NCERT Exemplar Solutions of Class 11 Biology – Chapter 13: Photosynthesis in Higher Plants

VERY SHORT ANSWER TYPE QUESTIONS

1. Examine the figure and answer:

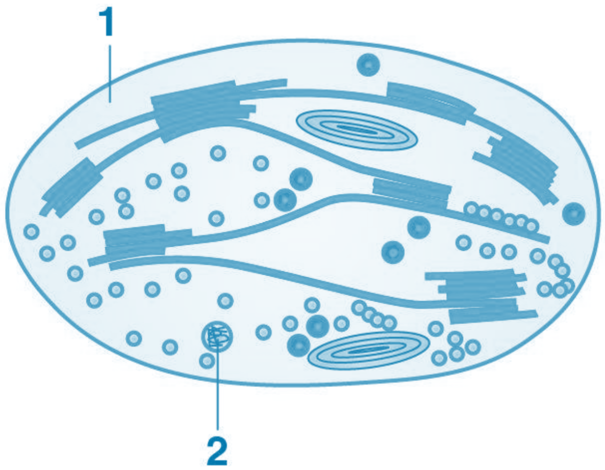

Figure Description: Chloroplast diagram showing (1) thylakoids and (2) stroma

a. **Is this structure present in an animal cell or plant cell?**

Solution: This structure is present in the plant cell.

b. **Can these be passed on to the progeny? How?**

Solution: Chloroplasts can self-replicate and hence can be passed on to the progeny through maternal inheritance via the cytoplasm of the egg cell.

c. **Name the metabolic processes taking place in the places marked (1) and (2)**

Solution: (1) Shows light-dependent reactions (photolysis, electron transport, ATP and NADPH synthesis)

(2) Shows the stroma where light-independent reactions (Calvin cycle) occur and also the site of chloroplast DNA replication.

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

Based on the above equation, answer the following questions:

a. **Where does this reaction take place in plants?**

Solution: This reaction takes place in Photosystem II (PSII) at the oxygen-evolving complex on the lumen side of the thylakoid membrane.

b. **What is the significance of this reaction?**

Solution: This photolysis of water serves multiple crucial functions:

- Provides electrons to replace those lost from chlorophyll in PSII
- Generates protons (H^+) for the proton gradient essential for ATP synthesis
- Releases oxygen as a byproduct, which is essential for aerobic life on Earth
- Maintains the electron transport chain for continuous energy conversion

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3. Cyanobacteria and some other photosynthetic bacteria don't have chloroplasts. How do they conduct photosynthesis?

Solution: Cyanobacteria conduct photosynthesis using thylakoid membranes that are folded into the cytoplasm rather than being enclosed in chloroplasts. They contain photosynthetic pigments including:

- Chlorophyll a (primary pigment)
- Phycocyanin (blue pigment)
- Phycoerythrin (red pigment) These pigments are organized in phycobilisomes attached to the thylakoid membranes, allowing efficient light capture and photosynthetic electron transport.

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4. Fill in the blanks:

a. **NADP reductase enzyme is located on** outer side of thylakoid membrane (stroma side).

b. **Breakdown of proton gradient leads to release of** ATP molecules.

Enhanced Explanation:

a. NADP reductase is positioned on the stroma side where it can access $NADP^+$ and reduce it to NADPH using electrons from ferredoxin.

b. The proton gradient drives ATP synthase, and when protons flow back through ATP synthase, ATP is synthesized from ADP + Pi.

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5. Can girdling experiments be done in monocots? If yes, how? If no, why not?

Solution: No, girdling experiments cannot be done effectively in monocots because:

- Vascular bundles in monocot stems are scattered throughout the cross-section rather than arranged in a ring
- There is no distinct cambium layer separating xylem and phloem
- It's impossible to remove just the phloem without damaging the entire vascular system
- The scattered arrangement makes it technically unfeasible to create a continuous girdle around the phloem tissue

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6. $3CO_2$ + 9ATP + 6NADPH + Water → glyceraldehyde-3-phosphate + 9ADP + $6NADP^+$ + 8Pi

Analyse the above reaction and answer:

a. **How many molecules of ATP & NADPH are required to fix one molecule of CO_2?**

Solution: For fixing one molecule of CO_2:

- ATP required: 9 ATP ÷ 3 CO_2 = 3 ATP molecules
- NADPH required: 6 NADPH ÷ 3 CO_2 = 2 NADPH molecules

b. **Where in the chloroplast does this process occur?**
Solution: This Calvin cycle reaction occurs in the stroma of the chloroplast, where all the enzymes for carbon fixation and reduction are located.

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7. Does moonlight support photosynthesis?
Solution: No, moonlight does not support photosynthesis because:
- Moonlight is reflected sunlight with much lower intensity
- The photon energy in moonlight is insufficient to excite chlorophyll electrons to higher energy levels
- The light intensity is below the compensation point required for net photosynthesis
- Only direct sunlight or artificial light of sufficient intensity can drive the photochemical reactions of photosynthesis

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8. Some of these terms/chemicals are associated with the C_4 cycle. Explain:
a. **Hatch-Slack pathway**
Solution: The Hatch-Slack pathway is another name for the C_4 photosynthetic pathway, named after its discoverers. It describes the initial fixation of CO_2 into 4-carbon compounds in C_4 plants.
b. **Calvin cycle**
Solution: The Calvin cycle is the second phase of C_4 photosynthesis that occurs in bundle sheath cells, where the CO_2 released from C_4 acids is refixed by RuBisCO into the same 3-carbon pathway as C_3 plants.
c. **PEP carboxylase**
Solution: PEP carboxylase is the primary carboxylating enzyme in C_4 plants, located in mesophyll cells. It has high affinity for CO_2 and lacks oxygenase activity, making it more efficient than RuBisCO.
d. **Bundle sheath cells**
Solution: Bundle sheath cells are specialized cells surrounding the vascular bundles in C_4 plants. They have thick walls, lack intercellular spaces, and contain RuBisCO for the Calvin cycle, creating a CO_2-concentrating mechanism.

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9. Where is NADP reductase enzyme located in the chloroplast? What is the role of this enzyme in proton gradient development?
Solution:
Location: NADP reductase is located on the outer surface (stroma side) of the thylakoid membrane.
Role in proton gradient: This enzyme doesn't directly develop the proton gradient but utilizes it. It receives electrons from ferredoxin and reduces $NADP^+$ to NADPH, using protons from the stroma. This reaction helps maintain the proton gradient by

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consuming protons on the stroma side, contributing to the pH difference across the membrane.

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10. ATPase enzyme consists of two parts. What are those parts? How are they arranged in the thylakoid membrane? Conformational change occurs in which part of the enzyme?

Solution:

Two parts: ATP synthase consists of:

1. **F_0 component** - embedded in the thylakoid membrane
2. **F_1 component** - protruding into the stroma

Arrangement:

- F_0 is integrated into the membrane forming a proton channel
- F_1 extends into the stroma and contains the catalytic sites

Conformational change: The conformational changes occur primarily in the **F_1 component**, specifically in its β subunits, as protons flow through F_0, causing rotation and driving ATP synthesis.

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11. Which products formed during the light reaction of photosynthesis are used to drive the dark reaction?

Solution: The products of light reactions that drive dark reactions are:

- **ATP** - provides energy for carbon fixation and reduction reactions
- **NADPH** - provides reducing power for converting CO_2 into carbohydrates
- **O_2** - released as a byproduct (not used in dark reactions)

The ATP and NADPH are consumed in the Calvin cycle to convert CO_2 into glucose and other organic compounds.

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12. What is the basis for designating C_3 and C_4 pathways of photosynthesis?

Solution: The designation is based on the **number of carbon atoms in the first stable product** of CO_2 fixation:

- **C_3 pathway:** First stable product is 3-phosphoglycerate (3PGA), a 3-carbon compound
- **C_4 pathway:** First stable product is oxaloacetate (OAA), a 4-carbon compound

This difference reflects the different initial carboxylation reactions and enzymes used in each pathway.

SHORT ANSWER TYPE QUESTIONS

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

Solution: Succulents use **Crassulacean Acid Metabolism (CAM)** to meet their CO_2 requirements:

Night-time process:

- Stomata open at night when temperatures are cooler and humidity is higher
- CO_2 is fixed to PEP by PEP carboxylase, forming oxaloacetate
- Oxaloacetate is converted to malate and stored in vacuoles as malic acid

Day-time process:

- Stomata close to prevent water loss
- Stored malic acid is decarboxylated, releasing CO_2 internally
- Released CO_2 enters the Calvin cycle through RuBisCO
- This temporal separation allows photosynthesis while minimizing water loss

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2. Chlorophyll 'a' is the primary pigment for light reaction. What are accessory pigments? What is their role in photosynthesis?

Solution:

Accessory pigments include:

- Chlorophyll b
- Carotenoids (β-carotene, lycopene)
- Xanthophylls (lutein, zeaxanthin)

Roles in photosynthesis:

1. **Light harvesting:** Capture light wavelengths not efficiently absorbed by chlorophyll a
2. **Energy transfer:** Channel absorbed light energy to chlorophyll a reaction centers
3. **Photoprotection:** Carotenoids protect against photodamage by quenching excited chlorophyll and scavenging harmful radicals
4. **Extend absorption spectrum:** Allow utilization of broader range of light wavelengths
5. **Antenna complex formation:** Form light-harvesting complexes that increase efficiency

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3. Do reactions of photosynthesis called 'Dark Reactions' need light? Explain.

Solution: Dark reactions do **not directly require light** but are **indirectly light-dependent**:

Direct independence from light:

- Calvin cycle enzymes don't require light energy directly
- Can occur in darkness if ATP and NADPH are available
- Temperature-dependent rather than light-dependent

Indirect light dependence:

- Requires ATP and NADPH produced during light reactions
- RuBisCO activation requires proper pH and Mg^{2+} levels maintained by light reactions
- Starch synthesis regulation is influenced by light-dependent factors

- In natural conditions, dark reactions occur simultaneously with light reactions during daylight

Conclusion: While termed "dark reactions," they effectively require light indirectly through their dependence on light reaction products.

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4. How are photosynthesis and respiration related to each other?

Solution: Photosynthesis and cellular respiration are **complementary processes**:

Chemical relationship:

- Photosynthesis: $6CO_2 + 6H_2O$ + light energy → $C_6H_{12}O_6 + 6O_2$
- Respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + ATP

Interdependence:

1. **Products and reactants:** Products of one serve as reactants for the other
2. **Temporal relationship:** Photosynthesis occurs during day, respiration occurs continuously
3. **Energy flow:** Photosynthesis stores energy, respiration releases energy
4. **Gas exchange:** CO_2 from respiration used in photosynthesis; O_2 from photosynthesis used in respiration
5. **Carbon cycle:** Both processes are essential components of the global carbon cycle

In plants: Both processes occur simultaneously during daylight, with net CO_2 uptake when photosynthesis rate exceeds respiration rate.

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5. If a green plant is kept in dark with proper ventilation, can this plant carry out photosynthesis? Can anything be given as a supplement to maintain its growth or survival?

Solution:

Photosynthesis in darkness: No, photosynthesis cannot occur in complete darkness because:

- Light reactions cannot proceed without photon energy
- No ATP and NADPH production from light reactions
- Dark reactions cease due to lack of energy currency

Survival strategies:

1. **Short-term survival:**
    - Use stored starch and sugars for respiration
    - Maintain basic metabolic processes
2. **Possible supplements:**
    - **Sugar solutions** - provide glucose for respiration
    - **Artificial light** - enable photosynthesis to resume
    - **Proper ventilation** - ensure adequate CO_2 and O_2 exchange

Limitations: Even with sugar supplementation, the plant will eventually die because:

- Cannot synthesize essential proteins and other complex molecules efficiently
- Chlorophyll degradation without replacement
- Disrupted hormone balance and developmental processes

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6. Photosynthetic organisms occur at different depths in the ocean. Do they receive qualitatively and quantitatively the same light? How do they adapt to carry out photosynthesis under these conditions?

Solution:

Light variation with depth:

- **Quantitative:** Light intensity decreases exponentially with depth
- **Qualitative:** Red light is absorbed first, blue light penetrates deepest

Adaptations at different depths:

Surface organisms:

- High concentration of chlorophyll a and b
- Protective carotenoids against high light intensity

Intermediate depths:

- Increased antenna pigment complexes
- Enhanced light-harvesting efficiency

Deep water organisms:

- **Phycoerythrin** - absorbs blue-green light that penetrates deep
- **Phycocyanin** - extends light absorption range
- Larger light-harvesting complexes
- Lower light saturation points
- Reduced oxygen production per photon absorbed

Specialized adaptations:

- Some use bioluminescence or chemosynthesis
- Enhanced pigment-protein ratios
- Modified photosystem structure for low-light efficiency

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7. In tropical rain forests, the canopy is thick and plants growing below receive filtered light. How are they able to carry out photosynthesis?

Solution: Understory plants (**sciophytes**) have several adaptations for low-light photosynthesis:

Morphological adaptations:

- **Larger leaves** - increased surface area for light capture
- **Thinner leaves** - reduced self-shading
- **Horizontal leaf orientation** - maximize light interception

Physiological adaptations:

- **Higher chlorophyll content** - especially chlorophyll b for blue light absorption
- **Enhanced accessory pigments** - better utilization of filtered light

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- **Larger photosynthetic units** - more antenna pigments per reaction center
- **Lower light compensation point** - can photosynthesize at very low light intensities
- **Higher chlorophyll a:b ratio** - optimized for shade conditions

Biochemical adaptations:

- More efficient electron transport chains
- Reduced photorespiration
- Lower metabolic rates to match reduced energy availability
- Enhanced light-harvesting complex efficiency

These adaptations allow sciophytes to achieve positive carbon balance even under the dense forest canopy.

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8. What conditions enable Rubisco to function as an oxygenase? Explain the ensuing process.

Solution:

Conditions favoring oxygenase activity:

1. **Low CO_2 concentration** - reduces competitive binding
2. **High O_2 concentration** - increases oxygen binding probability
3. **High temperature** - increases oxygenase vs. carboxylase activity
4. **High pH** - shifts equilibrium toward oxygenase function
5. **Water stress** - closed stomata reduce CO_2 availability

Photorespiration process:

1. **Oxygenation:** RuBisCO catalyzes RuBP + O_2 → 3-PGA + phosphoglycolate
2. **Phosphatase activity:** Phosphoglycolate → glycolate + Pi
3. **Peroxisome:** Glycolate → glyoxylate + H_2O_2 (by glycolate oxidase)
4. **Transamination:** Glyoxylate → glycine (in peroxisomes)
5. **Mitochondria:** 2 Glycine → serine + CO_2 + NH_3 + NADH
6. **Conversion:** Serine → glycerate (in peroxisomes)
7. **Return:** Glycerate → 3-PGA (in chloroplasts)

Consequences:

- Loss of fixed CO_2
- Energy waste (consumes ATP)
- Reduced photosynthetic efficiency
- This is why C_4 and CAM plants evolved CO_2-concentrating mechanisms

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9. Why does the rate of photosynthesis decrease at higher temperatures?

Solution: Photosynthesis rate decreases at higher temperatures due to several factors:

Enzyme denaturation:

- **RuBisCO instability** - loses catalytic efficiency above optimal temperature
- **Other Calvin cycle enzymes** become less stable

- **Protein structure disruption** reduces enzyme activity

Increased photorespiration:

- Higher temperature favors RuBisCO oxygenase activity
- Solubility of CO_2 decreases faster than O_2 with increasing temperature
- Shifts CO_2:O_2 ratio unfavorably

Stomatal closure:

- **Water stress** at high temperatures causes stomata to close
- **Reduced CO_2 uptake** limits photosynthesis
- **Heat stress** directly affects stomatal function

Chlorophyll breakdown:

- High temperatures accelerate chlorophyll degradation
- Reduced light-harvesting efficiency
- Photosystem damage

Membrane stability:

- **Thylakoid membrane** becomes more permeable
- **Proton gradient** less efficiently maintained
- **Electron transport** disrupted

Optimal temperature: Most plants show optimal photosynthesis at 25-35°C, with sharp decline above 40°C.

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10. Explain how during light reaction of photosynthesis, ATP synthesis is a chemiosmotic phenomenon.

Solution: ATP synthesis in photosynthesis follows the **chemiosmotic theory**:

Proton gradient establishment:

1. **Water photolysis:** $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$ (in thylakoid lumen)
2. **Proton pumping:** Cytochrome b_6f complex pumps H^+ from stroma to lumen
3. **NADPH formation:** $NADP^+ + H^+ + 2e^- \rightarrow NADPH$ (consumes H^+ from stroma)

Gradient characteristics:

- **Chemical gradient:** Higher $[H^+]$ in lumen than stroma
- **Electrical gradient:** Positive charge in lumen, negative in stroma
- **pH difference:** Lumen pH ~4, stroma pH ~8
- **Electrochemical gradient:** Combination provides driving force

ATP synthesis mechanism:

1. **Proton flow:** H^+ flows down gradient through ATP synthase
2. **Conformational changes:** F_1 component undergoes rotational changes
3. **Catalytic cycle:** ADP + Pi → ATP in F_1 catalytic sites
4. **Energy coupling:** Proton-motive force drives ATP synthesis

Quantitative relationship:

- Approximately 3-4 H^+ required per ATP synthesized
- Links light energy → proton gradient → chemical energy (ATP)

This demonstrates how light energy is converted to chemical energy through an electrochemical intermediate.

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11. Find out how Melvin Calvin worked out the complete biosynthetic pathway for synthesis of sugar.

Solution: Calvin used **radioactive tracer technique** with $^{14}CO_2$:

Experimental design:

1. **Radioactive labeling:** Used $^{14}CO_2$ (carbon-14 labeled carbon dioxide)
2. **Controlled conditions:** Green algae (Chlorella) in controlled light conditions
3. **Time course experiments:** Varied exposure time from seconds to minutes
4. **Rapid killing:** Quick immersion in hot alcohol to stop reactions instantly

Methodology:

1. **Pulse-chase experiments:**
   - Short $^{14}CO_2$ pulse followed by $^{12}CO_2$ chase
   - Tracked radioactive carbon through metabolic intermediates
2. **Chromatographic separation:**
   - Two-dimensional paper chromatography
   - Separated all organic compounds from cell extracts
3. **Autoradiography:**
   - X-ray film exposure to detect radioactive compounds
   - Identified which compounds contained ^{14}C
4. **Time sequence analysis:**
   - First labeled compound: 3-phosphoglycerate (3-PGA)
   - Later labeling: ribulose bisphosphate, glucose, etc.

Key discoveries:

- CO_2 acceptor is RuBP (5-carbon)
- First stable product is 3-PGA (3-carbon)
- Cyclic nature of carbon fixation
- Energy requirements (ATP and NADPH)

Nobel Prize: Calvin received the 1961 Nobel Prize in Chemistry for this work, leading to the pathway being called the "Calvin Cycle."

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12. Six turns of the Calvin cycle are required to generate one mole of glucose. Explain.

Solution: This requirement stems from the **stoichiometry of carbon fixation**:

Basic calculation:

- **Glucose = $C_6H_{12}O_6$** (6 carbon atoms)
- **Each Calvin cycle turn fixes 1 CO_2** (1 carbon atom)
- **Therefore: 6 turns needed for 6 carbon atoms**

Detailed pathway analysis:

Per turn of Calvin cycle:

- Input: 1 CO_2, 3 ATP, 2 NADPH
- Output: 1/6 of glucose equivalent

For complete glucose synthesis (6 turns):

- **Carbon fixation:** 6 CO_2 + 6 RuBP → 12 × 3-PGA
- **Reduction:** 12 × 3-PGA + 12 NADPH + 12 ATP → 12 × G3P
- **Regeneration:** 10 × G3P + 6 ATP → 6 RuBP
- **Net product:** 2 × G3P → 1 glucose

Total requirements:

- 6 CO_2
- 18 ATP (12 for reduction + 6 for regeneration)
- 12 NADPH
- Net output: 1 glucose molecule

Why not fewer turns:

- Each RuBisCO carboxylation adds only one carbon
- Glucose requires six carbon atoms
- The cycle must turn six times to accumulate sufficient carbon

This explains why photosynthesis is energetically expensive, requiring substantial light energy input.

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13. Complete the flow chart for cyclic photophosphorylation of photosystem-I

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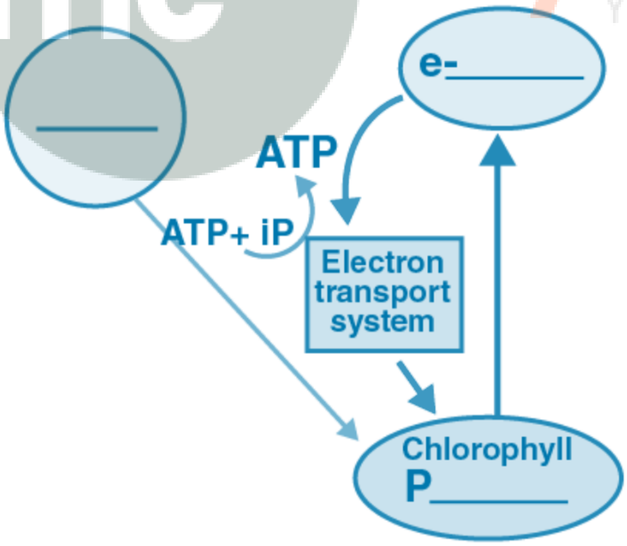

Flow Chart:

Light → Photosystem I → Excited Electron → Primary Electron Acceptor → Ferredoxin → Cytochrome b_6f Complex → Plastocyanin → Photosystem I

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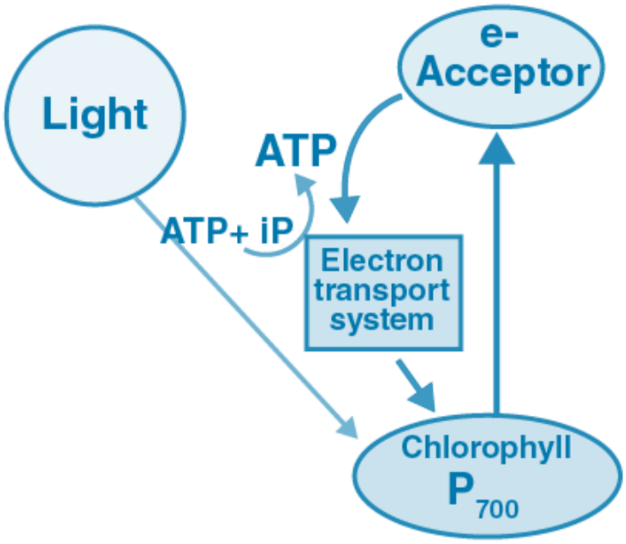
ATP ← ATP + Pi ← Proton Gradient

Enhanced Explanation:



Cyclic photophosphorylation characteristics:

1. **Only PSI involved** - PSII is not active
2. **No water splitting** - no oxygen production
3. **No NADPH production** - only ATP synthesis
4. **Electron recycling** - electrons return to PSI

Process details:

1. **Light absorption:** PSI absorbs photons
2. **Electron excitation:** Chlorophyll a in PSI reaction center excited
3. **Electron transport:** e^- → ferredoxin → cytochrome b_6f → plastocyanin → PSI
4. **Proton pumping:** Cytochrome b_6f pumps H^+ across thylakoid membrane
5. **ATP synthesis:** Proton gradient drives ATP synthase

Biological significance:

- Provides additional ATP when ATP:NADPH ratio needs adjustment
- Occurs under high light conditions
- Important for balancing energy requirements in Calvin cycle

Q14. In what kind of plants do you come across 'Kranz' anatomy? To which conditions are those plants better adapted? How are these plants better adapted than the plants which lack this anatomy?

Answer:

Kranz anatomy is a special structural feature found in the leaves of **C4 plants** such as maize, sugarcane, and sorghum. These plants show two types of cells in their leaves – bundle sheath cells and mesophyll cells – which are arranged in a wreath-like pattern.

C4 plants are better adapted to conditions of **high temperature, water scarcity, and limited carbon dioxide**. They minimize photorespiration, making carbon fixation more efficient.

Compared to C3 plants, C4 plants conserve energy, fix more CO2 even at lower concentrations, and perform well under stress conditions, giving them a survival advantage.

Q15. In a way, green plants and cyanobacteria have synthesized all the food on the earth. Comment.

Answer:

Cyanobacteria are unicellular, prokaryotic organisms containing pigments like chlorophyll-a, phycocyanin, and phycoerythrin. These allow them to perform photosynthesis and produce food independently.

Green plants, being multicellular, also perform photosynthesis using chlorophyll pigments, carbon dioxide, water, and sunlight.

Together, green plants and cyanobacteria have acted as the **primary producers** of the biosphere, synthesizing food and releasing oxygen for all life forms on Earth. Hence, they are the foundation of the food chain.

Q16. Tomatoes, carrots, and chillies are red due to the presence of one pigment. Name the pigment. Is it a photosynthetic pigment?

Answer:

The red colour of tomatoes, carrots, and chillies is due to the presence of the pigment **carotene**. It is not a primary photosynthetic pigment but rather an **accessory pigment**, as it helps in harvesting light energy and passing it on to chlorophyll.

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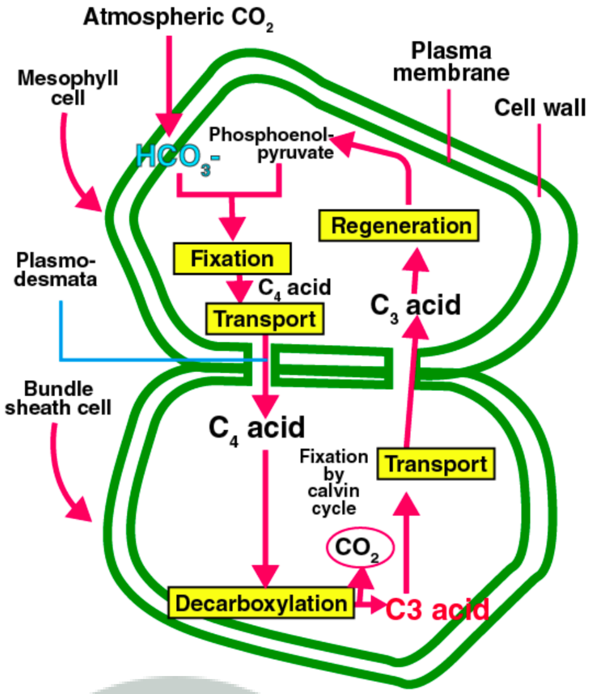
Q17. Why do we believe chloroplast and mitochondria to be semi-autonomous organelles?

Answer:

Both chloroplasts and mitochondria are known as **semi-autonomous organelles** because they possess their own **DNA, ribosomes, and protein-synthesizing machinery**. They can replicate independently and synthesize some of their own proteins and enzymes, yet they depend on the cell nucleus for full functionality.

Q18. Observe the diagram and answer the following:



- a. Which group of plants exhibits these two types of cells?
- b. What is the first product of the C4 cycle?
- c. Which enzyme is present in bundle sheath and mesophyll cells?

Answer:

a. Monocotyledonous C4 plants show both bundle sheath cells and mesophyll cells, arranged in Kranz anatomy.

b. The first stable product of the C4 cycle is **oxaloacetic acid (OAA)**.

c. The key enzyme in mesophyll cells is **PEP carboxylase**, and Rubisco is present in the bundle sheath cells.

Q19. A cyclic process is occurring in a C3 plant which is light-dependent and requires O2. This process consumes energy instead of producing it.

Answer:

a. The given process is **Photorespiration**.

b. Photorespiration is *not essential for survival* but occurs as a side reaction due to Rubisco's affinity for oxygen.

c. The end-products are **CO2 and hydrogen peroxide (H2O2)**.

d. It occurs in the **chloroplast, mitochondria, and peroxisomes**.

Q20. Suppose Euphorbia and maize are grown in a tropical area.

- a. Which one will be able to survive?
- b. Which one is more efficient in terms of photosynthesis?
- c. What differences exist in their leaf anatomy?

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Answer:

a. Both can survive in tropical areas because Euphorbia is a **CAM plant** and maize is a **C4 plant**.

b. Maize, being a C4 plant, is more photosynthetically efficient than CAM plants under such conditions.

c. Maize leaves exhibit **Kranz anatomy** with well-developed bundle sheath cells, while Euphorbia lacks Kranz anatomy and instead shows CAM adaptations like nocturnal CO2 fixation.

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