors affecting photosynthesis.

36. Explain the photochemical phase of photosynthesis. What is the light reaction product?

37. Where does Calvin cycle take place in chloroplast? Describe the three phases of Calvin cycle.

38. **(a)** Name the first stable compound formed in sugarcane plant during CO_2 fixation.

(b) Describe Hatch and Slack pathway of CO_2 fixation?

39. Name the cell organelles involved in photorespiration. Explain the mechanism of this process.

ANSWERS

OBJECTIVE TYPE QUESTIONS

1. (a) : Julius von Sachs demonstrated that green parts in plant produce glucose which is stored as starch. Starch is the first visible product of photosynthesis.

2. (d) : Photosynthesis is primary source of food on earth. All animals and heterotrophic plants depend upon photosynthesis. Photosynthesis is the only known method by which oxygen is added to the atmosphere to compensate for oxygen being used in respiration of organisms and burning of organic fuels.

3. (d) : Presence of intact chloroplast is important for photosynthesis.

4. (d) : Phycobilins are important accessory pigments of blue green algae and red algae. Phycocyanin, allophycocyanin and phycoerythrin are types of phycobilins.

5. (a) : Chlorophyll *a* is found in all photosynthetic plants except bacteria. It is universal photosynthetic pigment. Chlorophyll *a* is main pigment of photosynthesis. It performs primary reactions of photosynthesis which involves conversion of light into chemical or electrical energy.

6. (b) : Lycopene is bright red colour carotene pigment which provides color to tomatoes and carrots.

7. (d) : Mn^{2+}, Cl^-, Ca^{2+} elements are required for liberation of oxygen through photolysis of water.

8. (a) : DCMU is a herbicide which does not allow the flow of electrons from PS II to plastoquinone.

9. (b) : 4 electrons and 4 protons are obtained by photolysis of two water molecules.

10. (b) : Both photosystems *i.e.*, PS I and PS II participate during non-cyclic photophosphorylation.

11. (c) : Non-cyclic photophosphorylation is also called as Z-scheme because of its zig-zag shape based on redox potential of different electron carriers.

12. (c) : Plastocyanin is copper containing protein that plays a role in electron transport process. It carries electrons from cytochrome b_6f to PS I.

13. (a) : Photocentre of PS II called P_{680} is highly oxidizing and take part in splitting of water molecule.

14. (d) : In C_4 plants PEP carboxylase enzyme is responsible for primary fixation of CO_2. Here, the mesophyll cells lack RuBisCO enzyme, which can function both as carboxylase and oxygenase. In the presence of PEP carboxylase, oxalo-acetic acid is formed which is either reduced to malic acid or transaminated to form aspartic acid. Thus, in C_4 plants photosynthesis is less limited by atmospheric CO_2.

15. (c) : In dark reactions carbon dioxide combines with the acceptor RuBP in the presence of enzyme RuBisCO and gives 3-phosphoglyceric acid.

16. (a) : Carboxylation, reduction and regeneration are the sequential stages of Calvin cycle.

17. (b) : The first CO_2 acceptor is ribulose-1, 5 biphosphate (RuBP).

18. (c) : In CAM plants, photosynthesis involve double fixation of CO_2 which occurs in the same cells but at different times, night and day. At night CO_2 is fixed into organic acid and during day CO_2 is released from stored organic acid which is again fixed through Calvin cycle. Thus, CAM plants do not show photorespiration.

19. (d) : In C_3 plants, the first stable product is PGA (3-phosphoglyceric acid). Hence radioactivity can be found in 3-phosphoglyceric acid.

20. (c) : Reduction is the stage of Calvin cycle where glucose is formed.

21. (b) : According to law of minimum, when a process is conditioned as to its rapidity by a number of separate factors, the rate of process is limited by the pace of slowest factor.

22. (a) : CO_2 compensation point or threshold value is where illuminated plant parts stop absorping CO_2 from environment.

23. (a) : Number, age, size and orientation of leaves mesophyll cells, chloroplast, internal CO_2 concentration and amount of chlorophyll are plant factors affecting photosynthesis.

24. (d) : Thylakoids possess four types of major complexes-photosystem I, photosystem II, cyt b_6-f complex and coupling factor (ATP synthetase).

25. (c)

26. (b) : Five types of chlorophylls occur in plants are a, b, c, d and e. Out of these only two chlorophylls occur in the chloroplasts of higher plants, a and b. The amount of chlorophyll b is roughly one fourth of total chlorophyll content.

27. (c)

28. (d) : Non-cyclic photophosphorylation is carried out in collaboration of both photosystems I and II. Electron released during photolysis of water is picked up by photocentre of PS II called P_{680}. The same is extruded out when the photocentre absorbs light energy ($h\nu$). The extruded electron has an energy equivalent of 23 kcal/mole. It passes through a series of electron carriers-phaeophytin, PQ, cytochrome b-f complex and plastocyanin. While passing over cytochrome complex, the electron loses sufficient energy for the synthesis of ATP. The electron is handed over to photocentre P_{700} of PS I by plastocyanin. P_{700} extrudes the electron after absorbing light energy. The extruded electron passes through special chlorophyll X, Fe-S, ferredoxin, to finally reach $NADP^+$. The latter then combines with H^+ (released during photolysis) with the help of NADP-reductase to form NADPH. This is called Z scheme due to its characteristic zig-zag shape based on redox potential of different electron carriers.

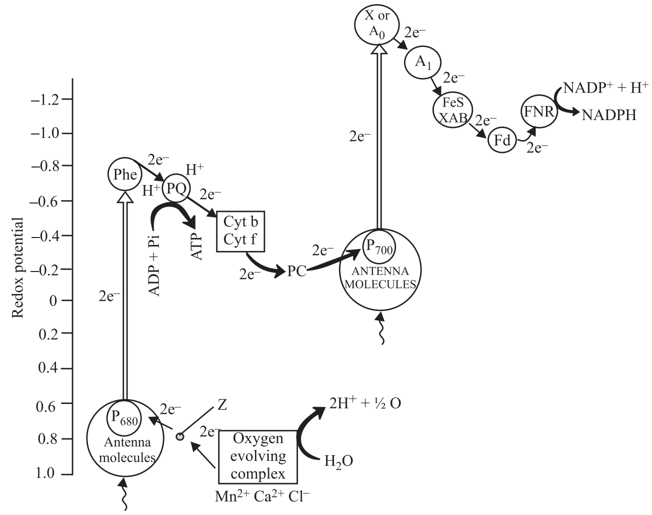
29. (a) : Large cells around the vascular bundles of the C_4 plants are called bundle sheath cells, and the leaves which have such anatomy are said to have 'kranz' anatomy. 'Kranz' means 'wreath' and is a reflection of the arrangement of cells. The bundle sheath cells may form several layers around the vascular bundles; they are characterised by having a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces. The chloroplasts of the mesophyll cells are smaller. They have well developed grana and a peripheral reticulum but no starch.

30. (a)

31. (b) : Six molecules of CO_2 enter Calvin cycle to produce one hexose molecule whereas 18 ATP, 12 NADPH+ H^+ molecules are used up. The light reaction of photosynthesis results in ATP and NADPH formation.

32. (d) : Dark reaction is a thermochemical reaction. It takes place in the stroma of the chloroplast.

33. (a) : In the Z scheme of photophosphorylation transfer of electrons, starts from the PS II, uphill to the acceptor, down the electron transport chain to PS I, excitation of electrons, transfer to another acceptor, and finally down hill to $NADP^+$ causing it to be reduced to NADPH + H^+. Due to its characteristic shape it is called as the Z scheme. This shape is formed when all the carriers are placed in a sequence on the redox potential scale. The Z scheme is represented as follows :



34. (c)

35. (b) : A limiting factor is defined as a factor which is deficient to such an extent that increase in its magnitude directly increases the rate of the process. The effect of limiting factors was studied by Blackman in 1905. He formulated the principle of limiting factors which states that when a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the slowest factor. When light intensity was increased, the rate of photosynthesis increased initially but soon it levelled off. The rate of photosynthesis could be further enhanced only on the increase in availability of CO_2. Thus, initially light intensity was limiting the rate of photosynthesis. When the same was available in sufficiency, CO_2 became limiting.

36. (a) : At very high oxygen concentration, the rate of photosynthesis begins to decline in all plants. This phenomenon is referred to as Warburg effect.

37. (a) : The second step of Calvin cycle (*i.e.*, reduction) involves utilisation of 2 molecules of ATP for phosphorylation and 2 of NADPH for reduction per CO_2 molecule fixed.

38. (a)

39. (d) : Biosynthetic phase of photosynthesis or dark phase is the process that does not directly depend on the presence of light but is dependent on the products of the light reaction, *i.e.*, ATP and NADPH, besides CO_2 and H_2O.

40. (d)

41. (c) : In the given diagram, A represents PS I and B represents PS II.

42. (c) : P_{680} or photosystem II absorbs light energy gets excited and transfer its electrons to phaeophytin. After losing electrons, P_{680} becomes a strong oxidant and pave the way for light dependent splitting of water. The electrons lost by PS II must be replaced. This is done by electrons available due to splitting of water.

43. (b)

44. (b) : Cytochrome is involved in electron transfer.

45. (a)

46. (b) : 18 ATP and 12 NADPH are required for production of one glucose during C_3 cycle.

47. (a)

48. (d) : Bundle sheath cells have thick walls to prevent gaseous exchange. They have no intercellular spaces but have large number of chloroplasts.

49 (b) : Calvin cycle takes place in mesophyll cells of C_3 and bundle sheath cells of C_4 plants.

50. (a)

51. (c) : The donor of electrons for PS II in green plants is water. In PS II, H_2O is oxidised to liberate O_2. The donor of electrons in PS I is plastocyanin, a copper-containing protein that is related to two quinones, *i.e.*, vitamin K (Phylloquinone) and plastoquinone. Plastoquinones are highly mobile lipophilic molecules that could establish a dynamic link between the two photosystems by flowing within the membrane.

52. (b) : On receiving a photon of light energy, the photocentre expels an electron with a gain of energy 23 kcal/mole. It is the primary reaction of photosynthesis which involves the conversion of light energy into chemical form. The phenomenon is also known as quantum conversion as unit quantity of light energy is called quantum.

The function of light reaction phase is to produce assimilatory power consisting of reduced coenzyme NADPH and energy rich ATP molecules.

53. (c) : The synthesis of carbohydrates with the reduction of CO_2 can take place after the plant that had been exposed to light is placed in the dark. This is why reactions involved in this cycle are called "dark reactions". The plant will die in the absence of light - phase of photosynthesis. Dark reaction consumes NADPH and ATP (assimilation power).

54. (b) : Plants that utilise primarily RuBP to fix CO_2, which results in the formation of the three-carbon compound 3-PGA are called C_3 plants. Hatch and Slack proposed a new pathway of CO_2 fixation *via* the carboxylation of PEP. Because the products are four carbon compounds (oxaloacetic, malic and aspartic acids), plants exhibiting this pathway are referred to as C_4 plants.

55. (b) : Plants that utilise primarily RuBP to fix CO_2, which results in the formation of the three-carbon compound 3-PGA, are called C_3 plants. Hatch and Slack proposed a new pathway of CO_2 fixation *via* the carboxylation of PEP. Because the products are four-carbon compounds, plants exhibiting this pathway are referred to as C_4 plants.

56. (a)

57. (b) : An absorption spectrum is a measure of the extent to which a given substance absorbs the light of different colours or wavelengths. An action spectrum is the measure of the efficiency of a process induced by light of different wavelengths but of the same intensity or in other words it is the measure of relative rates of photosynthesis at different wavelengths of light. It is actually a plot of the extent of a response (such as photosynthesis) against different wavelengths of light. A comparison of an action spectrum with the absorption spectrum of a pigment indicates whether or not the pigment is involved in the response. For example, the absorption spectrum of chlorophyll *a* is very similar to the action spectrum of photosynthesis in most plant tissues. Although, light energy is absorbed by chlorophyll as well as by other accessory pigments, only chlorophyll *a* participates in conversion of light energy to chemical energy.

58. (c) : In case of cyclic photophosphorylation, the electron while passing between ferredoxin and plastoquinone and/or over the cytochrome complex, loses sufficient energy to form ATP from ADP and inorganic phosphate.

In cyclic photophosphorylation no NADPH formation takes place. But in case of non-cyclic photophosphorylation, $NADP^+$ reduced through H^+ released during photolysis forms NADPH. ATP synthesis is not direct and the energy released by electron is actually used for pumping H^+ ions across the thylakoid membrane. It creates a proton gradient. The gradient triggers the coupling fact or to synthesise ATP from ADP and inorganic phosphate.

59. (d) : In photorespiration, uptake of oxygen and evolution of carbon dioxide are light dependent.

60. (c) : CAM plants do not exhibit the structural compartmentation (C_3 and C_4 cycles taking place in different cells) of conventional C_4 plants. CAM plants fix CO_2 at night because their stomata are open at night and closed during the day.

SUBJECTIVE TYPE QUESTIONS

1. Joseph Priestley hypothesised that foul air produced during burning of candles or animal respiration could be converted into pure air by plants.

2. The electrons move to downstream components of ETC and finally to PS-I from the electron acceptor of the PS-II in the Z-scheme.

3. Succulents (water storing) plants such as cacti, fix CO_2 into organic compound using PEP carboxylase at night, when the stomata are open.

4. If the CO_2 concentration in C_3plants almost get doubles from its present level in the atmosphere, plants will eventually grow much faster and lead to higher productivity due to higher rate of photosynthesis but then show a decline if CO_2 concentration increases.

5. Photosynthesis is an oxidation reduction process continues because water is oxidised to oxygen and carbon is reduced to carbohydrate.

6. The light range between 400-700 nm is called PAR.

7. **(i)** Grana-lamellae **(ii)** Energy in form of ATP.

8. Development of proton gradient across the thylakoid membrane is essential for ATP synthesis during photosynthesis.

9. A – Chlorophyll *b*
B – Carotenoids
C – Chlorophyll *a*

10. Six turns of Calvin cycles is required to generate one molecule of glucose.

11. The necessary components of the electron transport that process in the light reaction of photosynthesis are cytochrome b, cytochrome f, plastoquinone, plastocyanin, ferredoxin, and $NADP^+$.

12. Photorespiration is the light dependent process of oxygenation of ribulose biphosphate (RuBP) and release of carbon dioxide by the photosynthetic organs of a plant.

13. ATPase enzyme consists of two parts, *i.e.*, a stalk (F_0) and a headpiece (F_1). These two parts are located completely across the inner mitochondrial membrane. The conformational changes occur in the headpiece (F_1) of this enzyme.

14. **(i)** 3 molecules of ATP and 2 molecules of NADPH are required to fix one molecule of CO_2.

(ii) In the stroma of chloroplast.

15. A - Mesophyll cell, B-Phosphoenol pyruvate (PEP), C_4 acid, D-Bundle sheath cells, E-Pyruvate, F-Phosphoglyceric acid (PGA).

16. Cyanobacteria and some other photosynthetic bacteria have thylakoids suspended freely in the cytoplasm (*i.e.*, they are not enclosed in membrane) and also have bacteriochlorophyll to conduct photosynthesis.

17. No, plants will not carry out photosynthesis, as reaction centre is formed by chlorophyll *a*. The other chlorophyll and accessory pigments absorb different wavelengths of light and pass on the energy to reaction centre for more efficient photosynthesis.

18. Dark reactions are dependent on light but not directly, rather they are dependent on products of light reaction, which are ATP and NADPH. Since, facilitation of dark reactions does not need light so, they are called dark reactions.

19. The acidic nature of lumen of thylakoids is due to the accumulation of protons by the spliting of water. The same does not occurs in stroma so, it has alkaline nature.

20. Water stress causes closure of stomata and decreases the availablity of CO_2 for photosynthesis. Water stress also causes wilting of leaves, thus reducing the surface area of leaves for metabolic functions.

21. (i) Photosynthesis can occur in absence of sunlight but only for a certain period. The sunlight originally supplies the energy for conversion of CO_2 to carbohydrate.

(ii) Yes, the chlorophyll is the most prominent plant pigment but not always. Some other accessory pigments such as xanthophylls and carotenoids can also perform photosynthesis separately.

(iii) Photosynthesis can occur under water only when the water is clear and shallow. Some algae (Rhodophyta) can synthesise food at deep water layers as they absorb more blue light region efficiently.

22. Differences between Cylic and non-cyclic photophosphorylation are as follows:

	Cyclic photophosphorylation	Non-cyclic photophosphorylation
(i)	It is performed by photosystem I independently.	It is performed by collaboration of both photosystem II and I.
(ii)	An external source of electrons is not required because the same electrons get recycled.	The process requires an external electron donor.
(iii)	It is not connected with photolysis of water Therefore, no oxygen is evolved.	It is connected with photolysis of water and liberation of oxygen.
(iv)	It synthesises only ATP.	Noncylic photophosphorylation is not only connected with ATP synthesis but also production of NADPH.
(v)	It operates under low light intensity, anaerobic conditions or when CO_2 availability is poor.	Noncyclic photophosphorylation takes place under optimum light, aerobic conditions and in the presence of carbon dioxide.

(vi)	The system does not take part in photosynthesis except in certain bacteria.	The system is connected with CO_2 fixation in all plants.
(vii)	It occurs mostly in stromal or intergranal thylakoids.	It occurs in the granal thylakoids.
(viii)	ATP synthesis is not affected by DCMU.	DCMU inhibits noncylic photophosphorylation.

23. Differences between absorption spectrum and action spectrum are as follows:

Absorption Spectrum	Action Spectrum
It shows the amount of light absorbed at different wavelengths	It shows the use of light energy of different wavelengths in photosynthesis
Absorption spectrum is graphic representation of amount of light of different wave lengths absorbed by a pigment	Action spectrum is graphic representation of the rate of photosynthesis at different wave lengths of light
It is studied directly	It is studied in relation to either O_2 evolved or CO_2 absorbed
Absorption spectrum requires a single exposure to full light	It requires study of light utilisation at various wavelengths

24. T.W. Engelmann experimented on a green alga *Cladophora*. He splits light into its components by the prism and then illuminated *Cladophora* (a green alga) placed in a suspension of aerobic bacteria. He found that bacteria accumulated in the region of blue and red light of the split spectrum. He thus discovered the effect of different wave lengths of light on photosynthesis and plotted the first action spectrum of photosynthesis.

25. (a) : C_4 plants such as monocots, *e.g.*, sugarcane, maize, etc. and dicots, *e.g.*, *Amaranthus* possess these two types of cells, *i.e.*, bundle sheath cells and mesophyll cells (in Kranz anatomy) and exhibit this type of carbon fixation.

(b) A four-carbon compound, oxaloacetic acid is the first product of this C_4 cycle.

(c) Mesophyll cells have PEP carboxylase to fix atmospheric CO_2 to form a 4-carbon compound oxaloacetic acid, whereas bundle sheath cells have RuBP carboxylase which fixes CO_2 to form 3 carbon compound 3 PGA (3 phosphoglyceric acid).

26. (a) : Photorespiration is the light dependent process of oxygenation of ribulose biphosphate (RuBP) and release of carbon dioxide by the photosynthetic organs of plant.

(b) Photorespiration is either a necessary evil of plant metabolism or it may have some adaptive functions that are not apparent. Photorespiration allows plant leaves to use up excess light energy and reduce photooxidative damage when the plant is water-stressed and stomata are closed.

(c) The end product of this process is phosphoglycerate. The site of photorespiration is chloroplast whereas peroxisome and mitochondria are required for completing the process.

27. The light reaction are temperature sensitive but not much affected by temperature change however, dark reaction is temperature controlled because it involves enzymatic reactions. The optimum temperature is 10°–25°C for C_3 plants and 30–40°C for C_4 plants. When temperature is increased from minimum to optimum, the rate of photosynthesis doubles for every 10°C rise in temperature. At low temperature, enzymes become inactive. C_4 plants show little photosynthesis even at not so low temperature (2–10°C) because their enzyme pyruvate phosphate dikinase is particularly sensitive to it. C_3 plants show different responses to lower temperatures depending upon their adaptability. At high temperature, C_3 plants are more affected because of increased affinity of RuBisCO to oxygen.

28. P is stroma lamellae that is the site of cyclic photophosphorylation and synthesis of ATP.

Q is granum where both cyclic and non-cyclic photophosphorylation takes place that results in synthesis of NADPH and ATP.

R is stroma which plays role in CO_2 fixation and synthesis of sugar.

29. Emerson (1957) found a sharp reduction in the rate of photosynthesis when monochromatic beam of more than 680 nm was used alone. It is called red drop. Emerson *et al* (1957) found that rate of photosynthesis can be enhanced if monochromatic beams of two different wavelengths (long and short) were applied simultaneously. It is in excess of sum total of photosynthesis carried out separately by two light beams. The phenomenon is called Emerson effect or photosynthetic enhancement. It is due to (i) presence of different types of harvesting molecules around a trap centre in photosynthetic unit and (ii) presence of two interconnected pigment systems with some common pigments.

30. Ribulose biphosphate carboxylase oxygenase (RuBisCO), the main enzyme of Calvin cycle which fixes CO_2, acts both as oxygenase and carboxylase. In presence of high concentration of O_2, the enzyme RuBisCO acts as oxygenase and splits a molecule of ribulose–1, 5-biphosphate into one molecule each of 3-phosphoglyceric acid and 2-phosphoglycolic acid. This process is called photorespiration. It causes the loss of fixed CO_2 and wastes the work already done. In C_4 plants RuBisCo is located only in bundle sheath cells where photosynthetic release of oxygen does not occur. Bundle sheath cells have a high intracellular concentration of CO_2 due to flow of C_4

acids and their decarboxylation to release CO_2. Therefore, RuBisCO functions purely as carboxylase in C_4 plants and no photorespiration occurs.

31. (a) Temperature does not influence light reactions of photosynthesis but affects the enzyme controlled dark reactions. The optimum temperature for photosynthesis is 18 to 35°C. When temperature is increased from minimum to optimum, the rate of photosynthesis doubles for every 10°C rise in temperature. Above the optimum temperature, the rate of photosynthesis shows an initial increase for short duration but later declines.

(b) The plant will not perform photosynthesis as moonlight does not carry enough energy to excite the chlorophyll molecules-reaction centres PS I and PS II. Hence light-dependent reactions are not initiated.

32. According to chemiosmotic theory, ATP synthesis is linked to the development of a proton gradient across thylakoid membrane. Chemiosmosis requires a membrane, a proton pump, a proton gradient and ATPase. The systematic process of ATP synthesis is as follows :

(i) The protons or hydrogen ions that are produced by the splitting of water accumulate within the lumen of the thylakoids.

(ii) As electrons move through the photosystems, protons are released into the inner side or the lumen side of the membrane.

(iii) Along with electrons that come from the acceptor of electrons of PS I, protons are necessary for the reduction of $NADP^+$ to $NADPH + H^+$. These protons are also removed from the stroma.

(iv) Hence, within the chloroplast, protons in the stroma decrease in number, while in the lumen there is accumulation of protons. This creates a proton gradient across the thylakoid membrane.

(v) The gradient is broken down due to the movement of protons across the membrane to the stroma through the transmembrane channel of the F_0 of the ATPase.

(vi) The break down of the gradient provides enough energy to cause a conformational change in the F_1 particle of the ATPase, which makes the enzyme synthesise several molecules of energy-packed ATP.

33. The differences between C_3 and C_4 pathways of dark reaction are as follows:

	C_3 pathway	C_4 pathway
(i)	Ribulose biphosphate is the first acceptor of CO_2.	Phosphoenol pyruvate is the first acceptor of CO_2, while ribulose biphosphate is the second acceptor.
(ii)	Phosphoglyceric acid is the first product.	Oxaloacetic acid is the first product.
(iii)	The plants operate only Calvin cycle.	Plants operate a dicarboxylic acid cycle in addition to Calvin cycle.
(iv)	CO_2 compensation point is 25 – 100 ppm.	CO_2 compensation point is 0 – 10 ppm.
(v)	Mesophyll cells perform complete photosynthesis.	Mesophyll cells perform only initial fixation.
(vi)	The rate of carbon assimilation is slow.	The rate of carbon assimilation is quite rapid.
(vii)	The plants are unable to perform photosynthesis at very low CO_2 concentration (say 10 – 50 ppm).	Photosynthesis continues even at very low CO_2 concentration of 10 – 50 ppm.
(viii)	The cycle operates in all plants.	The cycle is found only in some plants like maize, sugarcane, etc.
(ix)	Fixation of one molecule of CO_2 requires 3 ATP and 2NADPH.	Fixation of one molecule of CO_2 requires 5 ATP and 2NADPH.

34. (a) : C_4 pathway prevents photorespiration in plants. In C_4 plants, RuBisCO is located only in bundle sheath cells where photosynthetic release of oxygen does not occur. Bundle sheath cells have a high intracellular concentration of CO_2 due to flow of C_4 acids and their decarboxylation to release CO_2. Therefore RuBisCO functions purely as carboxylase in C_4 plants such as sugarcane and hence photorespiration is prevented.

(b) RubisCO or RuBP carboxylase – oxygenese has dual nature. It has affinity for both CO_2 and O_2 but has more affinity for CO_2 than O_2. Thus, the concentrations of two determines which of the two will bind to the enzyme. In a normal condition of C_3 plants, when CO_2 and O_2 concentrations are normal, it acts as carboxylase and fix CO_2 by combining with ribulose biphosphate and C_3 cycle operates normally, producing glucose molecule as by product of photosynthesis. In C_3 plants when O_2 concentration goes up and CO_2 goes down, it starts acting as an oxygenase enzyme and C_2 cycle (photorespiration) starts where RuBP binds with O_2 to from phosphoglycolate and phosphoglyceric acid.

In C_4 plants, RuBP acts as carboxylase and accepts liberated CO2 to form phosphoglyceric acid.

35. Various external as well as internal factors affect the rate of photosynthesis. These are discussed as follows :

External factors

(i) CO_2 concentration : Increase in CO_2 concentration increases rate of photosynthesis in most C_3 plants. When CO_2 concentration is reduced, there comes a point at which illuminated plant parts stop absorbing carbon dioxide from their environment. It is known as CO_2 compensation point or threshold value. At this value, CO_2 fixed in photosynthesis is equal to CO_2 evolved in respiration and photorespiration.

(ii) Light : At low light intensity the rate of photosynthesis is reduced. As the light intensity increases, the rate of photosynthesis also increases. The light intensity at which a plant can perform maximum amount of photosynthesis is called light saturation point.

(iii) Temperature : When temperature is increased from minimum to optimum, the rate of photosynthesis doubles for every 10°C rise in temperature. Above the optimum temperature, the rate of photosynthesis shows an initial increase for short duration but later declines. This decline with time is called time factor.

(iv) Oxygen : At a very high oxygen content the rate of photosynthesis begins to decline in all plants. The phenomenon is called Warburg effect.

(v) Water : The amount of water used in photosynthesis is very small, the rest is lost in transpiration. Even a slight increase in transpiration reduces the leaf hydration that cuts down photosynthesis by causing stomatal closure. Hence, photosynthesis is very sensitive to dehydration.

Internal or plant factors

(i) Chlorophyll-Photosynthesis does not occur in the absence of chlorophyll. Therefore, variegated leaves produce less organic food as compared to completely green leaves.

(ii) Leaf age : It also affects rate of photosynthesis. As a leaf grows, the rate of photosynthesis rises with the age till it becomes maximum at full maturity. Afterwards, the rate of photosynthesis begins to decline.

(iii) Phytohormones : Phytohormones like cytokinins and gibberellins increase the rate of photosynthesis but abscisic acid reduces the same.

(iv) Leaf anatomy : Size, structure, position and frequency of stomata, thickness of cuticle and epidermis, vascular strands distribution, etc., influences the CO_2 diffusion rate into mesophyll cells, availability of light, rate of translocation of end products, etc.

36. Photosynthesis occurs in two phases- photochemical and biosynthetic. Photochemical phase is also called light or Hill (after the name of the scientist who discovered its details) reaction. Biosynthetic phase is also termed as dark or Blackman's (after the name of scientist who first postulated it) reaction.

Photochemical phase occurs inside the thylakoids, especially those of grana region. Photochemical step is dependent upon light. The function of this phase is to produce assimilatory power consisting of reduced coenzyme NADPH and energy rich ATP molecules. Photochemical phase involves the following reactions:

(i) Photolysis of water : The phenomenon of breaking up of water into hydrogen and oxygen in the illuminated chloroplast is called photolysis or photocatalytic splitting of water. Light energy, an oxygen evolving complex (OEC) and an electron carrier are required for this. Oxygen evolving complex (formerly called Z-enzyme) has four Mn ions. Light energised changes in Mn (Mn^{2+}, Mn^{3+}, Mn^{4+}) removes electrons from OH^- component of water forming oxygen. Liberation of oxygen also requires two other ions, Ca^{2+} and Cl^-. The electrons released during photolysis of water are picked up by P_{680} photocentre of photosystem II and follow Z scheme of non-cyclic and cyclic photophosphorylation.

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

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

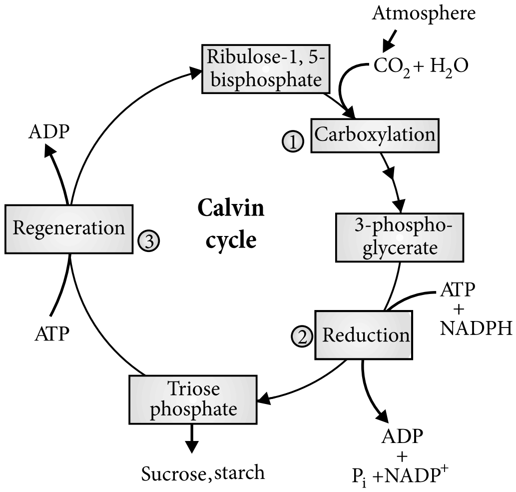
(ii) Production of assimilatory power (NADPH and ATP). The electrons released during photolysis of water are picked up by P_{680} photocentre of photosytem II. On receiving a photon of light energy, the photocentre expels an electron with a gain of energy (23 kcal/mole). It is the primary reaction of photosynthesis which involves the conversion of light energy into chemical form. The phenomenon is also known as quantum conversion. The electron extruded by the photocentre of photosystem II is picked up by the quencher phaeophytin. From here, the electron passes over a series of carriers in a downhill journey losing its energy at every step. The major carriers are plastoquinone (PQ), cytochrome b–f complex and plastocyanin (PC). While passing over cytochrome complex, the electron loses sufficient energy for the creation of proton gradient and synthesis of ATP from ADP and inorganic phosphate. The process is called photophosphorylation (non-cyclic).

From plastocyanin the electron is picked up by the trap centre P_{700} of photosystem I. On absorbing a photon of light energy, P_{700} pushes out the electron with a gain of energy. The electron passes over carriers X (a special chlorophyll molecule), FeS, ferredoxin and NADP-reductase. The latter gives electrons to $NADP^+$ for combining with H^+ ions to produce NADPH.

$$NADP^+ + 2e^- + H^+ \xrightarrow[\text{NADP reductase}]{} NADPH$$

NADPH is strong reducing agent. It constitutes the reducing power which also contains a large amount of chemical energy. The products of light reaction are ATP, NADPH and oxygen. Oxygen diffuses out of the chloroplast while ATP and NADPH are used to drive the processes leading to synthesis of food.

37. Calvin cycle takes place in stroma of the chloroplast. Calvin cycle can be described under three stages: carboxylation, reduction and regeneration.



(i) Carboxylation: Carboxylation is the fixation of CO_2 into a stable organic intermediate. A 5-carbon pentose sugar, ribulose 1,5 bisphosphate (RuBP) is the first acceptor of CO_2. Carboxylation of RuBP by atmospheric CO_2 in presence of the enzyme RuBP carboxylase or RuBisCO is the first step in Calvin cycle. Six molecules of RuBP combine with six molecules of CO_2 to form six molecules of a transient unstable compound 2 carboxy, 3-keto 1, 5 biphosphoribotol. This compound immediately breaks into 2 molecules of phosphoglyceric acid (PGA, 3C) with the help of the enzyme carboxydismutase.

$$\text{RuBP} + CO_2 \xrightarrow[Mg^{2+}]{\text{RuBP carboxylase}} \text{2 carboxy - 3 keto, 1, 5-biphosphoribotol}$$

$$\text{2 carboxy 3-keto 1, 5-biphosphoribotol} + H_2O \rightarrow \text{3-PGA}$$

(ii) Reduction: Phosphoglyceric acid or PGA is further phosphorylated by ATP with the help of enzyme triose phosphate kinase.

$$\text{3 PGA} + \text{ATP} \xrightarrow[\text{kinase}]{\text{Phosphoglycerate}} \text{1, 3-biPGA} + \text{ADP}$$

Biphosphoglyceric acid is reduced by NADPH through the agency of enzyme glyceraldehyde 3-phosphate dehydrogenase (triose phosphate dehydrogenase). It produces glyceraldehyde 3-phosphate or 3-phospho-glyceraldehyde (3PGAL).

$$\underset{\text{(2 mols)}}{\text{1, 3-BiPGA}} + \underset{\text{(2 mols)}}{\text{NADPH}} \xrightarrow[\text{dehydrogenase}]{\text{Glyceraldehyde 3-phosphate}} \underset{\text{(2 mols)}}{\text{3PGAL}} + \underset{\text{(2 mols)}}{H_3PO_4} + \underset{\text{(2 mols)}}{NADP^+}$$

Glyceraldehyde-3-phosphate is a key product which is used in synthesis of both carbohydrates and fats. For forming carbohydrates, or glucose, a part of it is changed into its isomer called dihydroxyacetone-3-phosphate (DHAP). The enzyme that catalyses the reaction is phosphotriose isomerase.

$$\underset{\text{(1 mol)}}{\text{3 PGAL}} \xrightarrow[\text{isomerase}]{\text{Phosphotriose}} \underset{\text{(1 mol)}}{\text{3-DHAP}}$$

In presence of the enzyme aldolase, PGAL (3C) and DHAP (3C) form hexose sugar, fructose 1,6 biphosphate (6C). Fructose 1,6 biphosphate (F-1, 6BP) is then dephosphorylated first to fructose mono-phosphate (or fructose-6-phosphate, F-6-P). Here, phosphatase enzyme catalyses the reactions. In presence of the enzyme isomerase, some fructose monophosphate molecules are isomerised to glucose monophosphate (G-6-P) and ultimately glucose (6C) is produced. The hexose sugars are further converted to sucrose or to starch.

$$\text{3 PGAL} + \text{DHAP} \xrightarrow{\text{Aldolase}} \text{F-1, 6BP}$$

$$\text{F-1, 6BP} + H_2O \xrightarrow{\text{Phosphatase}} \text{F-6-P} + H_3PO_4$$

$$\text{F-6-P} \xrightarrow{\text{Isomerase}} \text{G-6-P}$$

$$\text{G-6-P} \xrightarrow{\text{Phosphatase}} \text{Glucose} + H_3PO_4$$

As Calvin cycle takes only one carbon (as CO_2) at a time, so it takes six turns of the cycle to produce one molecule of glucose.

(iii) Regeneration of the CO_2 acceptor – RuBP: In the Calvin cycle, the 5 carbon compound RuBP is constantly required for the fixation of CO_2. It is regenerated through a chain of reactions, mediated by different enzymes.

Some molecules of fructose-6-phosphate (F-6-P)combine with PGAL to form erythrose-4-phosphate (E-4-P, 4C) and xylulose-5-phosphate (X-5-P, 5C) in presence of transketolase enzyme. Erythrose-4-phosphate combines with DHAP to form sedoheptulose-7- phosphate (Se-7-BP, 7C) in presence of phosphatase enzyme. This 7 carbon compound combines with PGAL to form xylulose-5-phosphate (R-5-P, 5C) and ribose-5-phosphate (5C). Transketolase is the enzyme in this step. Ribose-5-phosphate is converted to ribulose-5-phosphate (Ru-5-P) by isomerase and xylulose-5-phosphate is converted to ribulose-5-phosphate (5C) by epimerase.

Ribulose-5-phosphate is phosphorylated to produce RuBP (5C). ATP is the donor of one phosphate, in this step.

$$\text{F-6-P} + \text{3 PGAL} \xrightarrow{\text{Transketolase}} \text{E-4-P} + \text{X-5-P}$$

$$\text{E-4-P} + \text{3-DHAP} \xrightarrow{\text{Aldolase}} \text{Se-1,7-BP}$$

$$\text{Se-1,7-BP} + H_2O \xrightarrow[Mg^{2+}]{\text{Sedoheptulose 1, 7-biphosphatase}} \text{Se-7-P} + H_3PO_4$$

$$\text{Se-7-P} + \text{3PGAL} \xrightarrow{\text{Transketolase}} \text{X-5-P} + \text{R-5-P}$$

$$\text{X-5-P} \xrightarrow{\text{Ribulose 5-phosphate epimerase}} \text{Ru-5-P}$$

$$\text{R-5-P} \xrightarrow{\text{Ribulose 5-phosphate isomerase}} \text{Ru-5-P}$$

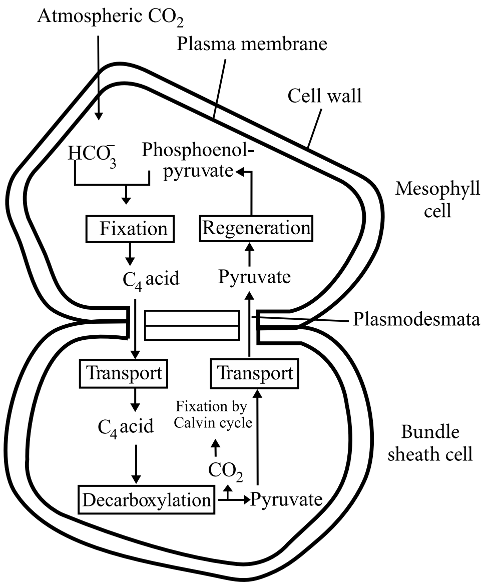
$$\text{Ru-5-P} + \text{ATP} \xrightarrow[Mg^{2+}]{\text{Phosphoribulokinase}} \underset{\text{(RuBP)}}{\text{Ru-1,5-BP}} + \text{ADP}$$

Dark reaction can be summarised as :

$$6CO_2 + 6\text{RuBP} + 18\text{ATP} + 12\text{NADPH} \rightarrow 6\text{RuBP} + C_6H_{12}O_6 + 18\text{ADP} + 12NADP^+ + 18\text{Pi}$$

38. (a) : Sugarcane is a C_4 plant, so first stable compound formed in this plant during CO_2 fixation is oxaloacetic acid.

(b) Mechanism of C_4 pathway (or Dicarboxylic acid pathway or Hatch and Slack pathway) can be illustrated as follows:



It involves following steps:

(i) Initial fixation : In C_4 plants, initial fixation of CO_2 or carboxylation occurs in mesophyll cells. The chloroplasts of mesophyll cells possess enzyme PEP carboxylase (or PEP case) for initial fixation of CO_2. The primary acceptor of CO_2 is phosphoenol pyruvate or PEP. It combines with CO_2 in the presence of PEP carboxylase (or PEPcase) to form oxaloacetic acid or oxaloacetate (OAA).

$$PEP + CO_2 + H_2O \xrightarrow{\text{PEP carboxylase}} OAA + H_3PO_4$$

$$\text{Oxaloacetic acid} + NADPH \xrightarrow{\text{Dehydrogenase}} \text{Malic acid} + NADP^+$$

$$\text{Oxaloacetic acid} + \text{Alanine} \xrightarrow{\text{Transaminase}} \text{Aspartic acid} + \text{Pyruvic acid}$$

(ii) Transport : Malic acid or aspartic acid is translocated to bundle sheath cells through plasmodesmata. Inside the bundle sheath cells they are decarboxylated (and deaminated in case of aspartic acid) to form pyruvate and CO_2. Since a number of mesophyll cells are feeding bundle sheath cells, the latter come to have a carbon dioxide concentrations several times that of atmosphere.

$$\text{Malic acid} + NADP^+ \xrightarrow[\text{enzyme}]{\text{Malic}} \text{Pyruvic acid} + CO_2 + NADPH$$

$$\text{Aspartic acid} + \text{Pyruvic acid} \xrightarrow{\text{Transaminase}} \text{Alanine} + \text{Oxaloacetic acid}$$

$$\text{Oxaloacetate} + H_3PO_4 \xrightarrow{\text{Decarboxylase}} PEP + CO_2 + H_2O$$

(iii) Final Fixation : CO_2 released in bundle sheath cells is fixed through Calvin cycle. RuBP of Calvin cycle is called secondary or final acceptor of CO_2 in C_4 plants.

(iv) Regeneration of PEP : Pyruvate and PEP formed in bundle sheath cells are sent back to mesophyll cells. Here, pyruvate is changed to phosphoenol pyruvate. Energy is required for this that is provided by ATP. The latter is changed into AMP (adenosine monophosphate).

$$\text{Pyruvate} + ATP + H_3PO_4 \xrightarrow[\text{dikinase}]{\text{Phosphopyruvate}} PEP + AMP + PPi$$

Conversion of AMP to ATP requires double the energy than energisation of ADP to ATP. Therefore, actual requirement of energy is equal to two molecules of ATP. So, the overall reaction of Hatch and Slack pathway is as follows:

$$6\ PEP + 6RuBP + 6CO_2 + 30\ ATP + 12\ NADPH \rightarrow 6\ PEP + 6\ RuBP + C_6H_{12}O_6 + 30\ ADP + 30\ H_3PO_4 + 12\ NADP^+$$

39. The site for photorespiration is chloroplast whereas peroxisome and mitochondrion are required for completing the process. The process of photorespiration is cyclic. The enzyme is RuBP carboxylase-oxygenase or RuBisCO. At high temperature, RuBP carboxylase functions as oxygenase and instead of fixing carbon dioxide, it oxidises ribulose 1,5-biphosphate to produce a 3-carbon phosphoglyceric acid and a 2-carbon phosphoglycolate. It is the first reaction of photorespiration. In photorespiration two molecules of phosphoglycolate formed by oxygenation of RuBP are changed into one molecule of PGA and one molecule of CO_2. Thus, 75% of carbon lost during oxygenation of RuBP is recovered by photorespiratory carbon oxygenation or PCO cycle. The detailed pathway of photorespiration is represented by the following diagram: