- A reaction center complex
- Light harvesting complexes
- PS I contains:
- Chlorophyll molecule P700 which absorbs light of 700 nm wavelength
- A primary electron acceptor to accept excited electrons
- PS II contains:
- Chlorophyll molecule P680 which absorbs light of 680 nm wavelength
- A primary electron acceptor to accept excited electrons
- The photosystems function when:
- Photons strike photosynthetic pigments causing electron excitation to higher energy states
- In PS II, excited electrons are accepted by primary electron acceptor
- Water splitting yields O2, H+ and electrons to neutralize excited PS II/P680+/P680
- In PS I, light causes electron excitation which is accepted by PS I primary electron acceptor
- The electrons flow through electron transport chains:
- Excited electrons from PS II pass through electron transport chain to PS I
- This neutralizes PS II/P700+/P700+
- Energy released during electron transport synthesizes ATP (Photophosphorylation)
- Excited electrons from PS I pass through electron transport chain
- Finally reduce NADP+ to NADPH (catalyzed by NADP+ reductase)

4. Write a short note on the negative impact of photorespiration in C3 plants

- Photorespiration, also known as the oxygenase reaction,
- is a wasteful process that impacts photosynthetic efficiency.
- The enzyme Rubisco can act as both carboxylase and oxygenase,
- where O2 and CO2 are competitive substrates.
- When Rubisco reacts with O2 instead of CO2,
- plants make 50% less 3-PGA than they would have if CO2 had been used. This leads to:
- Energy loss - Photorespiration is energy demanding
- Net loss of CO2
- Reduced productivity
- Loss of potential photosynthetic carbon fixation
- However, C4 plants have evolved to minimize these negative impacts through:
- Spatial separation of Rubisco in bundle sheath cells
- Maintaining high CO2 concentration at the site of Rubisco
- Using PEP carboxylase (which has no affinity for O2) for initial CO2 fixation
- Repression of the photorespiration/oxygenase reaction
- As a result, C4 plants have largely overcome the wasteful process of photorespiration

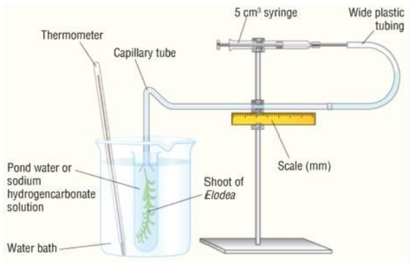
Essay 05:

(a) Explain how to determination of rate of photosynthesis by amount of oxygen released.

Answer

(a) Explain how to determination of rate of photosynthesis by amount of oxygen released.

1. Explain how the apparatus can be used to determine the effect of light intensity, temperature and CO2 concentration for photosynthesis.
2. Take an aquatic plants such *as Hydrilla* or *Elodea*
3. Set up the Audus photosynthesis apparatus.
4. Add 0.01% solution of Sodium bicarbonate in to the test tube
5. Make sure that the micro burette is completely filled with water.
6. Place a table lamp close to the aquatic plants to provide adequate light.
7. Apply little amount of soap on micro burette to allow free collection of air.
8. Observe the oxygen bubbles released due to photosynthesis and how oxygen gets collected at the bend of micro burette.
9. Measure the volumes of oxygen released by using a syringe at definite intervals.
10. Record the results.
11. Rate = Amount of Air collect/Time



12. Intensity of light,
13. Changing the distance of the table lamp.
14. Rate α 1/D2
15. Concentration CO2
16. Add 0.01% of Bicarbonate solution and determine the rate.
17. Repeat with 0.1% Bicarbonate solution.
18. Temperature
19. Carry out experiment at 0^0C, 25^0C and 40^0C.
20. Measure air volumes.

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UNIT 02

Energy Relationships in Metabolic Processes

Photosynthesis

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B.Sc. (Hons), M.Sc.

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Photosynthesis as an Energy fixing Mechanism

Photosynthesis

……………………………………………………………………………………………

…………………………………………………………………………………………..

Chemical energy is stored in chemical bonds of carbohydrates, fats, oils, and proteins. All life on Earth depends on photosynthesis either directly or indirectly. Photosynthesis occurs in ……………………., …………………………... and certain …………………………....

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

Global importance of photosynthesis;

- …………………………………………………………………………………………
  …………………………………………………………………………………………
- …………………………………………………………………………………………
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- …………………………………………………………………………………………..

During photosynthesis CO_2 is …………………….. by the H of H_2O and simple sugars are made using light energy. In eukaryotic photosynthetic cells, ………………………….. are the sites of photosynthesis. Process of photosynthesis consists of two main stages and they are integrated.

- ……………………………………………………………...
- ……………………………………………………………...

There are two types of photosynthetic mechanisms (path ways) based on the number of C atoms of the first stable product of the CO_2 fixation.

- C3 Mechanism — No of C atom of the first stable compound is three
- C4 Mechanism — No of C atom of the first stable compound is four

………………………………………………………………………………take place in the membrane system of ……………………..... They are flattened fluid-filled sacs, which form stacks called grana at ……………………….. Chlorophylls, carotenoids and electron

1. Describes the C4 pathway of photosynthesis

Essay 01 (Model Answer)

- The C4 pathway of photosynthesis involves initial CO2 fixation in mesophyll cells using
- PEP carboxylase as CO2 acceptor.
- The resulting oxaloacetate (OAA) is composed of four carbon atoms,
- which forms the basis for this metabolic pathway name.
- OAA is rapidly converted to malate
- that diffuses to bundle sheath cells.
- Here, CO2 is released by decarboxylating enzymes,
- and the released CO2 is refixed by Rubisco,
- which exclusively operates in bundle sheath cells.
- Malate, after releasing CO2, becomes 3-carbon
- pyruvate.
- Pyruvate diffuses back to leaf mesophyll cells
- and receives phosphate from ATP hydrolysis
- to regenerate PEP.
- C4 plants exhibit specialized Kranz anatomy
- where mesophyll and bundle sheath cells are tightly interconnected by plasmodesmata.
- Bundle sheath cells enclose vascular bundles
- and are surrounded by mesophyll cells.
- The bundle sheath cells have expanded physiological functions
- and higher organelle content compared to C3 plants.
- The chloroplasts in mesophyll cells are different from bundle sheath chloroplasts.
- Mesophyll chloroplasts carry out only light reactions, are rich in grana,
- and are large and highly differentiated for light reactions.
- Bundle sheath chloroplasts possess very few, less differentiated grana or lack them,
- containing only PS I and not PS II, with ATP generated through cyclic electron flow.
- This pathway helps plants improve CO2 fixation efficiency at lower CO2 concentrations
- by preventing photorespiration through spatially separating Rubisco.
- In hot-dry climates, when stomata close to prevent water loss, this pathway is essential.
- The PEP carboxylase enzyme is much more efficient for CO2 fixation than Rubisco
- and has no affinity for O2.
- Because Rubisco operates under high CO2 concentrations in bundle sheath cells, it works more efficiently than in C3 plants,
- consequently requiring less enzyme and providing better nitrogen-use efficiency.

2023 AL

2. (a) Describe the linear electron flow that takes place in the chloroplast during the light reaction of photosynthesis.

1. Electrons flow through Photosystem II (PS I) and Photosystem II (PS II)
2, 3. and other molecular components (embedded in thylakoid membrane of chloroplasts)
4, 5. Each photosystem has a reaction center complex and light harvesting complexes.
6.The reaction center complex contains
7.8. In PS I, chlorophyll molecule P700 absorbs light of 700 nm wavelength. In PS II, chlorophyll molecule P680/which absorbs light of 680 nm wavelength.
9. Striking of photons (of light) on the photosynthetic pigments results in the excitation of electrons from PS II to a higher energy state.
10. These electrons are accepted by the primary electron acceptor in PS II.
11. Splitting of water occurs due to
12. an enzyme catalyzed reaction
13, 14, 15. which yields O2, H+ and electrons.
16. These electrons (released as a result of hydrolysis) neutralize excited PS II or P680+.
17. Striking of photons (of light) on pigments results in excitation of electrons from PS I to a higher energy state
18. These electrons will be accepted by the primary electron acceptor in PS I.
19. Excited electrons at PS II (at primary electron acceptor of PS II) pass through an electron transport chain, 20.
21. to PS I and neutralize the excited PS II/P700+/P700+ while
22.energy released due to the passage of electrons from higher energy state to lower energy state
23. results in synthesis of ATP/ Photophosphorylation
24. Excited electrons at PS I (at primary electron acceptor of PS I) pass through an electron transport chain and
25. reduce NADP+
26. to form NADPH
27. Which is catalyzed by NADP+ reductase.

(b) Briefly discuss the reasons for high efficiency of photosynthesis in C4 plants.

1.(In C4 plants), mesophyll cells and bundle sheath cells are tightly interconnected.
2.CO2 fixation occurs twice,
3.initially in mesophyll cells,
4.secondly, in bundle sheath cells.
5.In mesophyll cells CO2 is fixed by PEP Carboxylase
6.using Phophoenolpyruvate/ PEP as the CO2 accepter.
7.In bundle sheath cells, CO2 is concentrated/ released by decarboxylating enzymes
8.and refixed by Rubisco.
9.Due to high concentration of CO2 at the site of Rubisco/ bundle sheath cells
10.and by spatial separation of Rubisco,
11.photorespiration/ oxygenase reaction (which is a wasteful process) is repressed.

29 + 11= 40 points
Any 37 points X 4 =148 marks
If more than 37 points written add 2 marks
Maximum 150 marks

3. Write a short note on the role of photo-systems in light dependent reaction

- The photosystems play essential roles in the light-dependent reaction through:
- Two distinct photosystems (PS I and PS II) are embedded in thylakoid membrane of chloroplasts
- Each photosystem contains:

B. (i) Chloroplasts are the sites of photosynthesis in eukaryotic cells. They contain thylakoids where light-dependent reactions occur and stroma where the Calvin cycle takes place. Their specialized structure and pigments enable efficient light capture and energy conversion.
(ii) Chlorophyll a is the key light-capturing pigment that participates directly in the light reaction. It becomes excited by absorbing light, transfers electrons to electron acceptors, and initiates the electron transport chain that ultimately produces ATP and NADPH.
(iii) Different wavelengths of light have varying effects on photosynthetic efficiency. Blue and red light are most effective for photosynthesis, while green light is less effective. This is reflected in both the absorption and action spectra of photosynthesis.
(iv) They receive excited electrons from chlorophyll molecules and facilitate electron transport. This electron transport chain ultimately leads to the production of ATP and NADPH needed for the Calvin cycle .
(v) Different photosynthetic pigments absorb different wavelengths of light. This allows plants to utilize a broader range of the light for photosynthesis.

C. (i) Form a 6C molecule which is unstable and immediately breaks down into two molecules of 3-phosphoglycerate (3-PGA). This is the first stable product of photosynthesis. Catalyze by RuBP carboxylase oxygenase (Rubisco).
(ii) In the reduction phase, 1,3-Bisphosphoglycerate is reduced to Glyceraldehyde 3-phosphate (G3P) through step-by-step enzyme-catalyzed reactions. This process requires NADPH and ATP from the light reaction. G3P acts as a precursor for carbohydrate synthesis (glucose).
(iii) Photorespiration occurs because Rubisco is capable of catalyzing two distinct reactions, acting as both a carboxylase and an oxygenase. In the oxygenase reaction, Rubisco uses the same substrate (RuBP) but reacts with O_2 instead of CO_2. CO_2 and O_2 are competitive substrates, with each inhibiting the other's reaction.
(iv) Photorespiration is energy demanding and leads to a net loss of CO_2. When Rubisco reacts with O_2 instead of CO_2, plants make 50% less 3-PGA than they would have if CO_2 had been used. This potentially eliminates the net gain in photosynthetic carbon and reduces productivity.

3. A. (i) C3 : Wheat/Rice/Barley C4 : Maize/Sugarcane/Grasses
(b) C4 plants have Kranz anatomy where mesophyll and bundle sheath cells are tightly interconnected by plasmodesmata. Bundle sheath cells enclose vascular bundles and are surrounded by mesophyll cells. This specialized anatomy allows for efficient CO_2 concentration and reduces photorespiration.
(ii) Non photosynthetic bundle sheath cells present C3 plants and Kranz anatomy with photosynthesis present in C4 plants.
(iii) PEP carboxylase is more efficient for CO_2 fixation than Rubisco and has no affinity for O_2. It allows C4 plants to fix CO_2 initially in mesophyll cells, creating a four-carbon compound (oxaloacetate) that will later release CO_2 in bundle sheath cells.
(iv) C4 plant CO_2 concentration mechanism allows them to acquire enough CO_2 even when keeping their stomata more closed. This reduces water loss through transpiration while maintaining efficient photosynthesis.

B. (i) Mesophyll cell chloroplasts are rich in grana and carry out only light reactions. Bundle sheath chloroplasts possess very few, less differentiated grana or lack them entirely, containing only PS I and not PS II, with additional ATP generated through cyclic electron flow.
(ii) CO_2 enters through stomata, is fixed by PEP carboxylase in mesophyll cells to form oxaloacetate, which is converted to malate. Malate diffuses to bundle sheath cells where CO_2 is released and refixed by Rubisco. The resulting 3-carbon pyruvate returns to mesophyll cells to regenerate PEP.
(iii) C4 plants prevent photorespiration by spatially separating initial CO_2 fixation from the Calvin cycle. The high CO_2 concentration maintained in bundle sheath cells allows Rubisco to operate efficiently with minimal oxygenase activity.
(iv) C4 plants need less Rubisco than C3 plants because they concentrate CO_2 in bundle sheath cells, making the enzyme work more efficiently. This leads to better nitrogen-use efficiency since less protein (Rubisco) is needed for the same photosynthetic output.

C. (i) C4 plants maintain high photosynthetic rates even at lower CO_2 concentrations due to their CO_2 concentrating mechanism. They can operate efficiently at lower CO_2 levels than C3 plants, making them more adapted to conditions where CO_2 might be limiting.
(ii)
Blackman proposed that when a chemical process is affected by more than one factor, its rate is limited by the factor which is nearest its minimum value. This principle explains how different environmental factors interact to determine photosynthetic rate.
(iii) The rate of photosynthesis increases linearly with increasing light intensity initially, then gradually levels off as other factors become limiting. At very high light intensities, chlorophyll may bleach and slow down photosynthesis, though plants have protective mechanisms like thick cuticles and hairy leaves.
(iv) C4 plants can maintain photosynthesis with partially closed stomata, reducing water loss. Their specialized anatomy and biochemistry prevent photorespiration, which typically increases at high temperatures.
(v) carbon dioxide, light, temperature

acceptors are located on this membrane system of thylakoids. Stroma is a ……………. like structure containing …………………. …………………….. and other ………………….., which is the site of the ………………….. cycle.

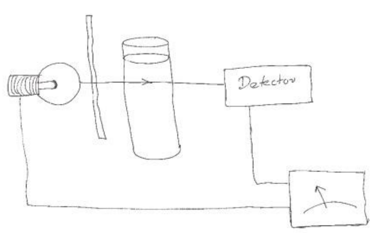
Photosynthetic pigments are ……………………………………………………………….... In a leaf we see ………………………. colour because chlorophylls absorb ……………..., ……………….. and ……………………. light and therefore, they transmit and reflect green colour. Different pigments absorb different wavelengths of light. In chloroplast, there are two types of chloroplast pigments such as ………………………. and ……………………….. …………………………... is the key light capturing pigment and they participate ………………….. in the light reaction of photosynthesis.

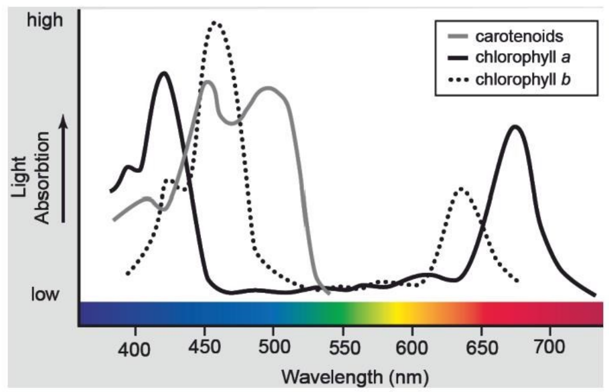
……………………………………………………………., chlorophyll a is more effective for ………………….. and ……………. light. ……………………….. and ……………………….. (carotenes and xanthophylls) are effective in absorption of specific range wavelengths of corresponding to different colours

Other important function of some carotenoids is …………………………... Photoprotection is ……………………………………………………………………………………., if not that excessive light may cause …………………… to the chlorophylls or interact with oxygen and form reactive oxidative molecules which are dangerous to the cell.

Absorption spectrum

An absorption spectrum is ………………………………………………………………………
……………………………………………………………………………………………………





Action spectrum

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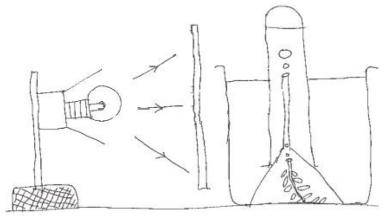

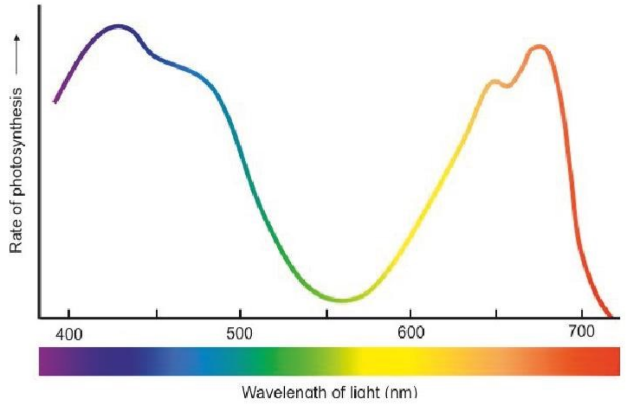

Excitation of chlorophyll by light

Chlorophyll a molecules absorb photons and become …………………….. The energy from the photons …………………….. electrons from the ………………………….. to a higher energy level. The excited electrons carrying higher energy is then accepted by …………………………………………………………………..

Thereafter, the chlorophyll a molecule becomes …………………………… charged. The excited state of electrons is unstable and therefore, they return to their ………………………………………………………………….. The excited electrons may pass through …………………………………………………………………….. until they reach the final electron acceptor.

Chlorophyll a ⟶ **Chlorophyll a$^+$ + e$^-$**

Therefore chlorophyll a is …………………….. and electron acceptor is …………………...

Photosystems

Chlorophyll molecules, other organic molecules and proteins are organized into …………………………….. in the thylakoid membrane of chloroplasts. They are called photosystems. A photosystem contains a ……………………………………………... and ……………………………………………………….. The reaction center complex contains organized proteins holding a pair of ……………………….. molecules and a …………………………………. Light harvesting complexes consist of various photosynthetic pigments. There are two types of photosystems found in the thylakoid membrane.

……………………………………………………………………………

……………………………………………………………………………

(v) Describe the major limiting factors in photosynthesis and their interactions.

……………………………………………………………………………

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……………………………………………………………………………

MCQ Answers

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

Structured Answers

1. A. (i) (a) Photosynthesis is a metabolic process by which light energy is trapped and converted to chemical energy.
(b) Light-dependent reaction and Calvin cycle
(ii) 700 nm (iii) Carboxylation (Carbon fixation), Reduction, Regeneration of carbondioxide acceptor
(iii) 3-phosphoglycerate (3-PGA) (iv) RuBP carboxylase oxygenase or Rubisco
(v) C3 Mechanism and C4 Mechanism

B. (i) Stroma (ii) O2 (g), H+ ions and electrons (iii) Ribulose bisphosphate (RuBP)
(iv) Linear electron flow and Cyclic electron flow
(v) (a) It becomes excited and electrons move to a higher energy level
(b) Absorption and dissipation of excessive light energy
(c) A graph of the relative amounts of light absorbed at different wavelengths by a pigment

C. (i) Photosynthesis is a metabolic process that traps and converts light energy into chemical energy. The chemical energy is stored in chemical bonds of carbohydrates, fats, oils, and proteins.
(ii) light-dependent reaction and the Calvin cycle.
light-dependent reactions produce ATP and NADPH, which are then used in the Calvin cycle to produce glucose from CO2.
(iii) C3 Mechanism involves the formation of a three-carbon compound as the first stable product of CO2 fixation. C4 Mechanism results in a four-carbon compound as the first stable product.
(iv) Thylakoids are flattened fluid-filled sacs that form stacks called grana at intervals. They contain chlorophylls, carotenoids, and electron acceptors on their membrane system. Light-dependent reactions of photosynthesis take place in this membrane system.
(v) Stroma is a gel-like structure containing soluble enzymes and other chemicals. It serves as the site of the Calvin cycle, where CO2 is fixed into glucose using the ATP and NADPH produced in the light -dependent reactions.

2. A. (i) Different pigments absorb different wavelengths of light. Chlorophyll a absorbs violet, blue, and red light, while reflecting green. Chlorophyll b and carotenoids (carotenes and xanthophylls) absorb different specific wavelengths, allowing for more efficient use of the light spectrum.
(ii) Carotenoids absorb and dissipating excessive light energy. This prevents damage to chlorophylls and prevents the formation of reactive oxidative molecules that could be dangerous to the cell.
(iii) An absorption spectrum is a graph showing the relative amounts of light absorbed at different wavelengths by a pigment. It helps understand which wavelengths of light are most effectively captured by different photosynthetic pigments.
(iv) Absorption spectrum shows which wavelengths of light are absorbed by pigments, the action spectrum shows the effectiveness of different wavelengths in stimulating .
(v) When chlorophyll a molecules absorb photons, their electrons become excited and move to a higher energy level. These excited electrons are then accepted by primary electron acceptors, leaving the chlorophyll molecule positively charged. The excited electrons eventually return to their original lower energy state through electron carriers.

(b) Describe the anatomical adaptations of C4 plants.
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....
....
(ii) State differences in the leaf structures of C3 and C4 plants.
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(iii) Explain the significance of PEP carboxylase in C4 plants.
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(iv) How do C4 plants achieve better water-use efficiency than C3 plants?
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B. (i) Describe the chloroplast differences between mesophyll and bundle sheath cells in C4 plants.
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....
(ii) Explain the pathway of CO2 fixation in C4 plants from initial entry to final sugar production.
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....
(iii) Describe how C4 plants prevent photorespiration.
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(iv) Explain the nitrogen-use efficiency advantage of C4 plants.
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C. (i) Describe the relationship between CO2 concentration and photosynthetic rate in C4 plants.
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(ii) Explain Blackman's principle of limiting factors in relation to photosynthesis.
....
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....
(iii) Describe how light intensity affects photosynthetic rate.
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....
....
(iv) Explain how C4 plants adapt to hot, dry climates.
....

They are ……………………………... (PS I) and ………………………………... II (PS II). In the PS I the chlorophyll a molecule is known as …………………... since they absorb light at 700nm wave length effectively. In the PS II the reaction center contains a chlorophyll a molecule which is known as ……………………. which absorbs light having a wavelength of 680 nm.

Light-dependent reaction /Light reaction photosynthesis

Linear electron flow

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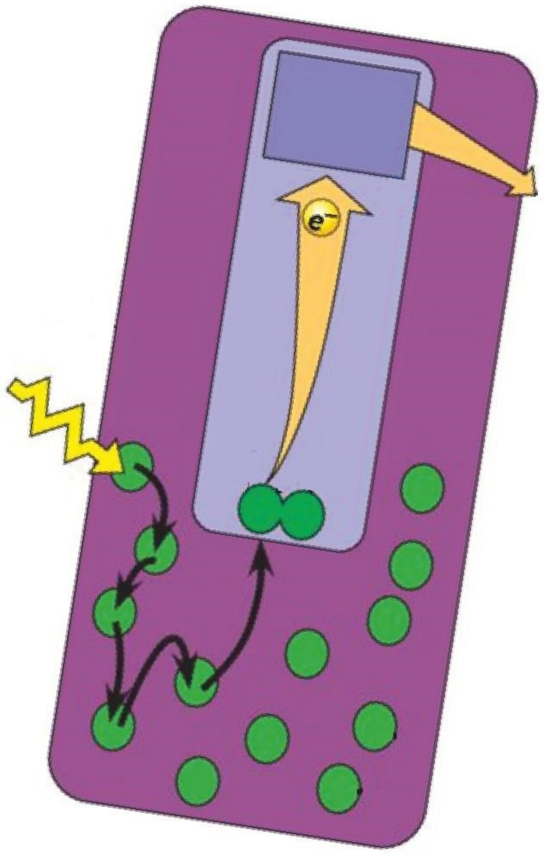
Splitting of water takes place as a result of an ………………………………………………
……………… and yields …………... (g), …………... ions and electrons.

Electrons released as a result of …………………….... may ………………………...excited photosystem II (P680+).

Striking of ………………………….. of light on the pigments results in the excitation of electrons from photosystem I (P700) to the higher energy state. Excited electrons will be accepted by a …………………………………….. of PSI.

Excited electrons of ……………. at primary electron acceptor of PS II will pass through an …………….. ……………………. ………….... to PS I and neutralize the excited PS I (P700+). The energy released due to the passage of electrons from higher energy state to lower energy result in the synthesis of ………………….. This is known as ………………………………………………..



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(v) Describe the process of chlorophyll excitation by light.
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B. (i) Discuss the role of chloroplasts in photosynthesis.
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(ii) Explain how chlorophyll a participates directly in the light reaction of photosynthesis.
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(iii) Describe the relationship between light wavelength and photosynthetic efficiency.
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(iv) Discuss the importance of electron acceptors in photosynthesis.
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(v) Explain how photosynthetic pigments help plants utilize the full spectrum of light.
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C. (i) Explain the first step of RuBP carboxylation and its products.
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……………………………………………………………………………

(ii) Describe the reduction phase in photosynthesis and its requirements.
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(iii) What is photorespiration and why does it occur?
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……………………………………………………………………………

(iv) Explain why photorespiration is considered a wasteful process.
……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

3. A. (i) Give examples for C3 and C4 plants

C3 : ……………………… C4 : ……………………………..

B. (i) Where does the Calvin cycle take place in the chloroplast? ……………

(ii) What is produced when water splits during photosynthesis?

……………………………………………………………………

(iii) What is the CO2 acceptor molecule in carbon fixation?

………………………………………………

(iv) What are the two types of electron flow in photosynthesis?

……………………………………………………………………

(v) (a) What happens to chlorophyll a when it absorbs light energy?

………

(b) What is the function of carotenoids in photoprotection?

………

(c) What is an absorption spectrum?

C. (i) Explain how photosynthesis serves as an energy fixing mechanism.

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(ii) Describe the two main stages of photosynthesis and explain how they are integrated.

....

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(iii) State main difference between C3 and C4 mechanisms in photosynthesis.

....

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(iv) Describe the structure and function of thylakoids in photosynthesis.

....

....

....

(v) State the nature of stroma and explain the role of stroma in photosynthesis.

....

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2. A. (i) Discuss how different pigments contribute to photosynthesis efficiency.

....

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(ii) Explain the photoprotective function of carotenoids.

....

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(iii) Define and explain the significance of the absorption spectrum in photosynthesis.

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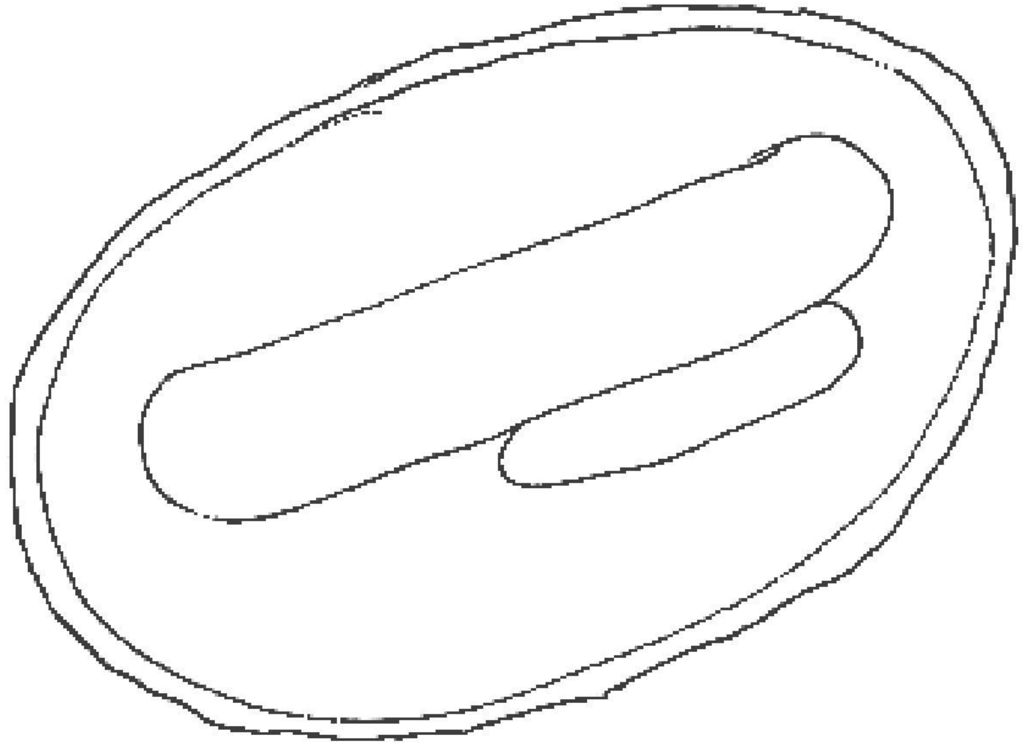
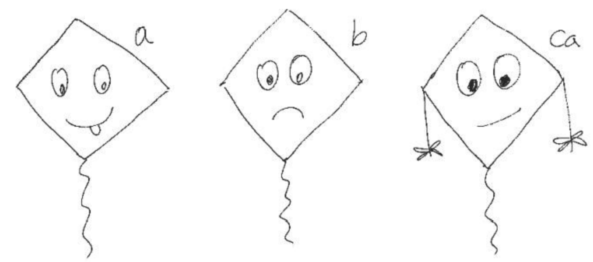
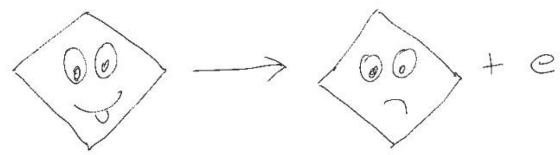
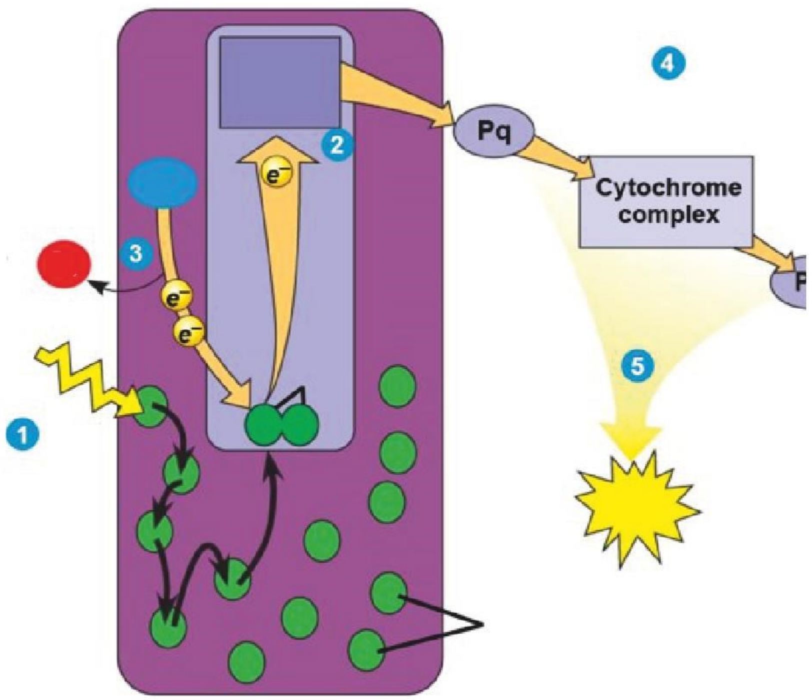
....

(iv). Compare the absorption spectrum with the action spectrum in photosynthesis.









(3) The rate of photosynthesis at different wavelengths of light.
(4) The amount of CO_2 absorbed at different wavelengths of light.
(5) The rate of photosynthesis at different light intensities. (AL 2011)

53. Which one of the following shows the correct combination of products formed during the light reaction photosynthesis and used in the Calvin cycle?
(1) H_2O, CO_2, ATP (2) ATP, H_2O, NADPH (3) CO_2, NADPH (4) ATP, NADPH (5) ATP, CO_2, NADPH (AL 2011/old)

54. Which of the following are reactants of the light reactions of photosynthesis?
(1) H_2O,ADPandNADP$^+$ (2) CO_2,ADPandNADP$^+$ (3) H_2O, ATP and NADPH (4) CO_2, ADP and NADPH (5) O_2, NADPH and ATP (AL 2013/old)

55. Identify the plant which is known to be most efficient converter of sunlight into chemical energy
(1) Tomato (2) Potato (3) Rice (4) Papaya (5) Sugar cane

56. Cyclic photophosporylation is confined to
(1) PS II (2) PS I (3) PS II and PS I (4) Electron acceptors (5) None

57. Identify the false statement
(1) C_3 plants respire in presence of light (2) C_4 plants exhibit Kranz anatomy
(3) C_4 plants exhibit Calvin cycle (4) C_3 plants lack Kranz anatomy
(5) C4 plants do not show respiration in presence of light

58. Select the false statement
(1) Photolysis of water is used in the reduction of NADP$^+$ (2) PS II split water
(3) PEP is the CO_2 acceptor in C_3 plants (4) Photorespiration usually occurs in C3 plants
(5) Photophosphorylation occurs during light stage

59. Select the pair that does not match.
(1) Photophosphorylation - Related to photosynthesis
(2) Making of ATP in photosynthesis - Photooxidation (3) PS II - Site of photolysis of H_2O
(4) Phloem cell - Transport products of photosynthesis to other parts of plants
(5) PS I - Cyclic electron transport

60. Calvin cycle represents one of the following phenomena
(1) Oxidative phosphorylation (2) Carbon fixation reaction (3) Reduction and Carboxylation
(4) Dark respiration (5) Electron transport chain

Structured Essay

1. A. (i) (a) Define photosynthesis
………
………
(b) What are the two main stages of photosynthesis?
………
(ii) What is the wavelength at which PS I chlorophyll molecules (P700) absorb light effectively?
…………………
(iii) What are the three steps of the Calvin cycle?
……………………… ………………………………… ………………………
(iii) What is the first stable product of photosynthesis?
………………………………………
(iv) What is the name of the enzyme that catalyzes CO2 fixation?
………………………………………
(v) What are the two types of photosynthetic mechanisms based on C atoms?
………………………………………

42. During photorespiration, the two-carbon product:
(1) Stays in the chloroplast (2) Moves only to mitochondria (3) Is converted to glucose
(4) Processed in peroxisome and mitochondria (5) Is immediately released as CO_2

43. C4 plants adapt to hot climates by:
(1) Increasing photorespiration (2) Having fewer chloroplasts (3) Maintaining high CO_2 around Rubisco
(4) Reducing photosynthetic rate (5) Eliminating bundle sheath cells

44. Which of the following statements about photosynthesis is **incorrect?**
(1) Photosynthesis can be considered an energy releasing process.
(2) Red and blue light are the most effective in photosynthesis.
(3) Chlorophyll is not the only pigment participating in photosynthesis.
(4) The oxygen released during photosynthesis originates from water.
(5) Carbon dioxide fixation can take place during day time. (AL 2000)

45. Which of the following is incorrect regarding RuBP carboxylase enzyme?
(1) It is present in the chloroplast. (2) It uses carbon dioxide as a substrate. (3) It is absent in C_4 plants.
(4) it catalyses the production of PG. (5) It participates in photosynthesis. (AL 2001)

46. Which of the following statements is incorrect regarding the light reactions of photosynthesis?
(1) They take place in the thylakoid membrane of grana in the chloroplast.
(2) The electrons lost by P_{680} in photosystem I is replaced by electrons from photolysis of water.
(3) Photosystem II provides energy in the form of ATP for dark reactions.
(4) Photosystem I provides NADPH for the dark reactions.
(5) Electron acceptors and carriers involved in light reactions are located within thylakoid membrane. (AL 2001)

47. Which is the correct statement regarding photosynthesis?
(1) Oxygen is formed in photosystem II of the light reaction.
(2) CO_2 is fixed in grana of the chloroplast.
(3) ATP is produced in photosystem I of the light reaction.
(4) NADPH and H^+ are produced in photosystem II of light reaction.
(5) Light reaction occurs in the stroma of chloroplast. (AL 2002)

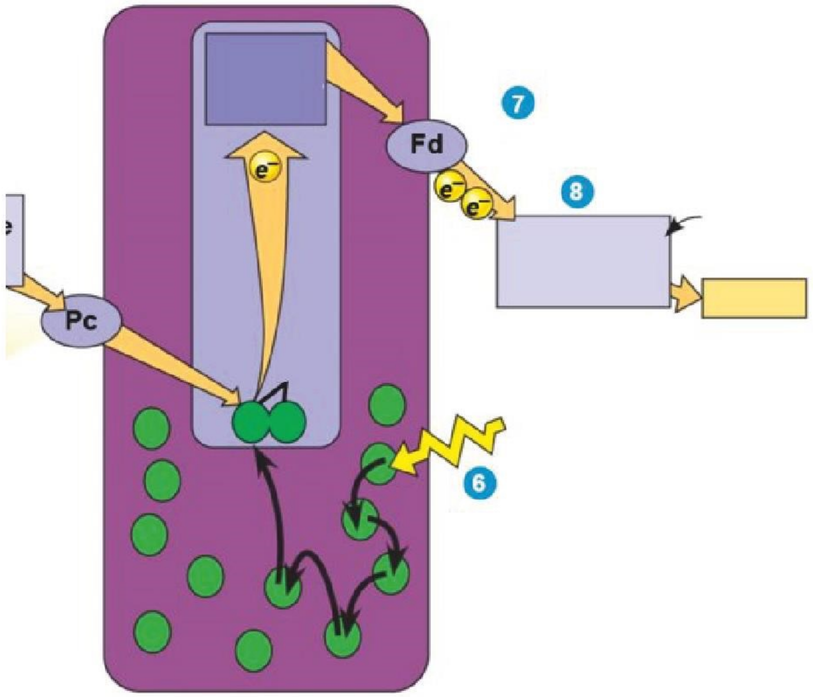
48. C_4 type of photosynthesis is more efficient than C_3 type because, in C_4 plants
(A) carbon dioxide acceptor is more efficient. (B) photorespiration does not occur
(C) Calvin cycle does not occur.
(D) Photolysis of water and production of carbon dioxide occur in different cells.
(E) carbon dioxide absorbed by the mesophyll cells is transported to cells of the bundle sheath. (AL 2002)

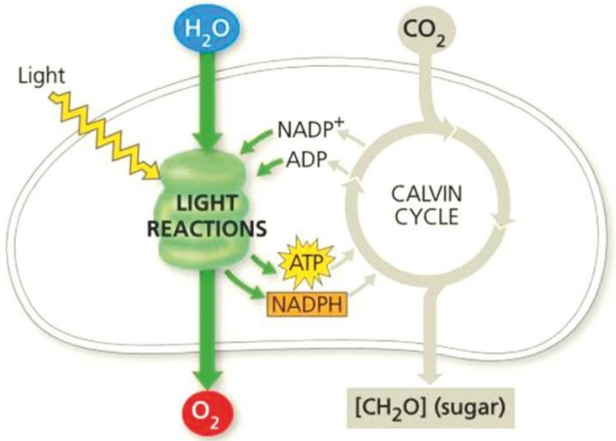
49. Which one of the following represents the first stable product of C_4 photosynthesis?
(1) Phosphoglycerate (2) Oxaloacetate (3) Malic acid (4) Phosphoenol pyruvate (5) Glycolate (AL 2003)

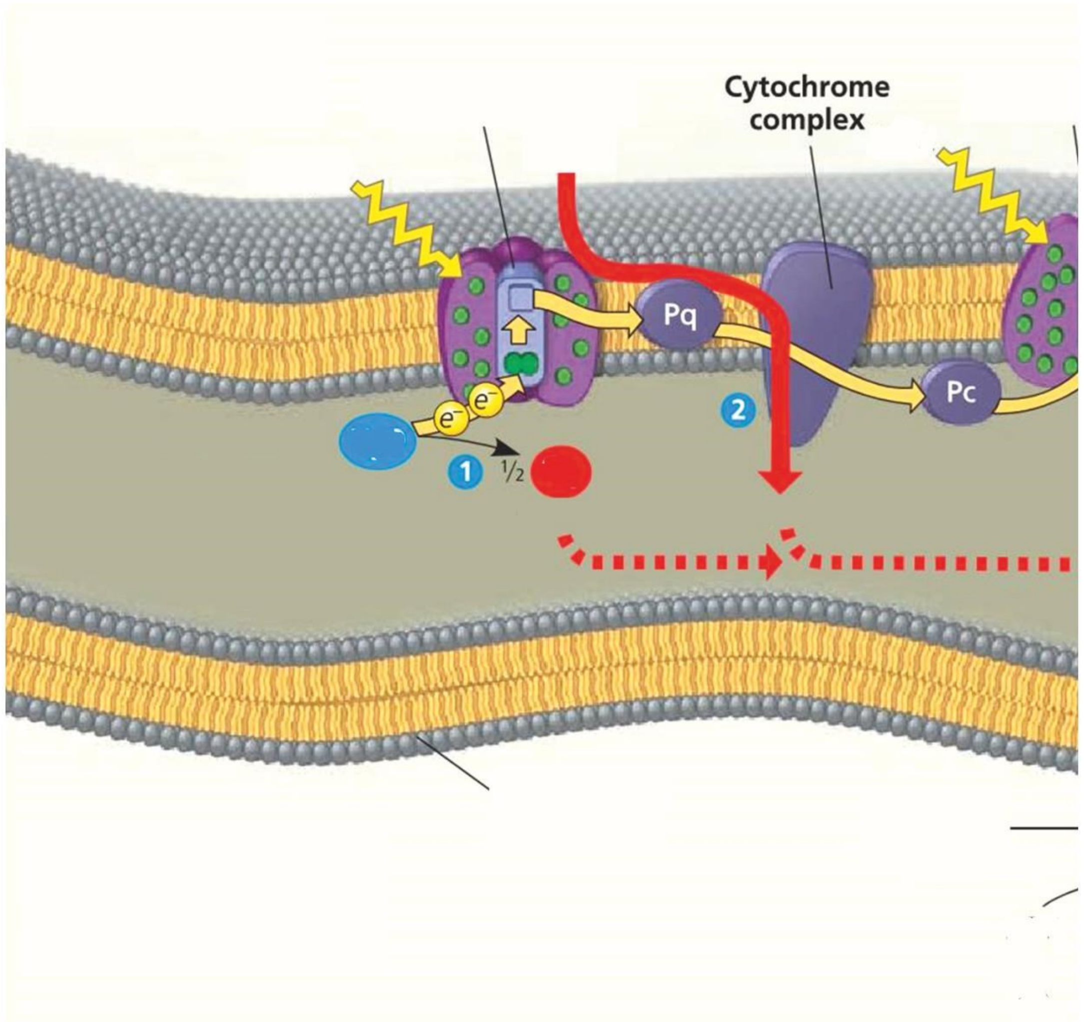
50. Which of the following is an incorrect statement?
(1) In mesophyll cells of C_4 plants, CO_2 is fixed by PEP.
(2) C_4 plants do not use RuBP for CO_2 fixation.
(3) Synthesis of starch in C_4 plants takes place in bundle sheath cells.
(4) RuBP carboxylase enzyme is found in the stroma of the chloroplast.
(5) In photorespiration, RuBP is oxidized by RuBP carboxylase. (AL 2006)

51. Which of the following is /are correct regarding photosynthesis?
(A) The light reactions of photosynthesis provide ATP and NADPH for the Calvin cycle.
(B) the correct sequence of flow of electrons during photosynthesis is $H_2O \rightarrow P_{680} \rightarrow$ electron-acceptors $\rightarrow P_{700} \rightarrow$ electron acceptors $\rightarrow$ NADP+
(C) CO_2 fixation during photosynthesis takes place in the thylakoid membrane.
(D) In C_4 photosynthesis, CO_2 is fixed twice.
(E) The red green areas of the spectrum are the most effective in photosynthesis. (AL 2010)

52. The action spectrum of photosynthesis is a graph showing
(1) The amount of light absorbed by pigments at different wavelengths of light.
(2) The amount of light absorbed by pigments at different times of the day.







26. Photorespiration results in:
(1) Increased photosynthetic efficiency (2) No effect on productivity (3) 25% loss of carbon fixed
(4) 50% less 3-PGA production (5) Increased CO2 fixation

27. C4 plants have better water-use efficiency because:
(1) They have more chloroplasts (2) They can keep stomata more closed while maintaining photosynthesis
(3) They use less ATP (4) They have larger leaves (5) They perform more photorespiration

28. The specialized leaf anatomy in C4 plants features:
(1) Only bundle sheath cells (2) Only mesophyll cells (3) Separated bundle sheath and mesophyll cells
(4) Kranz anatomy with interconnected cells (5) No specialized arrangement

29. PEP carboxylase is more efficient than Rubisco because:
(1) It requires less energy (2) It has no affinity for O_2 (3) It produces more ATP
(4) It works faster in low light (5) It fixes more carbon

30. In C_4 mesophyll cells, chloroplasts are characterized by:
(1) Absence of grana (2) Rich in grana for light reactions (3) Only PS I (4) Only PS II
(5) Neither PS I nor PS II

31. Bundle sheath chloroplasts in C_4 plants:
(1) Contain only PS I (2) Contain only PS II (3) Contain both PS I and PS II
(4) Contain neither PS I nor PS II (5) Vary between species

32. The primary CO_2 acceptor in C_4 mesophyll cells is:
(1) RuBP (2) PEP (3) Oxaloacetate (4) Malate (5) Pyruvate

33. According to Blackman's principle:
(1) All factors equally limit photosynthesis (2) Light is always the limiting factor
(3) The factor nearest its minimum value limits the rate (4) Temperature is the most important factor
(5) CO_2 is always limiting

34. C_4 pathway was evolved to:
(1) Increase water loss (2) Decrease photosynthetic efficiency (3) Concentrate CO_2 around Rubisco
(4) Increase photorespiration (5) Reduce carbon fixation

35. The first stable 4-carbon compound formed in C_4 pathway is:
(1) Malic acid (2) Pyruvic acid (3) Oxaloacetic acid (4) Phosphoenolpyruvate (5) Aspartic acid

36. C_4 plants show higher nitrogen-use efficiency because:
(1) They need more Rubisco (2) They need less Rubisco (3) They don't use nitrogen
(4) They fix more nitrogen (5) They lose more nitrogen

37. Representative C_4 plants include:
(1) Wheat and rice(2) Rice and barley(3) Maize and sugarcane(4) Wheat and barley (5) Potato and tomato

38. At very high light intensities:
(1) Photosynthesis always increases (2) Chlorophyll may bleach (3) CO_2 fixation doubles
(4) Water use decreases (5) Temperature decreases

39. Under normal conditions, the major limiting factor in photosynthesis is:
(1) Light intensity (2) Temperature (3) CO_2 concentration (4) Water availability (5) Mineral nutrients

40. The rate of photosynthesis is highest at:
(1) 15°C with atmospheric CO_2 (2) 15°C with high CO_2 (3) 25°C with atmospheric CO_2
(4) 25°C with high CO_2 (5) 35°C with normal CO_2

41. Bundle sheath cells in C_4 plants are:
(1) Not connected to mesophyll cells (2) Connected by plasmodesmata (3) Only present in stems
(4) Photosynthetically inactive (5) Absent in mature leaves

7. The enzyme that catalyzes the reduction of $NADP^+$ is:
(1) ATP synthase (2) Rubisco (3) NADP reductase (4) Carboxylase (5) Oxygenase

8. How many times must the Calvin cycle operate to produce one molecule of G3P?
(1) Once (2) Twice (3) Three times (4) Four times (5) Five times

9. Cyclic electron flow occurs in:
(1) PS I only (2) PS II only (3) Both PS I and PS II (4) Neither PS I nor PS II (5) Between PS I and PS II

10. During photorespiration, when Rubisco reacts with O_2, the productivity decreases by:
(1) 25% (2) 35% (3) 40% (4) 50% (5) 60%

11. The enzyme RuBP carboxylase oxygenase is present in:
(1) Thylakoid membrane (2) Chloroplast stroma (3) Cell membrane (4) Cytosol (5) Mitochondria

12. The process of photosynthesis consists of:
(1) One main stage (2) Two main stages (3) Three main stages (4) Four main stages (5) Five main stages

13. Which of the following is produced during linear electron flow?
(1) ATP only (2) NADPH only (3) O_2, ATP and NADPH (4) Neither ATP nor NADPH (5) Only O_2

14. Photosynthetic pigments are located in:
(1) Stroma (2) Cell wall (3) Thylakoid membrane (4) Outer membrane (5) Inner membrane

15. The wavelength at which PS II absorbs light effectively is:
(1) 620 nm (2) 640 nm (3) 660 nm (4) 680 nm (5) 700 nm

16. The product of the Calvin cycle is:
(1) RuBP (2) 3-PGA (3) G3P (4) ATP (5) NADPH

17. Which process occurs in photosystem II at P680?
(1) ATP synthesis (2) NADPH formation (3) Electron excitation (4) Carbon fixation (5) Oxygen evolution

18. The first product of RuBP carboxylation is an unstable:
(1) 3C molecule (2) 4C molecule (3) 5C molecule (4) 6C molecule (5) 7C molecule

19. Chlorophyll a is most effective in absorbing:
(1) Green and yellow light (2) Blue and red light (3) Only blue light (4) Only red light
(5) All wavelengths equally

20. During photorespiration, the two-carbon product is processed in:
(1) Chloroplast only (2) Peroxisome only (3) Mitochondria only (4) Chloroplast and peroxisome
(5) Peroxisome and mitochondria

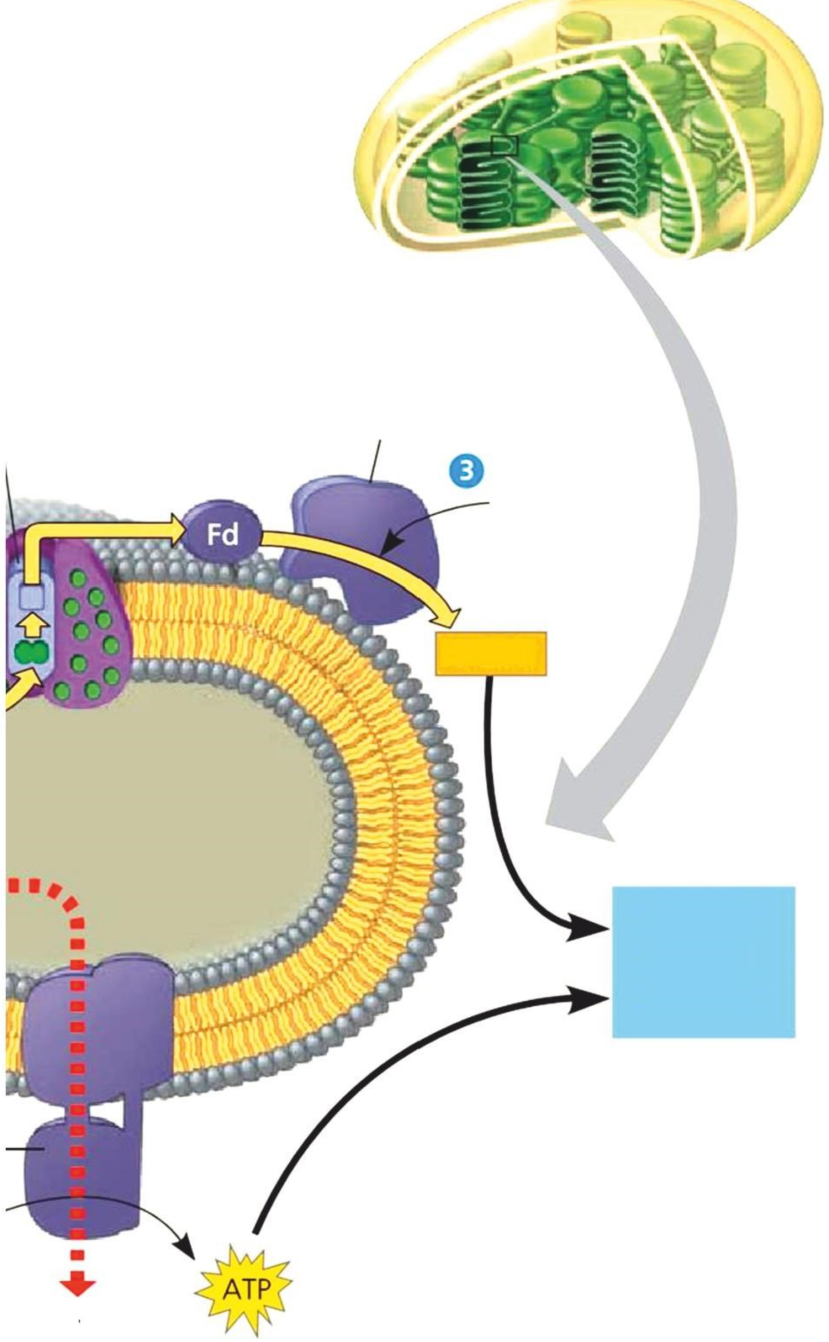
21. The action spectrum shows:
(1) Light reflection (2) Light transmission (3) Light absorption (4) Effectiveness of different wavelengths
(5) Chlorophyll concentration

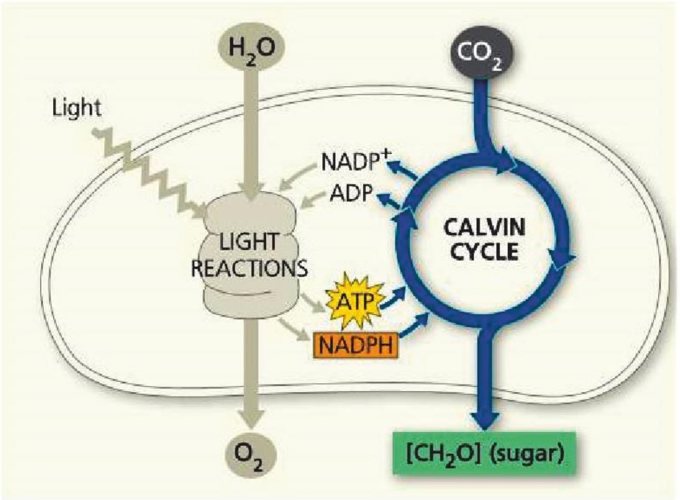
22. The final electron acceptor in the electron transport chain is:
(1) P700 (2) P680 (3) NADP+ (4) ATP (5) RuBP

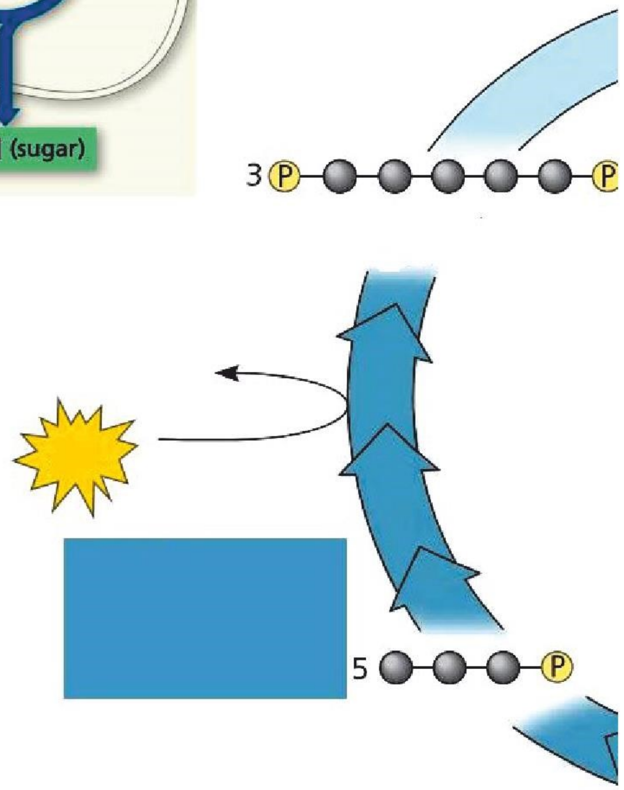
23. The enzyme Rubisco acts as:
(1)Only carboxylase (2) Only oxygenase (3) Both carboxylase and oxygenase
(4) Neither carboxylase nor oxygenase (5) Only phosphatase

24. The first product of RuBP carboxylation is:
(1) 3-phosphoglycerate (2) 6C unstable molecule (3) 1,3-bisphosphoglycerate
(4) Glyceraldehyde 3-phosphate (5) Ribulose 1,5-bisphosphate

25. In C4 plants, the enzymes found in bundle sheath cells include:
(1) Only PEP carboxylase (2) Only Rubisco (3) Both Rubisco and PEP carboxylase
(4) Neither Rubisco nor PEP carboxylase (5) Rubisco working efficiently under high CO2







PRACTICAL NO.7

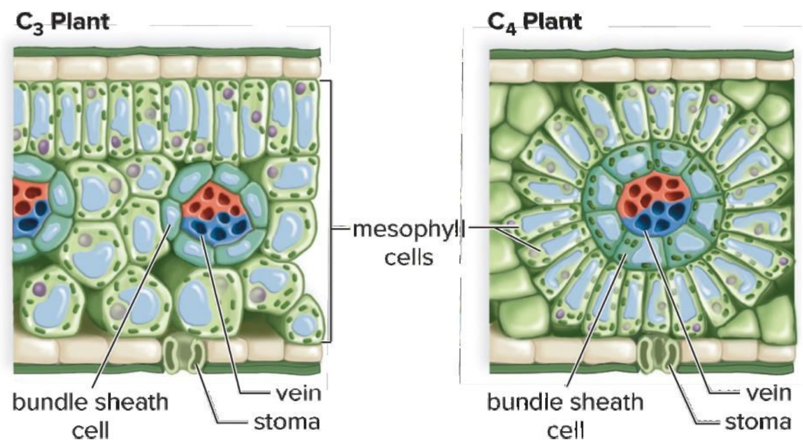
Microscopic observation of cross sections of C3 and C4 plant leaves with special reference to the adaptations for photosynthesis

Materials and equipment

- Microscopes.
- Prepared slides of cross sections of C3 and C4 plant leaves.

Instructions

- Allow students to examine slides under the low power of the microscope.
- Direct them to observe the differences in the cross sections of C3 and C4 plant leaves.
- Let suitable labeled diagrams to show the observed characters under low power of the microscope.
- Let the students correlate the observed structures with the adaptations of C3 and C4 plants for photosynthesis



MCQ

1. Which of the following is not a global importance of photosynthesis?
   (1) Production of fossil fuel (2) Maintenance of global temperature (3) Nitrogen fixation
   (4) Providing O2 for respiration (5) Maintaining O2 and CO2 balance

2. The site of Calvin cycle in chloroplast is:
   (1) Thylakoid membrane (2) Stroma (3) Outer membrane (4) Inner membrane (5) Intermembrane space

3. The first stable product of photosynthesis is:
   (1) Glucose (2) RuBP (3) 3-phosphoglycerate (4) Glyceraldehyde (5) NADPH

4. The number of carbon atoms in the first stable compound of C4 mechanism is:
   (1) Two (2) Three (3) Four (4) Five (5) Six

5. During photosynthesis, CO_2 is reduced by:
   (1) O_2 (2) NADPH (3) H of H_2O (4) ATP (5) RuBP

6. Which pigment provides photoprotection by dissipating excessive light energy?
   (1) Chlorophyll a (2) Chlorophyll b (3) Carotenoids (4) P700 (5) P680

PRACTICAL NO.6

Determination of rate of photosynthesis by the amount of oxygen released using Audus

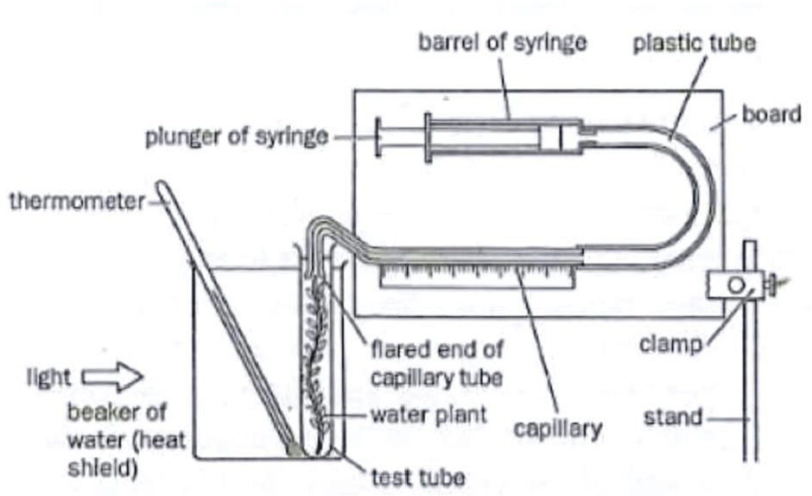
Apparatus (for different CO2 concentrations and light intensities)

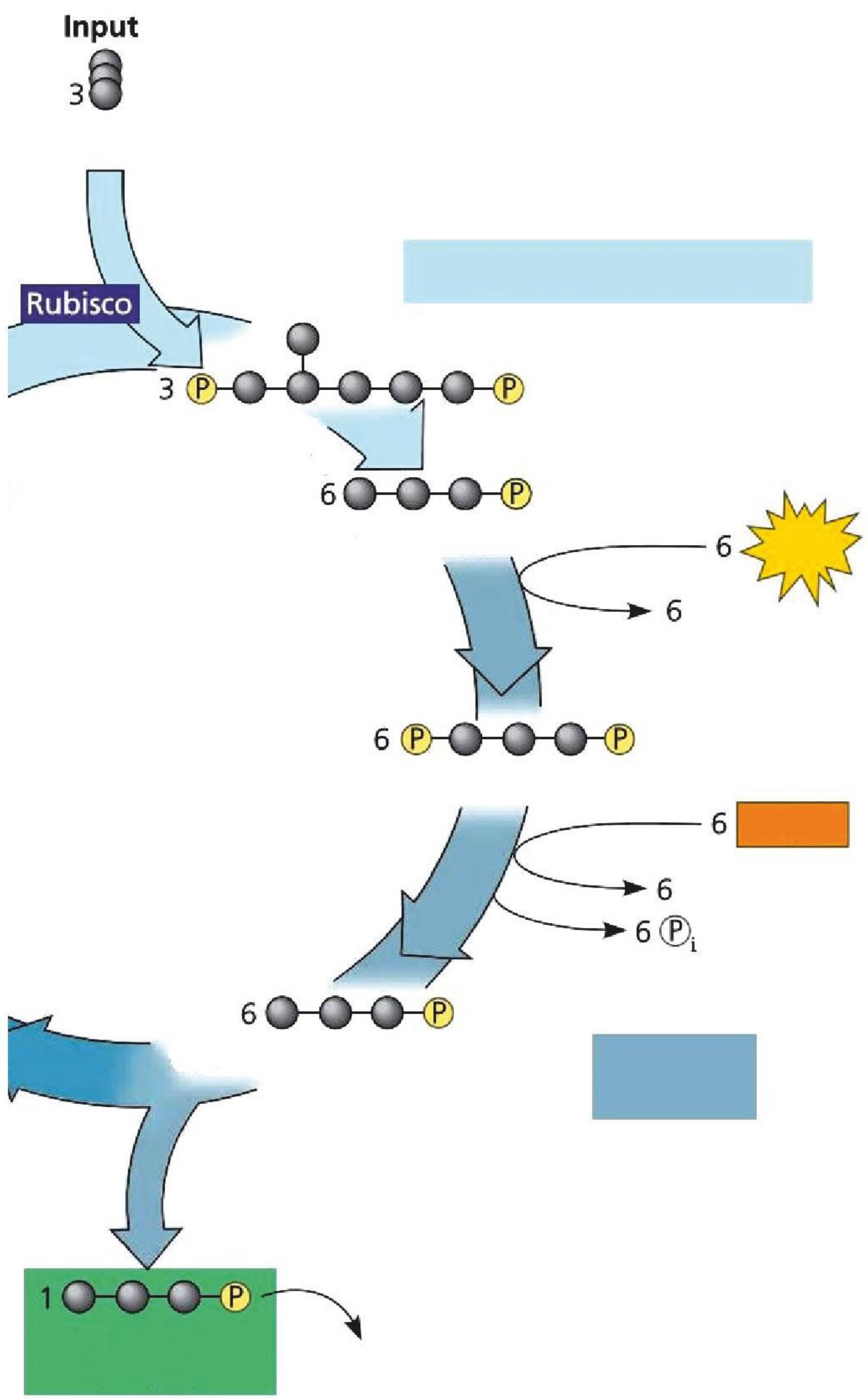
Materials and equipment

- Aquatic plants such as *Hydrilla* or *Elodea*
- Audus photosynthesis apparatus (micro burette)
- 0.01% solution of Sodium hydrogen carbonate
- Test tube, glass funnel, table lamp, thermometer, stop watch, ruler

Instructions

- Direct the students to set up the Audus apparatus. Make sure that the micro burette is completely filled with water. Place a table lamp close to the aquatic plants to provide adequate light (appendix II).
- Let them observe the oxygen bubbles released due to photosynthesis and how oxygen bubbles get collected at the bend of micro burette.
- Instruct them to measure the volumes of oxygen released by plant using a syringe at definite intervals.
- Direct them to determine the rate of photosynthesis at various conditions such as changing the intensity of light, (by changing the distance of the table lamp).
- Direct them to record and analytically interpret the results.
- Note : Guide students to suggest an appropriate experimental set up to demonstrate the effect of carbon dioxide concentration on the rate of photosynthesis.





Excited electrons of PS 1 at primary electron acceptor of PSI will pass through an electron transport chain and reduce ………………………….. and yield …………………….. The reduction of NADP+ is catalyzed by an enzyme called …………………. …………………...

Cyclic electron flow

This occurs in ………………………. but not in …………………………….. Here some photoexcited electrons uses …………..…….. …………………… ……………………....
This produces …………….... ………………. is not produced. Oxygen is ………… released.

The Calvin cycle

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The Calvin cycle of photosynthesis can be described in three steps;

1. Carboxylation (Carbon fixation)
2. Reduction
3. Regeneration of carbon dioxide acceptor

Carbon fixation

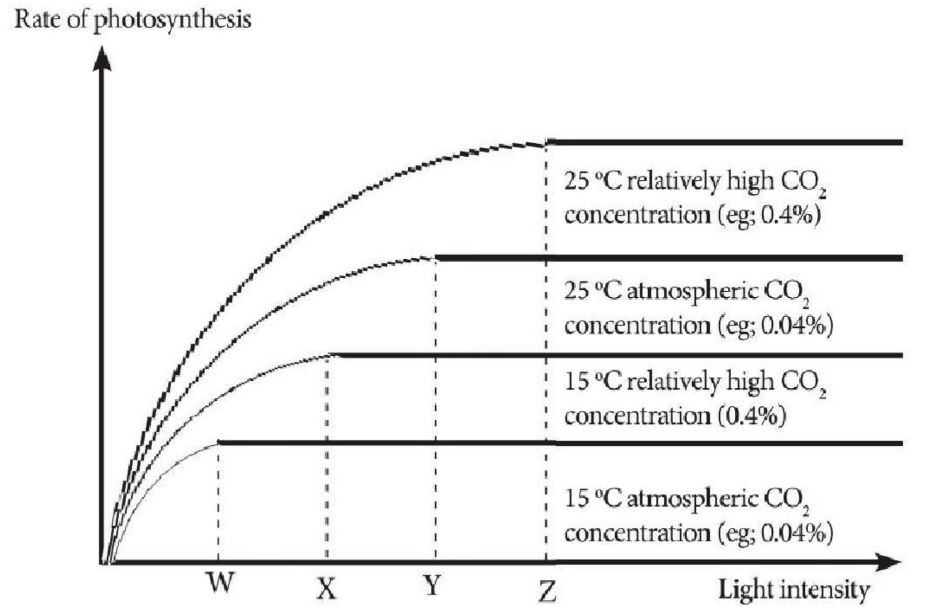
The CO2 acceptor is a 5C sugar, Ribulose bisphosphate (RuBP). The addition of CO2 to a RuBP is called ……………………... The enzyme involves in this reaction is ……………………………………………………. or ………………... The first product of RuBP carboxylation is a …………………………..….. which is unstable and breaks down immediately in to two molecules of ………………………. (3-PGA). This is the …………………………………………………………..... The enzyme RuBP carboxylase oxygenase (Rubisco) is present in large amounts in the chloroplast ……………………..

Factors affecting photosynthesis

- The rate of photosynthesis is an important factor in crop production. Rate is affected by various factors. Eg. ……………………………………………………………………… ………………………………………………………………………………………………
- The photosynthesis involves a series of reactions. Therefore various factors are involved in it.
- ……………………………. who is the scientist first proposed the idea of principle of limiting factors.
- When a chemical process is affected by more than one factor, its ………….. is limited by the factor which is nearest its …………………….. value. Eg. Light intensity

Light intensity

The rate of photosynthesis increases linearly with increasing light intensity. Gradually the rate of increase falls off as the other factors become limiting. Very high light intensities chlorophyll may bleach and slow down photosynthesis. However, plants exposed to such conditions are usually protected by devices such as thick cuticles, hairy leaves.



Under normal conditions, CO_2 is the major limiting factor in photosynthesis. Increase in photosynthetic rate is achieved by increasing CO_2 concentration. For example some greenhouse crops such as tomatoes are grown in CO_2 enriched atmosphere.

Characteristics	C_3 Plants	C_4 Plants
Representative species		
CO_2 fixation		
CO_2 acceptor		
CO_2 fixing enzyme		
First product of CO_2 fixation		
Leaf anatomy		
Productivity		

Reduction phase

3-PGA is converted to ………………………………………………. by adding one ……………………… group from ATP. 1.3 -Bisphosphoglycerate will be …………………… to Glyceraldehyde 3- phosphate (GBP) through step by step, enzyme catalyzed reactions utilizing ……………….. and …………………. from light reaction G3P will act as a precursor for carbohydrate synthesis (glucose).

Regeneration of RuBP

RuBP is regenerated by undergoing a series of complex reactions. This process uses energy from ATP generated in light reaction. Glucose is later synthesized from G3P through series of enzyme catalyzed reaction

Photorespiration

As its name suggests, ……………………………………………………………………………..…

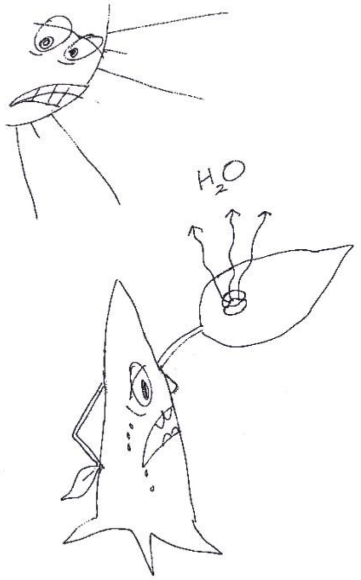
…………………………………………………………………………………………………….

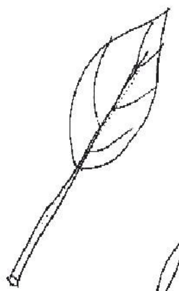
In the oxygenase reaction Rubisco uses the same substrate, RUBP, but reacts with O_2. The reaction is catalyzed on the same active site as the carboxylation reaction. Thus CO_2 and O_2 are competitive substrates. Therefore CO_2 …………..…….. the …………………….. and O_2 Inhibits the …………………………….. reaction. In photorespiration, the oxygenase reaction of rubisco forms just ………….. molecule of ……………….and a …………… ……………….. product. The two carbon product leaves chloroplast and get processed in …………………….. and ……………………………...

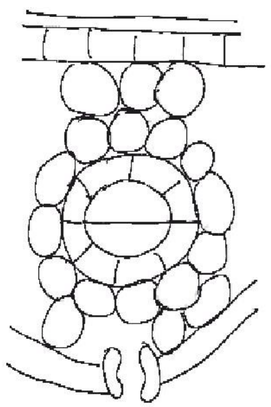
The photorespiratory pathway involves enzymes in the chloroplasts, peroxisome and mitochondria. (detail of this pathway is not expected). Photorespiration is not ………………… energy ……………………., but furthermore leads to a ……… …………… of CO_2. Each time Rubisco reacts with O_2 instead of CO_2 the plants makes ……………… less 3-PGA than it would have done if CO_2 had been used. This potentially eliminates the ………….. gain in photosynthetic carbon and ………….. the productivity.

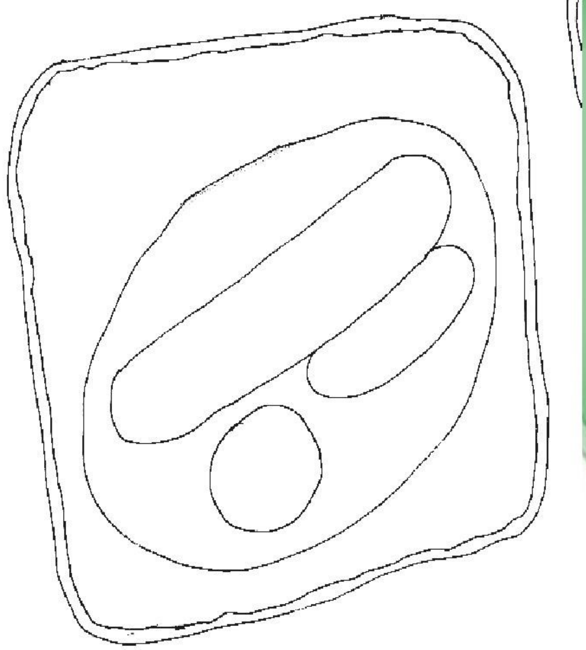
C4 Plants

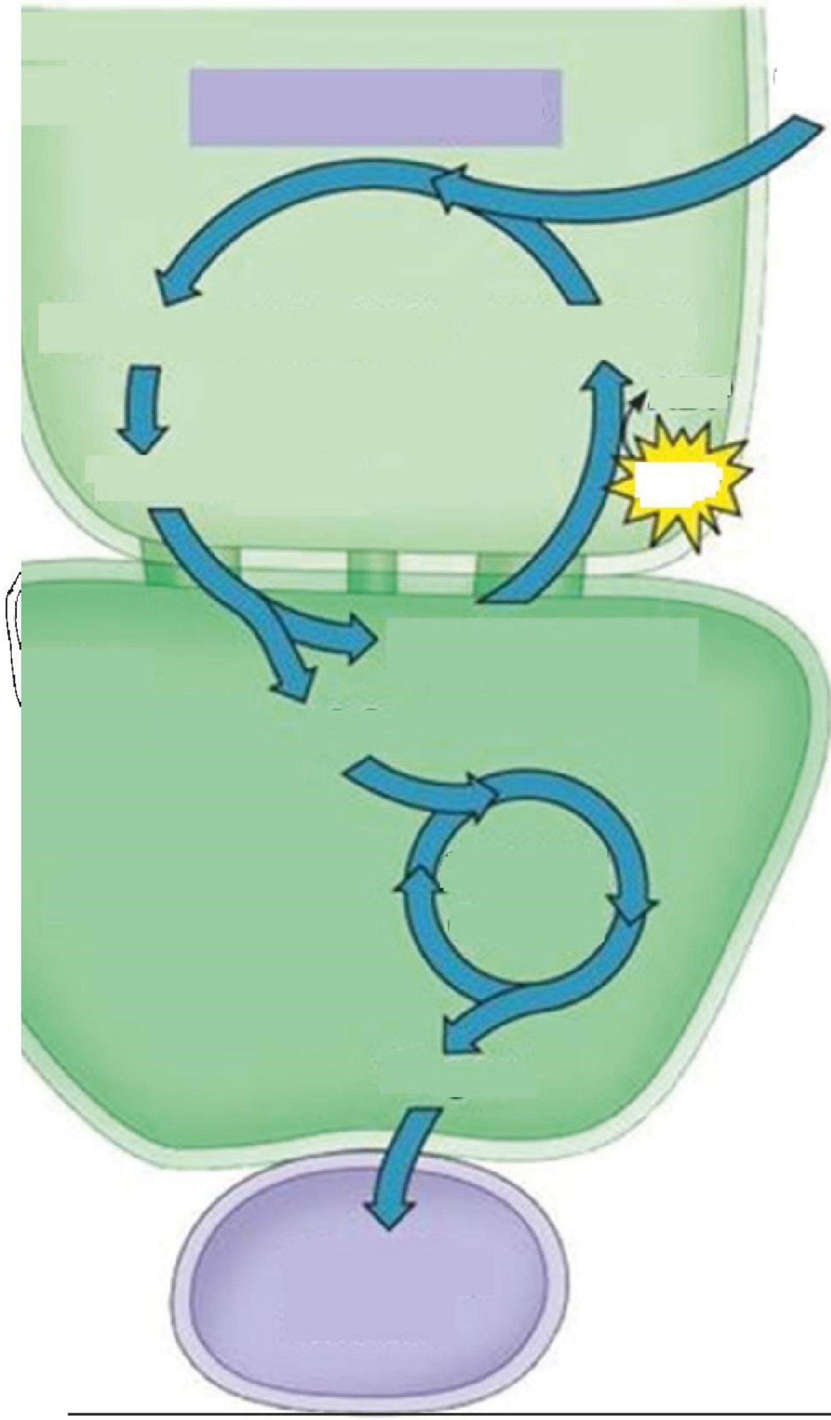
The CO2 required for photosynthesis enters a leaf via stomata. However, stomata are also the main ………………… of ………………….. On a hot, dry day, most plants ………….. their stomata in order to conserves water. At the same time O_2. released from the light reactions begins to increase and this leads to further reduction of (CO_2) to (O_2) ratio in the cytosol.

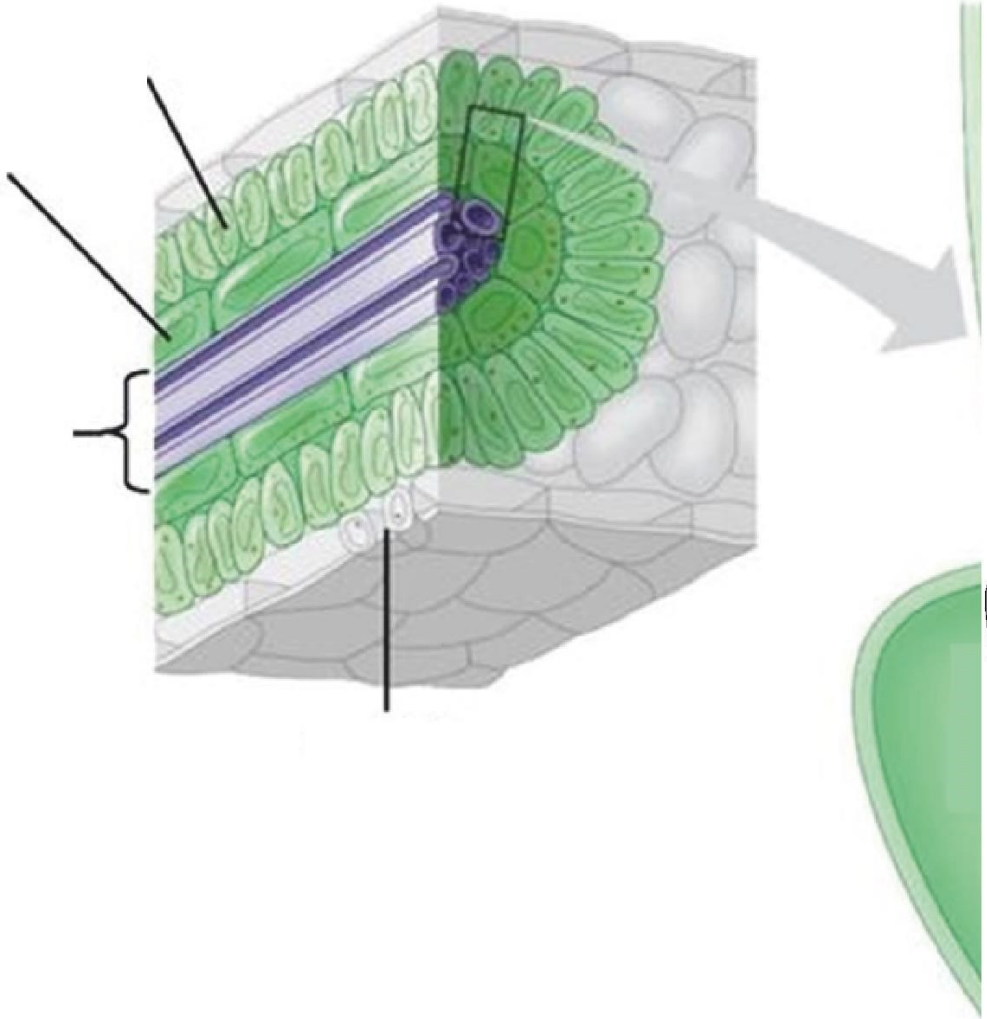

H_2O

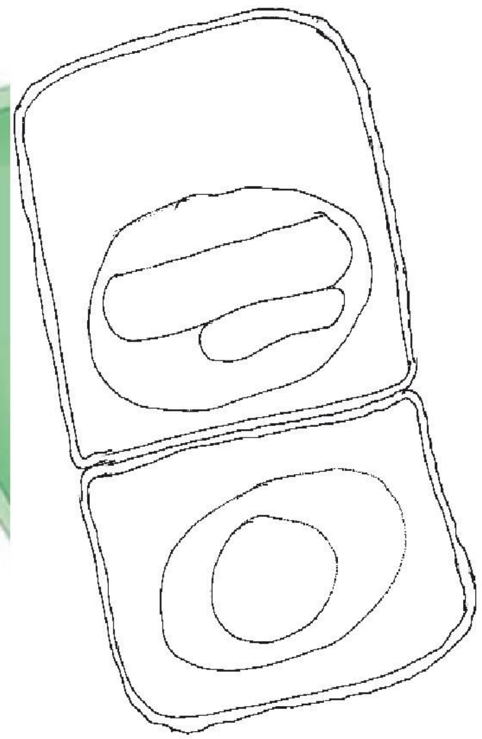


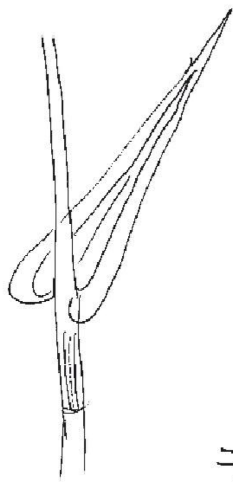


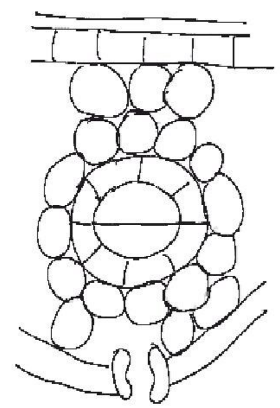












These conditions within the leaf favor a ……………….. process photorespiration under high temperature, dryness and high light intensities.

Therefore plants developed different ways to cope with this situation. During the evolution a most successful solution to …………………….. CO_2 around ………………... was provided by …………. …………………… …………………. The establishment of C_4 photosynthetic pathway includes several ………………….. and …………………….. modifications that allow plants with this pathway to concentrate CO2 at the site of Rubisco. Thereby its ……………….. reaction and the following ……………………are largely …………………….. in C_4 plants.

In most C_4 plants the CO_2 concentration mechanism is achieved by a ……………. ………… …………………. between two distinct specialized leaf cell types, the ……………….. and the ………………….. sheath cells. Compared to C_3 plants the bundle sheath cells of C_4 plants have ………………. ……………………... functions. This is reflected by the ……………………… and ………… …………………... content of these cells in C_4 species. For the efficient functioning of the C_4 pathway, mesophyll and bundle sheath cells are ……………………. interconnected to each other by high numbers of ………………….. The bundle sheath cells enclose the vascular bundles and are themselves surrounded by the mesophyll cells and this type of leaf anatomy was termed ………………..anatomy.

Since Rubisco can operate under high CO_2 concentrations in the bundle sheath cells. It works more efficiently than in C_3 plants. Because of the CO_2 concentration mechanism they can acquire enough CO_2 even when keeping their stomata more closed and minimize the water loss by transpiration.

C4 pathway of photosynthesis

In the leaf mesophyll cells of C_4 plants, CO_2 is initially fixed with the CO_2 acceptor …………………………………… (PEP) using ………………………….. as CO_2 accepter. The resulting ……………………...(OAA) is composed of …………… carbon atoms, which is the basis for the name of this metabolic pathway. Oxaloacetate is rapidly convened to the more stable C_4 acid ……………….. that diffuse to the bundle sheath cells. Here, CO_2 is released by decarboxylating enzymes and the released CO_2 is ……………. by Rubisco, which exclusively operates in the bundle sheath cells in C_4 plants. Malate, after releasing CO_2 becomes 3 carbon ………………., Pyruvate diffuses back in to the leaf mesophyll cells and receive phosphate from ……………... hydrolysis and regenerate PEP.

Chloroplasts found in mesophyll cells are different in anatomy in comparison to chloroplasts of bundle sheath cells.

Since chloroplasts of mesophyll cells carryout only light reaction, they are ……………. in grana. The grana of ……………. ……………….. are large and ……………. ……………... for light reaction. Bundle sheath chloroplasts possess a ………. ………., ……………. …………………….. grana or grana are absent. They contain only PS I and not PS II. Additional ATP generated through only cyclic electron flow. This PEP carboxylase enzyme is much more efficient for CO_2 fixation than rubisco. It has no affinity for O_2.

Significance of the C4 pathway

- Helps plants to improve the efficiency of CO_2 fixation at lower CO_2 concentrations by preventing the gateways for photorespiration by spatially separating Rubisco. In hot-dry climate, it is essential for the stomata to close to prevent water loss through transpiration. This reduces CO_2 intake of particular plants. Therefore, plants in tropical zones or hot climate may suffer from CO_2 deficiency. At lower CO_2 concentrations, C_4 mechanism increases the efficiency of photosynthesis by concentrating CO_2 in the bundle sheath cells.
- C_4 plants exhibit better water-use efficiency than C_3 plants because of the CO_2 concentration mechanism they can acquire enough CO_2 even when keeping their stomata more closed. Thus water loss by transpiration is reduced.
- Since Rubisco can operate under high CO_2 concentrations in the bundle sheath cells, it woks more efficiently than in C_4 plants, consequently C_4 plants need less of this enzyme, this leads to a better nitrogen-use efficiency of C_4 compared to C_3 plants.