Unit 06

Bioenergetics

STUDENTS LEARNING OUTCOMES (SLO's)

After studying this unit, the students will be able to

- Explain the role of light, carbon dioxide and water in photosynthesis.
- Identify the two general kinds of photosynthetic pigments (carotenoids and chlorophylls).
- Describe the roles of photosynthetic pigments in the absorption and conversion of light energy.
- Differentiate between the absorption spectra of chlorophyll 'a' and 'b'.
- Draw the molecular structure of chlorophyll.
- Describe the arrangements of photosynthetic pigments in the form of photosystem-I and II.
- Describe the events of non-cyclic photophosphorylation and outline the cyclic photophosphorylation.
- Draw the Z-scheme for explaining the events the light dependent reactions.
- Explain the Calvin cycle.
- Develop a flow chart for explaining the events of light reactions.
- Describe the features of ATP that make it suitable as the universal energy currency.
- Describe the synthesis and breakdown of ATP.
- Describe the four stages in aerobic respiration in eukaryotic cells:
- Explain the process of anaerobic respiration in terms of glycolysis and conversion of pyruvate into lactic acid or ethanol.
- Outline the events of glycolysis (naming the reactants and products of each step).
- Describe the link reaction, including the role of coenzyme A.
- Outline the Krebs cycle (naming the reactants and products of each step).
- Describe the role of NAD and FAD in cellular respiration.
- Explain that passage of electrons through electron transport chain highlighting the oxidation and reduction reactions (details of carriers are not required).
- Describe chemiosmosis and relate it to electron transport chain.
- Explain why the energy yield from respiration in aerobic conditions is much greater than the energy yield from respiration in anaerobic conditions.

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INTRODUCTION

Energy is the driving force behind all life processes. From the tiniest bacterium to the largest whale, every living organism depends on energy to grow, reproduce, and survive. Without a continuous supply of energy, life would simply cease to exist. But where does this energy originate? How do living cells capture, store, and use energy to carry out the numerous activities required for life?

> Nearly all the energy used by livingorganisms on Earth comes fromphotosynthesis. Plants, algae, andcertain bacteria capture sunlight andconvert it into chemical energy,forming the base of the food

The answers to these questions lie within the field of **bioenergetics**: "a branch of biology that focuses on the flow of energy in living systems". Bioenergetics examines how cells acquire energy, how they convert it into usable forms, and how this energy is ultimately utilized to sustain life. Key processes such as **photosynthesis** and **cellular respiration** are central to this field, revealing how organisms harness energy from their environment and convert it into a form that powers cellular functions.

Q 1. Explain the structure and function of ATP and how it acts as the energy currency of cells.

Ans. ATP: The Energy Currency of Cells

Cells use a special energy currency for their reactions. This currency is actually a nucleotide called **adenosine triphosphate (ATP)**. When cells store energy, they make ATP. When cells need energy, they break ATP.

A molecule of ATP has three subunits i.e.

- **adenine**, (a nitrogen-containing base)
- **ribose** (a five-carbon sugar)
- **three phosphate groups**.

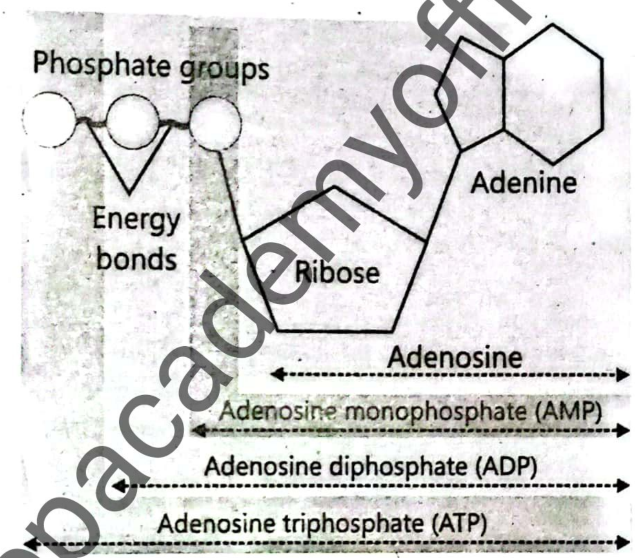

Fig. 6.1: Molecular structure of ATP

The covalent bonds between two phosphates are **high-energy bonds**. When one of these bonds is broken, **inorganic phosphate (Pi)** separates and **energy is released**. The breaking of one phosphate bond releases about **7.3 kcal (7,300 calories) per mole of ATP**.The chemical reaction is:

> ATP was discovered in 1929 by **KarlLohmann**. In 1941, the Nobel prize winner,**Fritz Lipmann** proposed that ATP isthe main energy-transfer moleculein the cell.

ATP + H_2O → ADP + Pi + energy (7.3 kcal/mole)

In common energy reactions, **only the outer P–P high-energy bond breaks**. When this happens, ATP becomes **ADP (adenosine diphosphate)** and one Pi is released.

In some cases, ADP is further broken down to AMP (adenosine monophosphate) and Pi:

ADP + H_2O → AMP + Pi + energy (7.3 kcal/mole)

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Cells get energy from the oxidation of food. They store this energy by combining ADP with Pi to form ATP. So we can summarize that ATP is made during energy-releasing processes and it is broken down during energy-consuming processes. In this way, ATP transfers energy between metabolic reactions.

MCQs

1. **What is bioenergetics?**
   A) The study of DNA replication
   B) The study of protein synthesis
   C) The study of energy flow in ecosystems
   D) The study of how energy flows through living systems ✓

2. **Which two processes help to understand the principles of bioenergetics?**
   A) Transcription and translation
   B) Photosynthesis and respiration ✓
   C) Fermentation and digestion
   D) Diffusion and osmosis

3. **What is the energy currency of cells?**
   A) DNA B) RNA
   C) ATP ✓ D) NADPH

4. **Which of the following is NOT a component of ATP?**
   A) Adenine B) Glucose ✓
   C) Ribose D) Phosphate groups

5. **What is released when a high-energy phosphate bond in ATP is broken?**
   A) NADH B) CO_2
   C) Inorganic phosphate and energy ✓
   D) Oxygen and sugar

6. **How much energy is released by breaking one phosphate bond in ATP?**
   A) 2 kcal/mole B) 4.6 kcal/mole
   C) 7.3 kcal/mole ✓ D) 10 kcal/mole

7. **What does ATP become when one phosphate group is removed?**
   A) AMP B) ADP ✓
   C) NADP D) Glucose

8. **What is the reaction for the breakdown of ATP?**
   A) $ADP + H_2O \rightarrow ATP + energy$
   B) $ATP \rightarrow ADP + CO_2$
   C) $ATP + H_2O \rightarrow ADP + Pi + energy$ ✓
   D) $ATP + CO_2 \rightarrow Glucose$

9. **How do cells generate ATP?**
   A) By combining oxygen with glucose
   B) By storing water
   C) By combining ADP with Pi using energy from food oxidation ✓
   D) By using nitrogen bases

10. **When is ATP broken down in cells?**
    A) During energy-storing processes
    B) During energy-consuming processes ✓
    C) During cell division only
    D) During passive transport only

SQ

1. What is bioenergetics?

Ans. Bioenergetics is the study of how energy flows through living systems. It explores the processes through which cells store and expend energy.

2. Why is energy important for living organisms?

Ans: Energy fuels their growth, reproduction, and daily survival. It is a fundamental aspect of life.

3. Which two biological processes help to understand the principles of bioenergetics?

Ans: The processes of photosynthesis and respiration help to understand some of the principles of bioenergetics. Photosynthesis acts as an energy–capturing process while respiration is an energy-releasing process.

4. What is ATP and what role does it play in cells?

Ans: ATP, or adenosine triphosphate, is a special energy currency that cells use for their reactions. When cells store energy, they make ATP, and when they need energy, they break ATP.

5. What are the components of an ATP molecule?

Ans: A molecule of ATP has three subunits: adenine (a nitrogen-containing base), ribose (a five-carbon sugar), and three phosphate groups. These components work together to store and release energy.

6. What happens when one high-energy bond of ATP is broken?

Ans: When one of the phosphate bonds is broken, inorganic phosphate (Pi) separates and energy is released. This breaking of one phosphate bond releases about 7.3 kcal (7,300 calories) per mole of ATP.

7. What is the chemical equation for the breakdown of ATP to ADP?

Ans: $ATP + H_2O \rightarrow ADP + Pi + energy$ (7.3 kcal/mole). In this reaction, ATP becomes ADP and one Pi is released.

8. What happens to ADP in some energy reactions?

Ans: In some cases, ADP is further broken down to AMP (adenosine monophosphate) and Pi. This also releases about 7.3 kcal/mole of energy.

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9. **How do cells get energy to form ATP?**

Ans: Cells get energy from the oxidation of food. They store this energy by combining ADP with Pi to form ATP.

10. **How does ATP function in metabolic reactions?**

Ans: ATP is made during energy-releasing processes and it is broken down during energy-consuming processes. In this way, ATP transfers energy between metabolic reactions.

6.1 PHOTOSYNTHESIS

INTRODUCTION

Photosynthesis involves the use of light energy that is absorbed and converted into chemical energy by photosynthetic pigments.

Photosynthesis in plants can be summarized as:

$$6CO_2 + 12H_2O + Light \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Carbon dioxide, water and light are the reactants, while glucose and oxygen are the products. Water appears on both sides of the equation because water is used as a reactant in some reactions and released as a product in others. However, there is no net yield of water.

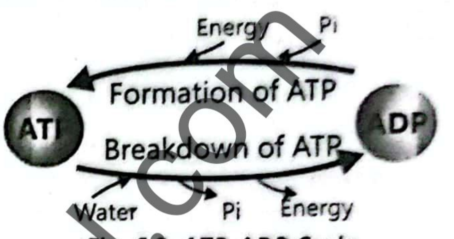

Fig. 6.2: ATP-ADP Cycle

Compensation Point: Photosynthesis uses the products of respiration and respiration uses theproducts of photosynthesis. Photosynthesis occurs only during day time but respiration goes on dayand night. During darkness, leaves and other parts respire and utilize oxygen and release carbondioxide. At dawn and dusk, when light intensity is low, the rate of photosynthesis and respiration maybe equal for a short time. Thus, the oxygen released from photosynthesis is just equal to the amountrequired for cellular respiration. Also, the carbon dioxide released by respiration is just equal to theamount required by photosynthesizing cells. At this moment there is no net gas exchange betweenleaves and atmosphere. This is termed as compensation point. At noon, when the light intensityincreases, the rate of photosynthesis also increases. At this time, there is more requirement of carbon dioxide. Respiration alone cannot supply this carbon dioxide. Similarly, the oxygen produced duringphotosynthesis is more than the need of the respiring cells. So, the result is the net release of oxygencoupled with the uptake of carbon dioxide

Q 2. What is the role of light in the process of Photosynthesis?

Ans. Role of Light

Light plays a crucial role in photosynthesis, providing the energy required to drive the chemical reactions that transform simple molecules into complex organic compounds. Light energy is absorbed by chlorophyll. The absorbed light energy is converted into chemical energy, which is in turn stored in organic compounds in the form of C–H bond energy. It happens like this:

Recalling:
Photosynthesis is the process in whichthe energy-poor inorganic compoundsof carbon (i.e., CO_2) are reduced toenergy-rich carbohydrates.

Q 3. What is the action spectrum, and how was it discovered?

Ans. Action Spectrum

Photosynthetic pigments absorb different wavelengths of light at different rates. Moreover, the different wavelengths are also differently effective in photosynthesis. The effectiveness of different wavelengths of light is determined in terms of **action spectrum**.

Plants convert only about 1-2%of the solar energy they receiveinto chemical energy duringphotosynthesis. Despite thisseemingly low efficiency, thisconversion is enough to sustainalmost all life on Earth

For getting action spectrum of light, a plant is illuminated with different colours of light one by one. While providing each colour, the rate of photosynthesis is measured by measuring the amount of oxygen emitted from leaves. The data is plotted in a graph called **action spectrum**.

The first action spectrum was made by a German biologist, **T. W. Engelmann in 1883**. He worked on the photosynthetic pigments of *Spirogyra*. When the cells of a filament of *Spirogyra* were illuminated with different

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wavelengths of light, maximum photosynthesis occurred in the cells which received blue and red spectrum of light and so maximum oxygen was emitted from these cells.

Q 4. Describe the role of carbon dioxide and water in the process of photosynthesis.

Ans. Role of Carbon Dioxide

Sugar is formed by the reduction of CO_2 by using ATP and NADPH. In this way, CO_2 acts as the source of carbon for making sugars. Carbon dioxide enters the leaves through **stomata** and gets dissolved in water absorbed by the cell walls of **mesophyll cells**. Stomata are found in large numbers in leaves. The entry of CO_2 into the leaves is dependent upon the opening of stomata.

About 10% of total photosynthesis is carried out byterrestrial plants, the rest occurs in oceans, lakes andponds. Aquatic photosynthetic organisms usedissolved CO2, bicarbonates and soluble carbonatesas carbon source. Land photosynthetic organisms useatmospheric CO2 as carbon source.

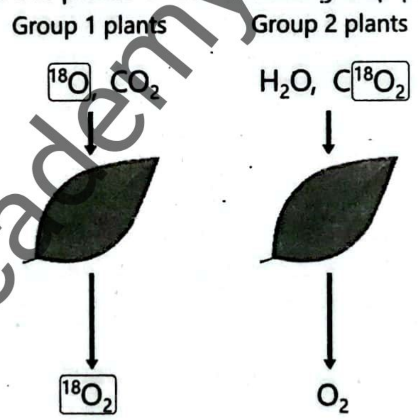
Neil's hypothesis was based on the investigations onphotosynthetic bacteria that make carbohydrate fromcarbon dioxide, but do not release oxygen.

Role of Water

Water is the source of hydrogen for the reduction of CO_2 during photosynthesis. Oxygen released during photosynthesis comes from water, and so water is an important source of atmospheric oxygen which most organisms need for aerobic respiration and thus for obtaining energy to live.

In 1930s, **Van Neil hypothesized** that plant splits water as a source of hydrogen, releasing oxygen as a by-product. Neil's hypothesis was later confirmed by scientists during the 1940s.

An experiment was conducted in which isotopic tracer (**^{18}O**) of oxygen was used. In laboratory, scientists prepared water with heavy-oxygen i.e., **$H_2{}^{18}O$**. They also prepared carbon dioxide with heavy oxygen i.e., **$C^{18}O_2$**. Experimental green plants in one group were given water $H_2{}^{18}O$ and normal carbon dioxide i.e., $C^{16}O_2$. Plants in the second group were given $C^{18}O_2$ and normal water i.e., $H_2{}^{16}O$. Both plants were given an environment to conduct photosynthesis. Oxygen released during photosynthesis of both plants was collected and tested. It was found that plants of the first group produced **^{18}O** but the plants of the second group produced normal oxygen (**^{16}O**).



Group 1

$$6\,CO_2 + 12H_2\boxed{^{18}O} \longrightarrow C_6H_{12}O_6 + 6H_2O + 6\boxed{^{18}O_2}$$

Group 2

$$6\,C\boxed{^{18}O_2} + 12H_2O \longrightarrow C_6H_{12}\boxed{^{18}O_6} + 6H_2\boxed{^{18}O} + 6O_2$$

Fig. 6.3: Experiment to prove that water is the source of oxygen released in photosynthesis

In photosynthesis, water is split to release hydrogen. This hydrogen reduces the coenzyme **nicotinamide adenine dinucleotide phosphate (NADP) to NADPH**. The reduced coenzyme, NADPH, serves as the "reducing power" for the reduction of CO_2 to form sugar.

Q 5. Explain the role of photosynthetic pigments in photosynthesis. OR What are chlorophylls and accessory pigments? Describe their structure and function.

Ans. Role of Photosynthetic Pigments

Photosynthetic pigments are present in thylakoid membranes. These pigments capture light energy necessary for photosynthesis. Some of the pigments are **chlorophyll a, chlorophyll b, xanthophylls, and carotenes**. Different

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pigments absorb light of different wavelengths (colours). Light behaves like a stream of particles called **photons**. Pigment molecules absorb one photon at a time.

When a pigment molecule absorbs a photon, its electrons move to a higher energy level. So, it becomes energy-rich or excited.

> Short wavelength photons (blue) havea higher energy than long wavelength(red) photons. More energeticphotons (shorter wavelength)promote electrons to higher energylevels.

i. Chlorophylls

Chlorophyll is a lipid molecule. Chlorophylls are of different kinds. **Chlorophyll a, b, c, and d** are found in plants and algae, while the others are found in photosynthetic bacteria and are known as **bacteriochlorophylls**.

Structure of Chlorophyll: A molecule of chlorophyll consists of two parts i.e., a **hydrophilic head** and a **hydrophobic tail**. The head is made of a **porphyrin ring**, which further consists of four **pyrrole rings** (5-sided N-containing compounds). The four pyrrole rings are held together by a **magnesium atom** in the centre. In **chlorophyll-a**, the second pyrrole ring has a **methyl (CH_3)** group while in **chlorophyll-b**, it has an **aldehyde (CHO)** group at the same spot. The porphyrin ring of chlorophyll absorbs light. The tail is made of a long hydrocarbon chain. It anchors the molecule in the thylakoid membrane.

> Carotenoids, such as beta-carotene, playdual role in photosynthesis. They capturelight energy in the blue and green regionsof the spectrum and protect thephotosynthetic apparatus from damage byexcess light.

Chlorophylls absorb mainly **violet-blue and orange-red** wavelengths of light. **Green wavelengths are least absorbed** by chlorophylls and are transmitted or reflected.

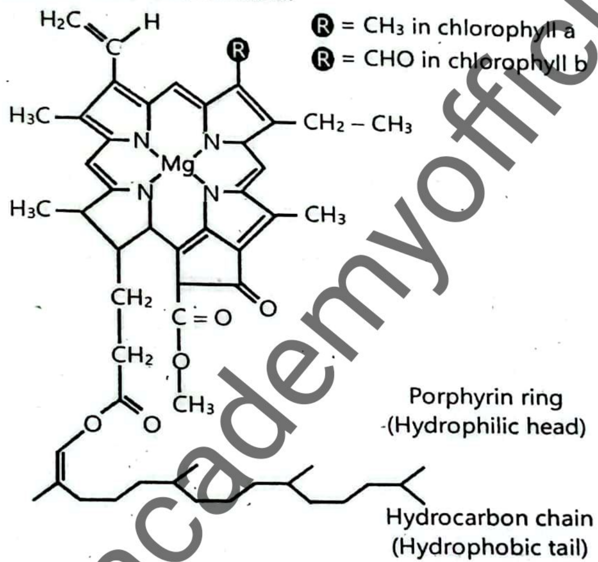

Fig. 6.4: Molecular structure of chlorophyll a and chlorophyll b

ii. Accessory Pigments

Accessory pigments include all the pigments, other than **chlorophyll a**, which can gather light for photosynthesis. **Chlorophyll b** is an accessory pigment and others are **carotenoids** (carotenes and xanthophylls) and **phycobilins**. Chlorophyll b and carotenoids are found in plants, while phycobilins are found in **red algae and cyanobacteria**. When accessory pigments absorb light, they pass on the energy towards chlorophyll a. It is generally believed that the order of transfer of energy in plants is:

6. What is the absorption spectrum and how does it relate to photosynthesis?

Ans. Absorption Spectrum

A graph showing different wavelengths absorbed by a pigment is called the **absorption spectrum** of the pigment. Absorption spectrum of chlorophylls indicates that **absorption of blue light (430 nm) and red light (670 nm)** is maximum. Absorption peaks of carotenoids are different from those of chlorophylls.

> Some wavelengths not absorbed bychlorophyll-a are very affectivelyabsorbed by chlorophyll-b and viceversa.
> Such differences increase therange of light absorbed by bothchlorophylls.

Action spectrum of photosynthesis also shows that blue and red parts of light are the most effective. This means that the action

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spectrum of photosynthesis coincides with the absorption spectrum of photosynthetic pigments.

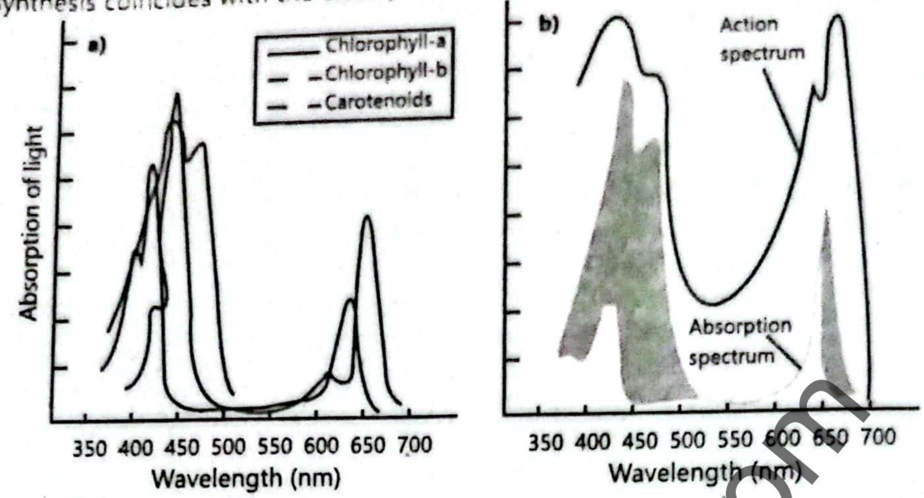

Fig. 6.5: (a)- Absorption spectrum; (b)- Action spectrum

MCQs

1. **What are the main reactants of photosynthesis in plants?**
   A) Oxygen, glucose, water
   B) Glucose, carbon dioxide, ATP
   C) Carbon dioxide, water, and light ✓
   D) Oxygen, ATP, water

2. **What are the products of photosynthesis?**
   A) CO_2 and H_2O B) Glucose and oxygen ✓
   C) NADPH and ATP D) Light and carbon dioxide

3. **Why does water appear on both sides of the photosynthesis equation?**
   A) It is used and released in equal amounts ✓
   B) It evaporates
   C) It forms glucose D) It is only a by-product

4. **What is the role of light in photosynthesis?**
   A) It evaporates water B) It breaks down glucose
   C) It drives the chemical reactions ✓
   D) It opens stomata

5. **Which pigment absorbs light energy in photosynthesis?**
   A) Glucose B) Chlorophyll ✓
   C) Starch D) Ribulose

6. **What is an action spectrum?**
   A) Graph of sugar production
   B) Spectrum of pigment absorption
   C) Effectiveness of different wavelengths ✓
   D) Map of chloroplasts

7. **Who made the first action spectrum?**
   A) Van Neil B) Engelmann ✓
   C) Hooke D) Mendel

8. **What did Engelmann use in his experiment?**
   A) Green algae B) Elodea
   C) Spirogyra ✓ D) Volvox

9. **Where does carbon dioxide enter a leaf?**
   A) Through phloem B) Through the cuticle
   C) Through stomata ✓ D) Through xylem

10. **What helps dissolve CO_2 in the leaf?**
    A) Air pockets B) Phloem sap
    C) Water absorbed by mesophyll cell walls ✓
    D) Glucose solution

11. **What is the role of water in photosynthesis?**
    A) It stores glucose B) It acts as a pigment
    C) It provides hydrogen and releases oxygen ✓
    D) It opens stomata

12. **Who hypothesized that water splits during photosynthesis?**
    A) Darwin B) Neil ✓
    C) Watson D) Sachs

13. **What did scientists use to confirm Van Neil's hypothesis?**
    A) Enzymes B) ^{18}O isotopes ✓
    C) Glucose D) X-rays

14. **What does NADPH do in photosynthesis?**
    A) Captures sunlight B) Opens stomata
    C) Acts as reducing power for CO_2 ✓
    D) Stores water

15. **Where are photosynthetic pigments located?**
    A) Cell wall
    B) Thylakoid membranes ✓
    C) Cytoplasm D) Stomata

16. **What happens when a pigment absorbs a photon?**
    A) It breaks B) It reflects light
    C) Its electrons become excited ✓
    D) It cools down

17. **What is the core structure of chlorophyll's head?**
    A) Carbon chain B) Pyrrole rings ✓
    C) Glucose D) Water

18. **What element is at the center of chlorophyll's porphyrin ring?**
    A) Calcium B) Iron

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C) Magnesium ✓ D) Potassium

19. **What makes chlorophyll-a different from chlorophyll-b?**

A) Color B) Presence of magnesium

C) Type of hydrocarbon tail

D) CH_3 group vs CHO group on the second pyrrole ring ✓

20. **Which wavelengths are least absorbed by chlorophyll?**

A) Red and blue B) Green ✓

C) Violet D) Orange

SQ

1. **What is photosynthesis?**

Ans. Photosynthesis involves the use of light energy that is absorbed and converted into chemical energy by photosynthetic pigments. It allows plants to produce glucose and oxygen from carbon dioxide and water using light energy.

2. **What are the reactants and products of photosynthesis?**

Ans. Carbon dioxide, water and light are the reactants while glucose and oxygen are the products. Water appears on both sides of the equation because water is used as reactant in some reactions and released as product in others.

3. **Why is there no net yield of water in photosynthesis?**

Ans. Water appears on both sides of the equation because water is used as a reactant in some reactions and released as a product in others. However, there is no net yield of water.

4. **What role does light play in photosynthesis?**

Ans. Light plays a crucial role in photosynthesis, providing the energy required to drive the chemical reactions that transform simple molecules into complex organic compounds. Light energy is absorbed by chlorophyll and converted into chemical energy, which is stored in organic compounds in the form of C-H bond energy.

5. **What is an action spectrum?**

Ans. The effectiveness of different wavelengths of light is determined in terms of action spectrum. For getting action spectrum of light, a plant is illuminated with different colours of light one by one, and the rate of photosynthesis is measured by measuring the amount of oxygen emitted from leaves.

6. **Who made the first action spectrum and how?**

Ans. The first action spectrum was made by a German biologist, T. W. Engelmann in 1883. He worked on the photosynthetic pigments of Spirogyra and found that maximum photosynthesis occurred in the cells which received blue and red spectrum of light.

7. **How does carbon dioxide enter the plant for photosynthesis?**

Ans. Carbon dioxide enters the leaves through stomata and gets dissolved in water absorbed by the cell walls of mesophyll cells. The entry of CO_2 into the leaves is dependent upon the opening of stomata.

8. **What is the role of CO_2 in sugar formation?**

Ans. Sugar is formed by the reduction of CO_2 by using ATP and NADPH. In this way, CO_2 acts as the source of carbon for making sugars.

9. **What is the role of water in photosynthesis?**

Ans. Water is the source of hydrogen for the reduction of CO_2 during photosynthesis. Oxygen released during photosynthesis comes from water, and so water is an important source of atmospheric oxygen.

10. **What was Van Neil's hypothesis?**

Ans. In the 1930s, Van Neil hypothesized that plant splits water as a source of hydrogen, releasing oxygen as a by-product. Neil's hypothesis was later confirmed by scientists during the 1940s.

11. **What experiment confirmed that oxygen comes from water in photosynthesis?**

Ans. An experiment using isotopic tracer (^{18}O) was conducted. It showed that plants given water with heavy oxygen ($H_2{}^{18}O$) produced $^{18}O_2$, confirming that the oxygen released came from water, not CO_2.

12. **How is NADPH formed in photosynthesis?**

Ans. In photosynthesis, water is split to release hydrogen. This hydrogen reduces the coenzyme NADP to NADPH, which serves as the "reducing power" for the reduction of CO_2 to form sugar.

13. **Where are photosynthetic pigments found?**

Ans. Photosynthetic pigments are present in thylakoid membranes. These pigments capture light energy necessary for photosynthesis.

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14. **What happens when pigment molecules absorb photons?**

Ans. When a pigment molecule absorbs a photon, its electrons move to higher energy level. So, it becomes energy-rich or excited.

15. **What is the structure of chlorophyll?**

Ans. A molecule of chlorophyll consists of two parts: a hydrophilic head and a hydrophobic tail. The head is made of a porphyrin ring with a magnesium atom in the centre, and the tail is made of a long hydrocarbon chain.

16. **How does chlorophyll-a differ from chlorophyll-b?**

Ans. In chlorophyll-a, the second pyrrole ring has a methyl (CH_3) group. In chlorophyll-b, it has an aldehyde (CHO) group at the same spot.

17. **What colors of light does chlorophyll absorb and reflect?**

Ans. Chlorophylls absorb mainly violet-blue and orange-red wavelengths of light. Green wavelengths are least absorbed and are transmitted or reflected.

18. **What are accessory pigments and where are they found?**

Ans. Accessory pigments include all the pigments other than chlorophyll-a which can gather light for photosynthesis. Chlorophyll b and carotenoids are found in plants, while phycobilins are found in the red algae and cyanobacteria.

19. **How is energy transferred by accessory pigments?**

Ans. When accessory pigments absorb light, they pass on the energy towards chlorophyll a. It is generally believed that the order of transfer of energy in plants starts with accessory pigments.

20. **What is the absorption spectrum and what does it indicate?**

Ans. A graph showing different wavelengths absorbed by a pigment is called absorption spectrum of the pigment. Absorption spectrum of chlorophylls indicates that absorption of blue light (430 nm) and red light (670 nm) is maximum.

Organization of Photosynthetic Pigments (Photosystems)

Q7. What are photosystems and how are photosynthetic pigments organized for efficient absorption of solar energy?

Ans. Photosystems and Their Location

Photosynthetic pigments are not scattered randomly within the chloroplast. For efficient absorption and utilization of solar energy, these pigments are organized into functional clusters known as **photosystems**. These **photosystems are embedded in the thylakoid membranes** of the chloroplasts, ensuring optimal orientation and function during photosynthesis.

Components of a Photosystem

Each photosystem is composed of two main parts:

1. **Antenna Complex**
2. **Reaction Centre**

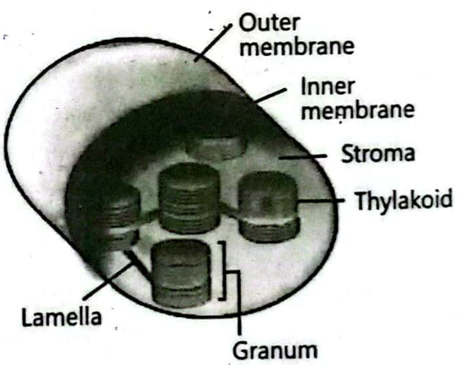

Fig. 6.6: Structure of Chloroplast

The **antenna complex** consists of numerous pigment molecules, such as chlorophylls and accessory pigments. These pigment molecules function collectively to capture light energy. Once the pigments absorb light, they transfer this energy in the form of **excitation energy (high-energy electrons)** to the **reaction centre**.

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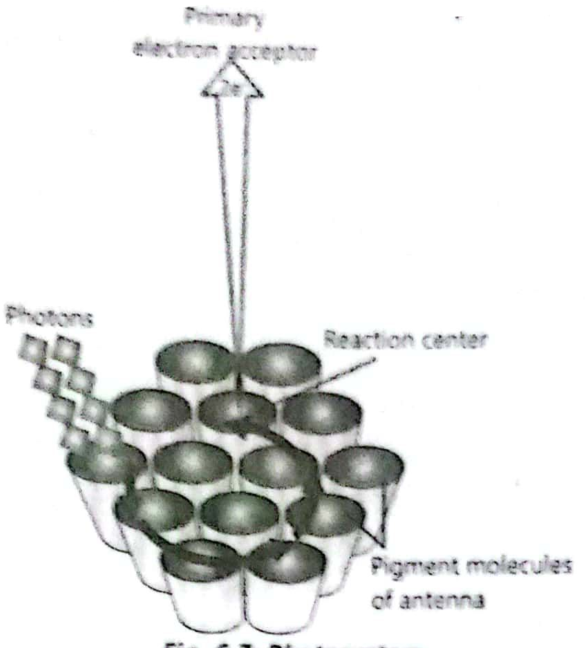
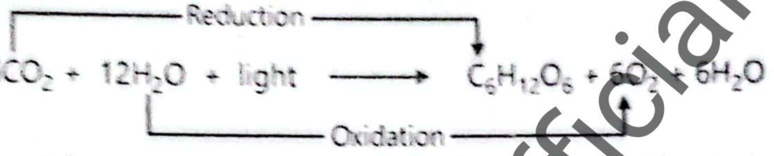


Fig. 6.7: Photosystem



$$6CO_2 + 12H_2O + light \longrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

The **reaction centre** contains one or more molecules of **chlorophyll-a**, which are capable of transferring these high-energy electrons to a **primary electron acceptor**. From there, the electrons are passed through a chain of electron carriers known as the **electron transport chain (ETC)**, where further chemical reactions occur to produce energy-storing molecules like ATP and NADPH.

Q 8. Differentiate between Photosystem I (PS-I) and Photosystem II (PS-II) based on their reaction centres and function.

Ans. **Types of Photosystems**

There are **two types of photosystems** found in chloroplasts:

- **Photosystem I (PS-I)**
- **Photosystem II (PS-II)**

These photosystems are named in the **order of their discovery**, not in the sequence in which they operate during the light-dependent reactions of photosynthesis.

Photosystem I (PS-I)

- **PS-I contains a special chlorophyll-a molecule known as P700** in its reaction centre.
- P700 is named for its ability to absorb light most efficiently at a wavelength of **700 nanometres (nm)**.
- PS-I functions primarily toward the end of the electron transport chain and is involved in the final steps of converting light energy into chemical energy.

Photosystem II (PS-II)

- **PS-II contains a different chlorophyll-a molecule known as P680** in its reaction centre.
- P680 absorbs light best at a wavelength of **680 nanometres (nm)**.
- PS-II initiates the light-dependent reactions by absorbing light and using that energy to **split water molecules (photolysis)** and generate high-energy electrons.

Together, PS-I and PS-II work in a coordinated manner to ensure the continuous flow of electrons through the **Z-scheme of photosynthesis**, ultimately leading to the production of **ATP and NADPH**, which are used in the Calvin cycle for glucose synthesis.

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9. Explain the overall mechanism of photosynthesis and its nature as a redox process.

Ans. Photosynthesis as a Redox Process

Photosynthesis is a redox (oxidation-reduction) process. As indicated in the photosynthesis equation, when water molecules are split apart, they are actually oxidized (they lose electrons and hydrogen ions) and yield oxygen. Meanwhile, CO_2 is reduced to sugar as electrons and hydrogen ions are added to it. In this way, oxidation and reduction go hand in hand.

Complex Metabolic Pathway

However, it is not a simple, single-step process. Rather, it is a complex metabolic pathway consisting of a series of reactions. The light-dependent reactions take place on the thylakoid membranes of the grana while the light-independent reactions take place in the stroma of the chloroplasts.

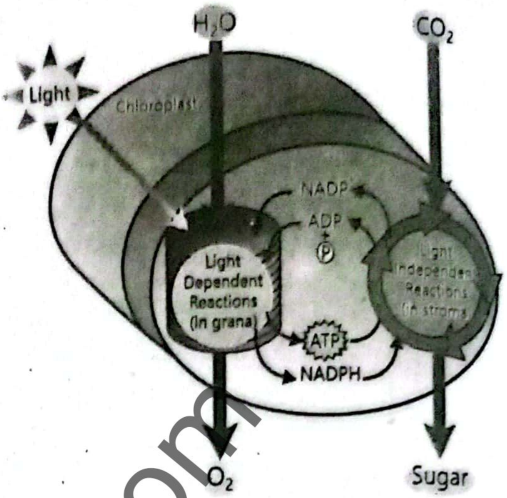

Fig. 6.8: Overview of photosynthesis

10. Describe the key events that occur during the light-dependent reactions of photosynthesis.

Ans. Light Absorption and Excitation of Electrons

The key events in the light-dependent reactions of photosynthesis are:

(1) the absorption of light energy by photosynthetic pigments,

(2) the excitation of electrons by that energy, and

(3) the formation of ATP and NADPH.

Photophosphorylation

The formation of ATP is the most important step of light-dependent reactions. It is called photophosphorylation. This process is either non-cyclic photophosphorylation or cyclic photophosphorylation.

> During light dependent reactions, lightenergy is absorbed and converted intochemical energy, which is in the form ofreducing and assimilating powers i.e.,NADPH and ATP.Light independent reactions use NADPHand ATP for the reduction CO2 and thusstore chemical energy in the form

11. Explain the process of non-cyclic photophosphorylation in detail.

Ans. Involvement of Both Photosystems

Non-cyclic photophosphorylation is the usual way of the production of ATPs during light-dependent reactions. In the non-cyclic pathway, both photosystems i.e., PS-I and PS-II participate and two electron chains are involved.

1- Absorption of Light by PS-II

When light falls on PS-II, the energy level of chlorophyll molecules of its antenna centre rises. Two excited electrons move from them and pass to different chlorophyll molecules. The excited electrons reach P680 chlorophyll present in the reaction centre. Due to energy boost of P680 chlorophyll, its two excited electrons pass to the primary electron acceptor of photosystem-II. Due to it, an electron "hole" is created in P680 chlorophyll, which has become a strong oxidizing agent.

2- Photolysis of Water

The electron "hole" in chlorophyll molecule is filled by the electrons from water. When water molecule reacts with oxidized chlorophyll in PS-II, it breaks into two hydrogen ions, an oxygen atom (which immediately combines with another oxygen to form O_2), and two electrons. These two electrons fill the "hole" in P680 chlorophyll. This water splitting step of photosynthesis is called photolysis.

> The oxygen produced duringphotolysis is the main source ofatmospheric oxygen.

3- Electron Flow from PS-II to PS-I

In step 1, the photoexcited electrons of P680 chlorophyll were received by primary electron acceptor of PS-II. Now, these electrons pass to PS-I via an electron transport chain of PS-II. This chain consists of electron carriers called

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plastoquinone (PQ), cytochrome complex, and plastocyanin (PC). As electrons move down the chain, their energy goes on decreasing and is used by thylakoid membrane to produce ATP through the process of chemiosmosis.

4- Absorption of Light by PS-I

In the next step, light energy is absorbed by PS-I. The energy level of its chlorophyll molecules boosts to very high level. The excited electrons of P700 chlorophyll of the reaction centre pass to the primary electron acceptor of PS-I. The electrons coming from PS-II fill the electron "hole" of P700 chlorophyll of PS-I.

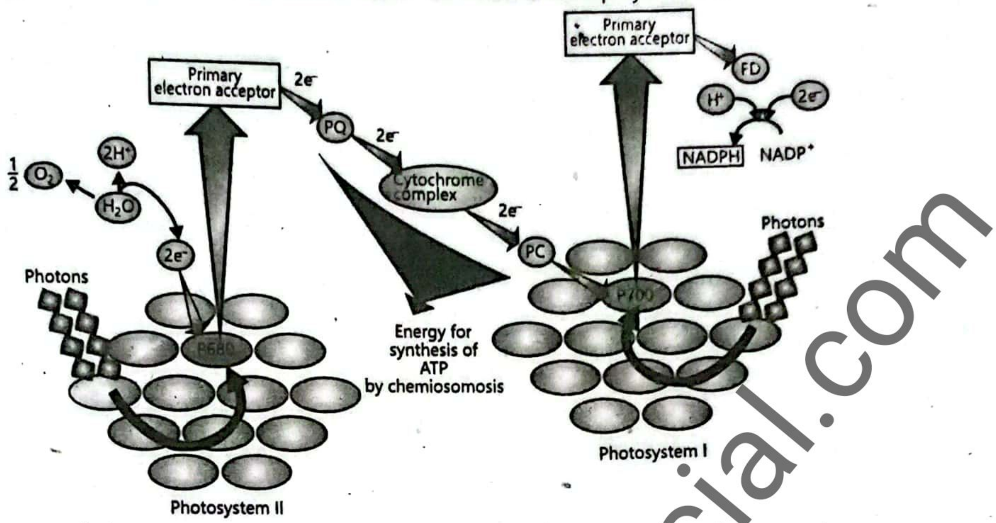

Fig. 6.9: Light-dependent reactions (noncyclic photophosphorylation)

5- Electron Flow from PS-I to NADP⁺

The primary electron acceptor of PS-I passes the photoexcited electrons to a second electron transport chain. These electrons are received by ferredoxin (FD). An enzyme NADP reductase transfers these electrons from FD to NADP⁺. When NADP⁺ gets two electrons and an H⁺ ion, it is reduced to NADPH. This reaction stores the high-energy electrons in NADPH. So, the light energy gets converted into chemical energy (ATP and NADPH). The zigzag path taken by electrons through PS-II and PS-I and electron transport chains, is called Z-scheme.

12. What is cyclic photophosphorylation, and how does it differ from non-cyclic photophosphorylation?

Ans. Alternative Electron Flow Pathway

Under certain conditions, photoexcited electrons of PS-I take an alternative path called cyclic electron flow. This path uses PS-I but not PS-II. These electrons cycle back from primary electron acceptor of PS-I to P700 chlorophyll via the electron transport chain.

Characteristics of Cyclic Photophosphorylation

There is no production of NADPH and no release of oxygen. Cyclic flow, however, generates ATP. It happens when Calvin cycle slows down and NADPH accumulates in chloroplast.

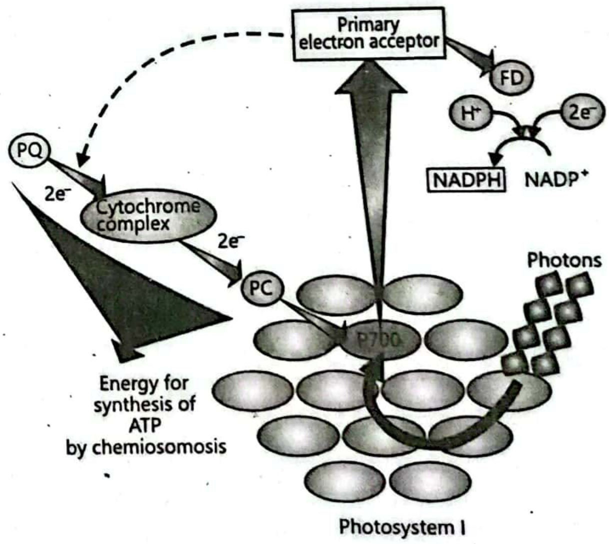

Fig. 6.10: Cyclic Photophosphorylation

13. Explain the process of chemiosmosis in light-dependent reactions of photosynthesis. How is ATP synthesized during this process?

Ans. Introduction to Chemiosmosis:

Chemiosmosis is the process by which ATP is synthesized during the light-dependent reactions of

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photosynthesis. It occurs within the thylakoid membranes of chloroplasts and involves a coupling between the redox (oxidation-reduction) reactions of the electron transport chain and ATP synthesis.

Redox Reactions in Electron Transport Chain:

When light energy excites electrons in chlorophyll, these high-energy electrons are transferred through a series of carriers in the electron transport chain (ETC) embedded in the thylakoid membrane. As electrons move from one carrier to the next, they undergo redox reactions—each carrier is oxidized as it donates electrons and reduced as it receives them.

During this carrier-to-carrier transfer, electrons lose energy gradually. This released energy is not wasted; it is harnessed to drive the active transport of hydrogen ions (H^+).

> The electron transport chains inmitochondria and chloroplastsgenerate ATP by the same mechanismof chemiosmosis.

Proton Gradient Formation:

The energy lost by electrons during ETC is used to pump H^+ ions from the stroma of the chloroplast into the inner thylakoid space (lumen). As a result, the concentration of H^+ ions become higher inside the lumen than in the stroma. This creates an electrochemical gradient (proton gradient), storing potential energy across the thylakoid membrane.

ATP Synthesis by ATP Synthase:

To neutralize this proton gradient, H^+ ions tend to diffuse back into the stroma. However, they can only pass through a specific enzyme embedded in the thylakoid membrane called **ATP synthase**. As the protons flow through ATP synthase, the enzyme utilizes this energy to catalyze the bonding of ADP (adenosine diphosphate) with an inorganic phosphate (Pi), thereby synthesizing **ATP**.

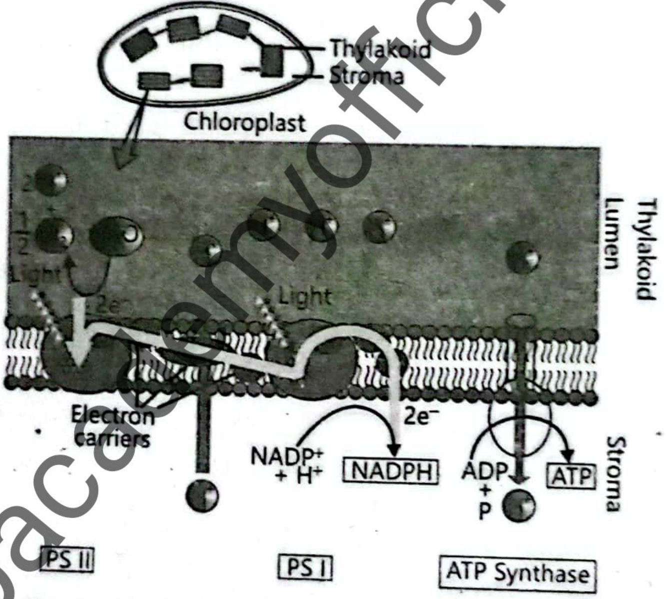

Fig. 6.11: Electron transport chain and chemiosmosis in chloroplast

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14. What are light-independent reactions in photosynthesis, and how does the Calvin cycle convert CO_2 into sugars? Describe its phases in detail.

Ans. Introduction to Light-Independent Reactions:

Light-independent reactions, also known as **dark reactions** or the **Calvin cycle**, occur in the stroma of chloroplasts. Unlike light-dependent reactions, these can take place in the absence of light as long as ATP and NADPH are available. These reactions use carbon from CO_2, energy from ATP, and hydrogen from NADPH to synthesize energy-rich sugars.

The Calvin cycle was discovered by **Melvin Calvin** and his colleagues at the University of California. In recognition of this work, Calvin was awarded the Nobel Prize in 1961.

The Calvin cycle consists of three main phases:

> Since the product of initial carbonfixation is a three-carbon compound,the Calvin cycle is also known as C-3pathway.

Phase I: Carbon Fixation

Carbon fixation is the first step in which inorganic CO_2 is incorporated into organic molecules.

- An enzyme called **RuBisCO**(ribulose bisphosphate carboxylase/oxygenase)—one of the most abundant enzymes on Earth—catalyzes the reaction.
- RuBisCOcombines **three molecules of CO_2** with **three molecules of RuBP** (a 5-carbon sugar called ribulose bisphosphate).
- This reaction produces **six molecules of 3-phosphoglyceric acid (3-PGA)**, a three-carbon compound.

Phase II: Reduction

In this phase, energy and reducing power are used to convert 3-PGA into a more energy-rich compound.

> G3P is the same three-carbon sugarwhich is formed in glycolysis (firstphase of cellular respiration) by thesplitting of glucose.

- **Six ATP molecules** donate phosphate groups to the six molecules of 3-PGA, converting them into **1,3-bisphosphoglyceric acid.**
- Then, **six NADPH molecules** provide hydrogen to reduce these compounds into **glyceraldehyde-3-phosphate (G3P)**.
- During this reduction, phosphate groups are also removed from 1,3-bisphosphoglyceric acid.
- **Six G3P molecules** are produced in total, but only **one G3P** exits the cycle to contribute to the synthesis of glucose and other carbohydrates.
- The remaining **five G3P molecules** are recycled to regenerate RuBP.

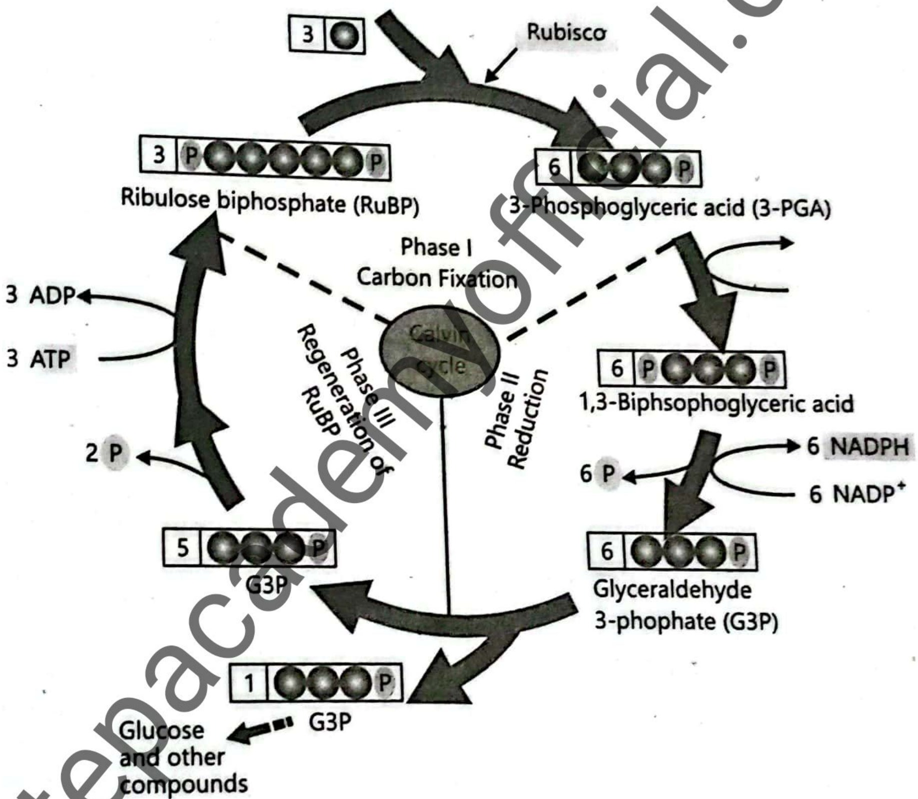

Fig. 6.12: The Calvin cycle

Phase III: Regeneration of RuBP

This phase ensures the continuity of the cycle by regenerating the CO_2 acceptor molecule.

- The **five G3P molecules** undergo a complex series of transformations to produce **three molecules of ribulose phosphate (RuP).**
- Then, **three ATP molecules** are used to add phosphate groups to each RuP, forming **three RuBP molecules.**
- These RuBP molecules are now ready to accept CO_2 again, restarting the cycle.

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Photosynthesis

1. **What are photosystems?**
   A) Enzymes in the stroma
   B) Clusters of pigments organized in chloroplasts ✓
   C) DNA-containing structures
   D) Protein pumps in mitochondria
2. **Where are photosystems located in plant cells?**
   A) Nucleus B) Cytoplasm
   C) Thylakoid membranes of chloroplasts ✓
   D) Cell membrane
3. **What are the two main parts of a photosystem?**
   A) Nucleus and chloroplast
   B) Antenna complex and reaction centre ✓
   C) Light and dark reactions
   D) Grana and stroma
4. **What is the function of the antenna complex in a photosystem?**
   A) Produces glucose B) Absorbs CO_2
   C) Captures light and passes energy to the reaction centre ✓
   D) Breaks water molecules
5. **Which pigment is found in the reaction centre of a photosystem?**
   A) Chlorophyll-a ✓ B) Chlorophyll-b
   C) Xanthophyll D) Phycobilin
6. **What happens when light energy reaches the reaction centre?**
   A) Glucose is formed B) CO_2 is absorbed
   C) Electrons are transferred to a primary electron acceptor ✓
   D) Oxygen is released
7. **What is the role of the primary electron acceptor?**
   A) Stores water B) Absorbs light directly
   C) Transfers electrons to the electron transport chain ✓
   D) Breaks down ATP
8. **How many photosystems are present in chloroplasts?**
   A) One B) Two ✓
   C) Three D) Four
9. **What is the special chlorophyll in the reaction centre of Photosystem I?**
   A) P680 B) Chlorophyll-b
   C) P700 ✓ D) ATP
10. **What is the light absorption peak of Photosystem II?**
    A) 700 nm B) 680 nm ✓
    C) 430 nm D) 400 nm

Mechanism of Photosynthesis

1. **What type of process is photosynthesis?**
   A) Hydrolysis B) Fermentation
   C) Redox (oxidation-reduction) ✓
   D) Neutralization
2. **What happens to water molecules during photosynthesis?**
   A) They combine with CO_2
   B) They are stored in chloroplasts
   C) They are oxidized and yield oxygen ✓
   D) They become sugars
3. **What is reduced during photosynthesis?**
   A) Oxygen B) ATP
   C) Water D) Carbon dioxide ✓
4. **Where do light-dependent reactions occur?**
   A) Cytoplasm B) Nucleus
   C) Thylakoid membranes of grana ✓
   D) Mitochondria
5. **Where do light-independent reactions take place?**
   A) Stroma ✓ B) Nucleus
   C) Grana D) Cytoplasm
6. **What is the most important step of light-dependent reactions?**
   A) Water formation B) Glucose production
   C) ATP formation ✓ D) Oxygen release
7. **What is photophosphorylation?**
   A) Water breakdown B) CO_2 fixation
   C) ATP formation using light energy ✓
   D) Pigment production
8. **How many types of photophosphorylation are there?**
   A) 1 B) 2 ✓
   C) 3 D) 4
9. **Which photosystems are involved in non-cyclic photophosphorylation?**
   A) PS-I only B) PS-II only
   C) Both PS-I and PS-II ✓
   D) None
10. **What occurs when light falls on PS-II?**
    A) Water is formed
    B) Chlorophyll becomes oxidized
    C) Chlorophyll molecules' energy levels rise ✓
    D) ATP is consumed
11. **What is P680?**
    A) A sugar molecule B) A chlorophyll in PS-I
    C) A chlorophyll in PS-II ✓
    D) A type of ATP
12. **What is created when P680 loses electrons?**
    A) NADPH B) Water
    C) Electron hole ✓ D) Oxygen
13. **What fills the electron "hole" in P680?**
    A) Electrons from glucose
    B) Protons from stroma
    C) Electrons from water ✓

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D) ATP

14. **What is photolysis?**
A) ATP synthesis B) Water splitting✓
C) CO_2 reduction D) Chlorophyll formation

15. **What are the products of photolysis?**
A) Sugar and ATP
B) Oxygen, hydrogen ions, and electrons✓
C) NADPH and CO_2 D) Chlorophyll and water

16. **What carries electrons from PS-II to PS-I?**
A) DNA B) Ribosomes
C) Electron transport chain✓
D) ATP synthase

17. **What are components of the electron transport chain between PS-II and PS-I?**
A) $NADP^+$ and ATP
B) PQ, cytochrome complex, and PC✓
C) ADP and water D) P700 and glucose

18. **How is ATP formed during electron transport from PS-II?**
A) Direct light absorption B) Chemiosmosis✓
C) Fermentation D) Respiration

19. **What happens when light is absorbed by PS-I?**
A) P700 becomes excited✓
B) P680 is oxidized
C) Water is split again D) NADPH breaks down

20. **What fills the electron hole in P700 chlorophyll?**
A) Electrons from NADPH
B) Electrons from PS-II✓
C) Hydrogen ions D) Oxygen

21. **What molecule receives electrons from PS-I's primary acceptor?**
A) Plastocyanin B) ATP
C) Ferredoxin (FD)✓ D) ADP

22. **Which enzyme is responsible for reducing $NADP^+$?**
A) ATP synthase B) NADP reductase✓
C) Dehydrogenase D) Cytochrome oxidase

23. **What does $NADP^+$ become after accepting electrons and a proton?**
A) NADH B) Water
C) NADPH✓ D) $FADH_2$

24. **What is the "Z-scheme" in photosynthesis?**
A) Calvin cycle shape B) NADPH formation path
C) Zigzag electron flow through photosystems and chains✓
D) ATP transport path

25. **What is cyclic photophosphorylation?**
A) Flow of electrons through both photosystems
B) Formation of sugar using CO_2
C) Electrons cycling within PS-I to generate ATP only✓
D) Continuous photolysis of water

Chemiosmosis and Calvin Cycle

1. **What is chemiosmosis in photosynthesis?**
A) Splitting of water molecules
B) Release of oxygen from chloroplast
C) ATP synthesis using a proton gradient✓
D) Movement of CO_2 into leaves

2. **Where does chemiosmosis occur in plant cells?**
A) Cytoplasm B) Thylakoid membrane✓
C) Mitochondrial membrane
D) Nucleus

3. **What creates the H^+ ion gradient in the thylakoid lumen?**
A) Breakdown of sugars B) Passive diffusion
C) Active transport using energy from electrons✓
D) Protein synthesis

4. **Which protein/enzyme facilitates the synthesis of ATP in chemiosmosis?**
A) RuBisCO B) Ferredoxin
C) ATP synthase✓ D) NADP reductase

5. **What powers ATP synthase to convert ADP to ATP?**
A) Light energy
B) Flow of hydrogen ions (H^+)✓
C) Glucose breakdown D) Carbon fixation

6. **What is the source of H^+ ions that build up in the lumen?**
A) Glucose B) Atmospheric CO_2
C) Water and proton pumping✓
D) Oxygen molecules

7. **What is the role of the thylakoid membrane in chemiosmosis?**
A) Captures sunlight only
B) Serves as a platform for electron and proton movement✓
C) Produces CO_2 D) Breaks down glucose

8. **Which of the following is a light-independent reaction?**
A) Photolysis B) Calvin cycle✓
C) Electron transport chain D) Photophosphorylation

9. **Where do the light-independent reactions occur in the chloroplast?**
A) Outer membrane B) Stroma✓
C) Thylakoid space D) Granum

10. **Which molecule captures CO_2 in the Calvin cycle?**
A) Glucose
B) RuBP (Ribulose Biphosphate)✓
C) ATP D) NADPH

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11. **What enzyme catalyzes carbon fixation?**
A) ATP synthase
B) RuBisCO ✓
C) Ferredoxin
D) NADP reductase

12. **What is the first stable product formed in the Calvin cycle?**
A) Glucose
B) G3P
C) 3-PGA ✓
D) ATP

13. **What happens in the reduction phase of the Calvin cycle?**
A) Formation of ATP
B) Oxidation of G3P
C) Conversion of 3-PGA to G3P using NADPH and ATP ✓
D) Breakdown of glucose

14. **What is the fate of G3P in the Calvin cycle?**
A) All are used to regenerate RuBP
B) Stored in the thylakoid
C) One exits to form glucose; the rest regenerate RuBP ✓
D) Used for protein synthesis

15. **Which of the following is NOT used in the Calvin cycle?**
A) CO_2
B) ATP
C) Oxygen ✓
D) NADPH

16. **Why is the Calvin cycle considered a "cycle"?**
A) Because glucose is reused
B) Because RuBP is regenerated at the end ✓
C) Because it uses light and dark
D) Because it produces water

17. **How many CO_2 molecules are fixed in one turn of the Calvin cycle?**
A) One
B) Three ✓
C) Five
D) Six

18. **How many G3P molecules are needed to produce one glucose molecule?**
A) One
B) Two ✓
C) Four
D) Six

19. **Which scientist discovered the Calvin cycle?**
A) Van Niel
B) Joseph Priestley
C) Melvin Calvin ✓
D) Robert Hooke

20. **What happens during the regeneration phase of the Calvin cycle?**
A) Formation of glucose
B) Conversion of G3P to RuBP ✓
C) Fixation of CO_2
D) Formation of ATP

PHOTOSYSTEMS

SQ

1. **What are photosystems in chloroplasts?**

Ans. Photosystems are clusters of photosynthetic pigments organized for efficient absorption and utilization of solar energy. They are embedded in the thylakoid membranes of chloroplasts.

2. **What are the two main components of a photosystem?**

Ans: A photosystem consists of a light-gathering antenna complex and a reaction centre. The antenna complex captures light energy and passes it to the reaction centre.

3. **What is the role of the antenna complex in a photosystem?**

Ans: The antenna complex contains many pigment molecules that absorb light energy. This energy is transferred in the form of high-energy electrons to the reaction centre.

4. **What happens at the reaction centre of a photosystem?**

Ans: The reaction centre contains one or more chlorophyll-a molecules which receive excitation energy. These molecules pass high-energy electrons to a primary electron acceptor.

5. **What is the function of the primary electron acceptor in photosynthesis?**

Ans: The primary electron acceptor receives high-energy electrons from the reaction centre. It then transfers them to a series of carriers in the electron transport chain.

6. **How many types of photosystems are present in chloroplasts?**

Ans: There are two photosystems in chloroplasts: Photosystem I (PS-I) and Photosystem II (PS-II). They are named in the order of their discovery.

7. **What type of chlorophyll-a does Photosystem I contain, and what light does it absorb best?**

Ans: Photosystem I has P700 chlorophyll-a in its reaction centre. It absorbs maximum light at a wavelength of 700 nm.

8. **What type of chlorophyll-a does Photosystem II contain, and what light does it absorb best?**

Ans: Photosystem II contains P680 chlorophyll-a in its reaction centre. It absorbs light best at 680 nm.

9. **What is the role of electron transport chain in photosynthesis?**

Ans: The electron transport chain consists of a series of carriers that receive electrons from the primary electron acceptor. These carriers facilitate further energy conversion processes, such as ATP and NADPH formation.

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10. **Why are PS-I and PS-II named in that specific order?**
Ans: PS-I and PS-II are named in the order of their discovery, not based on the sequence in which they function in photosynthesis. PS-II actually operates before PS-I in the light reactions.

MECHANISM OF PHOTOSYNTHESIS

1. **What type of process is photosynthesis?**
Ans. Photosynthesis is a redox (oxidation-reduction) process. In this process, water is oxidized and carbon dioxide is reduced.

2. **What happens to water molecules during photosynthesis?**
Ans: Water molecules are split apart, they are actually oxidized (they lose electrons and hydrogen ions) and yield oxygen.

3. **How is carbon dioxide reduced during photosynthesis?**
Ans: CO_2 is reduced to sugar as electrons and hydrogen ions are added to it. This reduction process is part of the redox reaction.

4. **Where do light-dependent reactions take place?**
Ans: The light-dependent reactions take place on the thylakoid membranes of the grana. These membranes contain the photosystems involved in capturing light energy.

5. **Where do light-independent reactions occur in the chloroplast?**
Ans: The light-independent reactions take place in the stroma of the chloroplasts. These reactions do not require light directly.

6. **What are the three key events in light-dependent reactions?**
Ans: The key events are: (1) the absorption of light energy by photosynthetic pigments, (2) the excitation of electrons by that energy, and (3) the formation of ATP and NADPH.

7. **What is the most important step of the light-dependent reactions?**
Ans: The formation of ATP is the most important step of light-dependent reactions. This process is called photophosphorylation.

8. **What are the types of photophosphorylation?**
Ans: Photophosphorylation is either non-cyclic photophosphorylation or cyclic photophosphorylation. Both processes produce ATP, but only non-cyclic also produces NADPH and O_2.

9. **Which photosystems are involved in non-cyclic photophosphorylation?**
Ans: Both photosystems i.e., PS-I and PS-II participate in non-cyclic photophosphorylation. Two electron chains are also involved.

10. **What happens when light falls on PS-II?**
Ans: When light falls on PS-II, the energy level of chlorophyll molecules of its antenna centre rises. Two excited electrons move from them and pass to the reaction centre.

11. **What is P680 chlorophyll and what is its role?**
Ans: P680 chlorophyll is present in the reaction centre of PS-II. It becomes excited and transfers electrons to the primary electron acceptor, creating an electron "hole".

12. **How is the electron "hole" in P680 chlorophyll filled?**
Ans: The electron "hole" is filled by the electrons from water. This happens through the process of photolysis of water.

13. **What is photolysis?**
Ans: Photolysis is the splitting of water during photosynthesis. Water reacts with oxidized chlorophyll in PS-II and breaks into hydrogen ions, oxygen, and electrons.

14. **What happens to the electrons after photolysis in PS-II?**
Ans: The electrons fill the "hole" in P680 chlorophyll. Oxygen atoms form O_2 and are released.

15. **What is the role of the electron transport chain in PS-II?**
Ans: Electrons from PS-II pass through an electron transport chain consisting of plastoquinone (PQ), cytochrome complex, and plastocyanin (PC). Their energy is used by the thylakoid membrane to produce ATP through chemiosmosis.

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16. **What happens when light is absorbed by PS-I?**

Ans: The energy level of chlorophyil molecules boosts to very high level. The excited electrons of P700 chlorophyll pass to the primary electron acceptor of PS-I.

17. **How are electrons from PS-II related to PS-I?**

Ans: The electrons coming from PS-II fill the electron "hole" of P700 chlorophyll of PS-I. This maintains the continuous flow of electrons.

18. **What happens to the photoexcited electrons of PS-I?**

Ans: They are passed to a second electron transport chain. These electrons are received by ferredoxin (FD).

19. **How is NADPH formed in non-cyclic photophosphorylation?**

Ans: An enzyme NADP reductase transfers the electrons from FD to $NADP^+$. When $NADP^+$ gets two electrons and an H^+ ion, it is reduced to NADPH.

20. **What is cyclic photophosphorylation and when does it occur?**

Ans: Cyclic photophosphorylation is an alternative path where electrons cycle back from the primary electron acceptor of PS-I to P700 chlorophyll via the electron transport chain. It occurs when the Calvin cycle slows down and NADPH accumulates.

SHORT ANSWER QUESTIONS CHEMIOSMOSIS

SQ

1. **What is chemiosmosis in photosynthesis?**

Ans. Chemiosmosis is the mechanism by which the energy released from electrons during redox reactions in the electron transport chain is used to synthesize ATP. It occurs across the thylakoid membrane in chloroplasts.

2. **What is the role of electron transport in chemiosmosis?**

Ans: Electrons pass through a series of carriers, undergoing oxidation and reduction reactions. This flow releases energy used for pumping H^+ ions into the thylakoid lumen.

3. **How is the proton (H^+) gradient formed inside the thylakoid lumen?**

Ans: The energy from the electron transport chain is used to actively transport H^+ ions from the stroma into the thylakoid lumen. This creates a concentration gradient with higher H^+ inside the lumen.

4. **What is the significance of the H^+ ion gradient in the thylakoid?**

Ans: The H^+ ion gradient represents stored potential energy. It drives the synthesis of ATP as H^+ ions diffuse back into the stroma through ATP synthase.

5. **What is the role of ATP synthase in photosynthesis?**

Ans: ATP synthase is a membrane protein enzyme that facilitates the production of ATP. It uses the energy released when H^+ ions move down their concentration gradient.

6. **How is ATP produced during chemiosmosis?**

Ans: ATP is produced when the flow of H^+ ions through ATP synthase drives the binding of ADP and inorganic phosphate (Pi). This stores energy in the form of ATP.

7. **Why is chemiosmosis essential in the light-dependent reactions?**

Ans: It links the redox reactions of the electron transport chain with ATP synthesis. Without chemiosmosis, the energy from light would not be stored efficiently.

LIGHT-INDEPENDENT REACTIONS (CALVIN CYCLE)

SQ

1. **Where do light-independent reactions occur in the chloroplast?**

Ans. These reactions take place in the stroma of chloroplasts. They do not directly require light and depend on ATP and NADPH from light-dependent reactions.

2. **What are the inputs required for the Calvin cycle?**

Ans: The Calvin cycle uses carbon dioxide (CO_2), ATP, and NADPH. These inputs help in the synthesis of energy-rich sugar molecules.

3. **Why are light-independent reactions called the Calvin cycle?**

Ans: They are named after Melvin Calvin, who discovered their mechanism. He received the Nobel Prize in 1961 for this work.

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4. **What happens during the carbon fixation phase of the Calvin cycle?**

Ans: CO_2 is fixed by the enzyme RuBisCOinto organic molecules. It combines with RuBP to form 3-phosphoglyceric acid (3-PGA).

5. **What is the role of RuBisCOin photosynthesis?**

Ans: RuBisCOcatalyzes the first step of the Calvin cycle by fixing CO_2. It is one of the most abundant and important enzymes on Earth.

6. **What occurs during the reduction phase of the Calvin cycle?**

Ans: ATP and NADPH are used to convert 3-PGA into G3P (glyceraldehyde-3-phosphate). This step stores energy in the sugar molecules.

7. **How is glucose formed in the Calvin cycle?**

Ans: One G3P molecule exits the cycle and combines with another to form glucose. This glucose may then be used or stored by the plant.

8. **What happens in the regeneration phase of the Calvin cycle?**

Ans: Five G3P molecules are converted into three RuBP molecules using ATP. This regeneration allows the cycle to continue fixing CO_2.

6.2 CELLULAR RESPIRATION

Q 15. What is Cellular Respiration and how is Glucose utilized in this process?

Ans. Definition and Overview

Cellular respiration is the universal process by which organisms break down complex carbon-containing compounds such as glucose to obtain usable energy. This process occurs in almost all organisms and provides the necessary energy for biological functions.

General Equation

The overall chemical reaction of cellular respiration is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

In this equation, glucose ($C_6H_{12}O_6$) combines with oxygen to produce carbon dioxide, water, and energy in the form of ATP (Adenosine Triphosphate).

Energy Storage and Release

Glucose has many carbon-hydrogen (C-H) bonds which store a large amount of energy. In contrast, CO_2 and H_2O have fewer or no such bonds, hence they possess much less energy. The breakdown of glucose leads to the release of this stored energy.

Types of Cellular Respiration

There are two main types of cellular respiration:

1. **Anaerobic respiration** – takes place in the absence of oxygen.
2. **Aerobic respiration** – occurs in the presence of oxygen.

> Many of the reactions that occurin your cells also occur in the cellsof frog, mice, planaria,mushrooms and radishes.

Q 16. What is Anaerobic Respiration and What are Its Types and Mechanism?

Ans. Anaerobic Respiration Overview

Anaerobic respiration is a type of cellular respiration that occurs in the absence of oxygen. It takes place in many microorganisms, some plant cells, and the muscle cells of vertebrates. In this process, glucose is not completely oxidized and only a small amount of energy is released.

Energy Yield

From one glucose molecule, anaerobic respiration produces only **2 ATP molecules**, which is about **2% of the total energy content** of glucose (approximately 14.6 kcal).

Steps in Anaerobic Respiration

Anaerobic respiration includes:

1. **Glycolysis** – the breakdown of glucose into pyruvic acid.
2. **Reduction of Pyruvic Acid** – to either lactic acid or alcohol.

> When life evolved on planet Earth freeO2 was not available. So, only anaerobicrespiration was possible. But with theevolution of photosynthesis on Earth,molecular oxygen accumulated slowly inthe atmosphere. The presence of freeoxygen made evolution of aerobicrespiration possible.

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Types of Anaerobic Respiration

a. Alcoholic Fermentation:

Occurs in bacteria and yeast. Pyruvic acid is converted into **alcohol (C_2H_5OH)** and **carbon dioxide (CO_2)**.

b. Lactic Acid Fermentation:

Occurs in human and animal muscle cells under low oxygen conditions, and in some bacteria. Pyruvic acid is converted into **lactic acid ($C_3H_6O_3$)**.

The exchange of CO_2 and O_2 between the organism and itsenvironment is called externalrespiration or breathing. Cellularrespiration is the process bywhich energy is made available tocells in a step-by-step oxidation of food in the cells

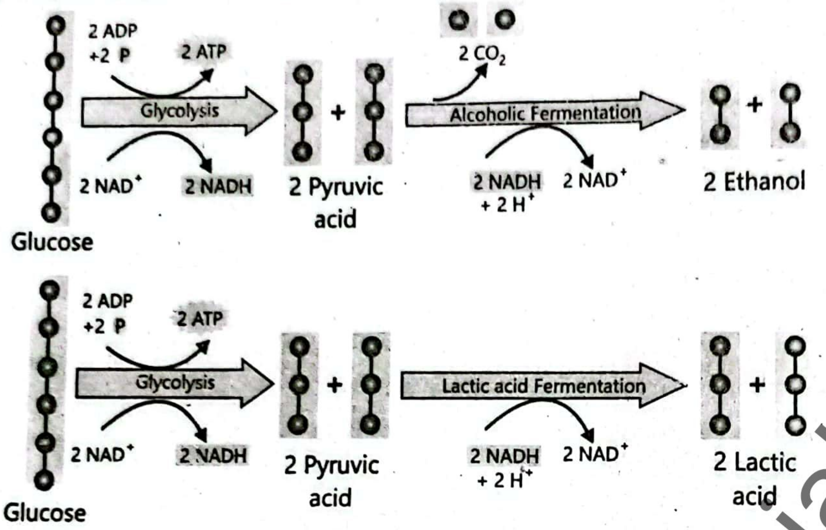

Fig. 6.13: Alcoholic fermentation and lactic acid fermentation

17. What is Aerobic Respiration and How Does Complete Oxidation of Glucose Occur?

Ans. Aerobic Respiration Overview

Aerobic respiration occurs in the presence of oxygen and results in the **complete oxidation** of glucose. The glucose is first converted into pyruvic acid, which is then completely broken down into carbon dioxide and water.

Stages of Aerobic Respiration

Aerobic respiration can be divided into four main stages:

1. **Glycolysis**
2. **Pyruvic Acid Oxidation**
3. **Krebs Cycle**
4. **Electron Transport Chain***(not discussed in the given text)*

Energy Yield

This form of respiration is highly efficient and releases a significant amount of energy stored in the glucose molecule.

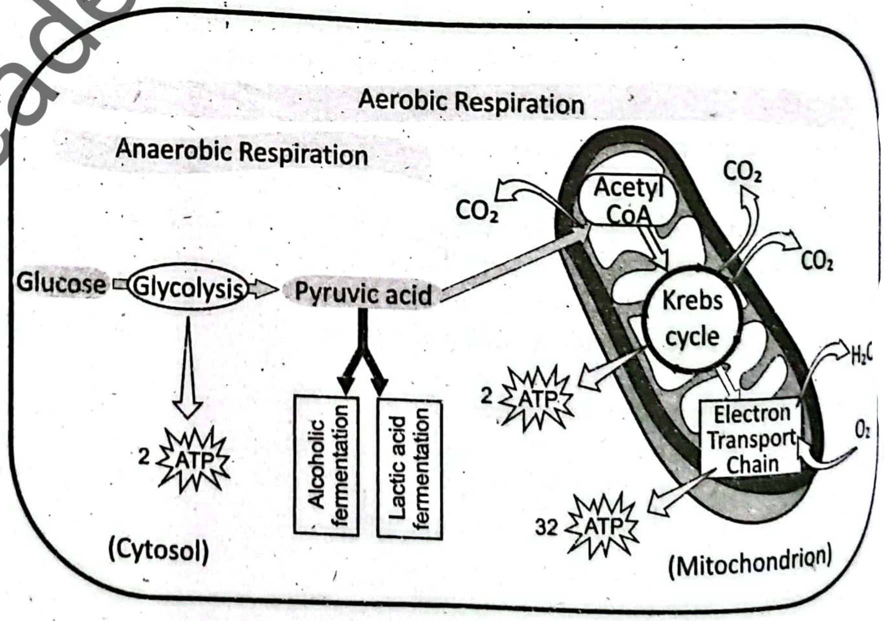

Fig. 6.14: Overview of cellular respiration

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18. What is Glycolysis? Describe the Steps Involved in Its Preparatory and Oxidative Phases.

Ans. Definition

Glycolysis is the process in which glucose (a six-carbon molecule) is broken down into two molecules of pyruvic acid (three-carbon compound). It occurs in the **cytosol** of cells and takes place in both aerobic and anaerobic respiration.

Essential Components

- Specific enzymes (dissolved in the cytosol)
- ATP
- Coenzyme NAD^+ (nicotinamide adenine dinucleotide)

Preparatory Phase of Glycolysis

1. **Phosphorylation of Glucose**: A phosphate group is transferred from ATP to glucose, forming **glucose 6-phosphate.**
2. **Isomerization**: Glucose 6-phosphate is converted to **fructose 6-phosphate.**
3. **Second Phosphorylation**: Another ATP transfers a phosphate to fructose 6-phosphate, forming **fructose 1,6-bisphosphate.**
4. **Cleavage**: Fructose 1,6-bisphosphate splits into two three-carbon compounds: **glyceraldehyde 3-phosphate (G3P)** and **dihydroxyacetone phosphate (DAP).** DAP is converted into another G3P.

Oxidative Phase of Glycolysis

1. **Oxidation of G3P**: Each G3P molecule is oxidized, and NAD^+ accepts the electrons, forming **1,3-bisphosphoglyceric acid (1,3-BPGA).**
2. **ATP Formation**: 1,3-BPGA donates a phosphate to ADP to form **ATP** and **3-phosphoglyceric acid (3-PGA).**
3. **Conversion**: 3-PGA is converted into **2-phosphoglyceric acid (2-PGA).**
4. **Dehydration**: 2-PGA loses water to form **phosphoenol pyruvic acid (PEP).**
5. **Second ATP Formation**: PEP donates a phosphate to ADP, forming another ATP and resulting in **pyruvic acid.**

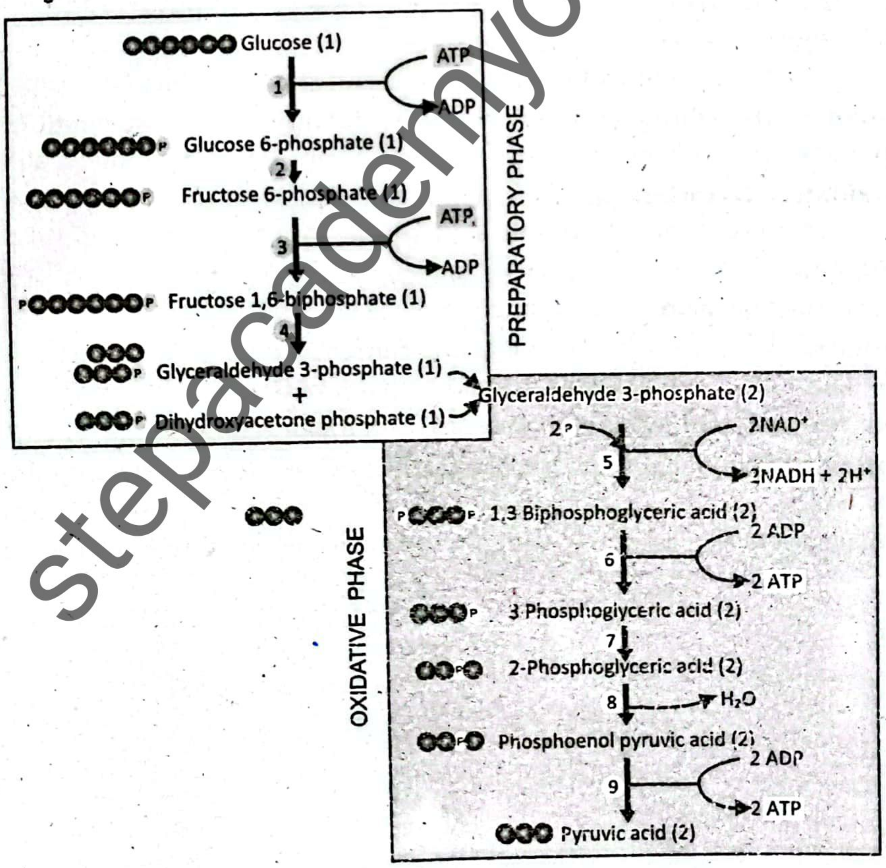

Fig. 6.15: Steps in glycolysis

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19. What Happens to Pyruvic Acid Before It Enters the Krebs Cycle? Describe the Oxidation of Pyruvic Acid.

Ans. Conversion of Pyruvic Acid

Before pyruvic acid can enter the **Krebs cycle**, it undergoes several chemical changes:

> Glucose enters cells from the tissue fluid by passivetransport using a specific glucose carrier. This carrier can be controlled (gated) by hormones such as insulin.

1. **Decarboxylation**: A molecule of carbon dioxide is removed from pyruvic acid, forming **acetaldehyde**.
2. **Oxidation**: Acetaldehyde is oxidized to form an **acetyl group**; NAD^+ is reduced to NADH.
3. **Formation of Acetyl-CoA**: The acetyl group combines with **coenzyme A (CoA)** to form **acetyl-CoA**, which is the molecule that enters the Krebs cycle.

> Pyruvic acid can also be turned back into glucose by reversing glycolysis. This is called gluconeogenesis.

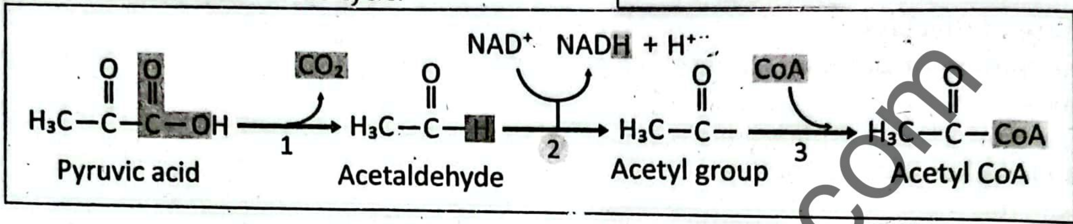

Fig. 6.16: Pyruvic acid oxidation

20. Describe the Krebs Cycle in Detail. What are the Major Chemical Reactions Involved?

Ans. Introduction

The **Krebs cycle** (also called the **citric acid cycle**) is a series of enzyme-catalyzed reactions that take place in the **mitochondria**. It is named after the British biochemist **Sir Hans Krebs**.

> The release of carbon dioxide takesplace before oxygen is involved. It istherefore not true to say that respirationturns oxygen into carbon dioxide. It ismore correct to say that respirationturns glucose into carbon dioxide, andoxygen into water.

Steps of the Krebs Cycle

1. **Formation of Citric Acid**: Acetyl-CoA splits into **CoA** and **acetyl group**. The acetyl group combines with a four-carbon molecule (**oxaloacetic acid**) to form **citric acid** (a six-carbon compound).
2. **First Oxidative Decarboxylation**: Citric acid undergoes **decarboxylation** (removal of CO_2) and **oxidation** (conversion of NAD^+ to NADH) to form a five-carbon compound, **alpha-ketoglutaric acid**.
3. **Second Oxidative Decarboxylation**: Alpha-ketoglutaric acid is further oxidized and decarboxylated to form a four-carbon compound, **succinic acid**, which binds to CoA forming **succinyl CoA**.
4. **ATP Formation**: Succinyl CoA releases energy upon splitting, which is used to form **ATP**. CoA is released, and **succinic acid** is regenerated.
5. **FAD Reduction**: Succinic acid is oxidized to **fumaric acid**. Since this step does not release enough energy to reduce NAD^+, **FAD** is used instead, forming **$FADH_2$**.
6. **Hydration**: **Fumaric acid** reacts with water to form **malic acid**.
7. **Regeneration of Oxaloacetic Acid**: Malic acid is oxidized to regenerate **oxaloacetic acid**, and NAD^+ is reduced to NADH.

This cycle continues as oxaloacetic acid combines with another molecule of acetyl-CoA, maintaining the cycle.

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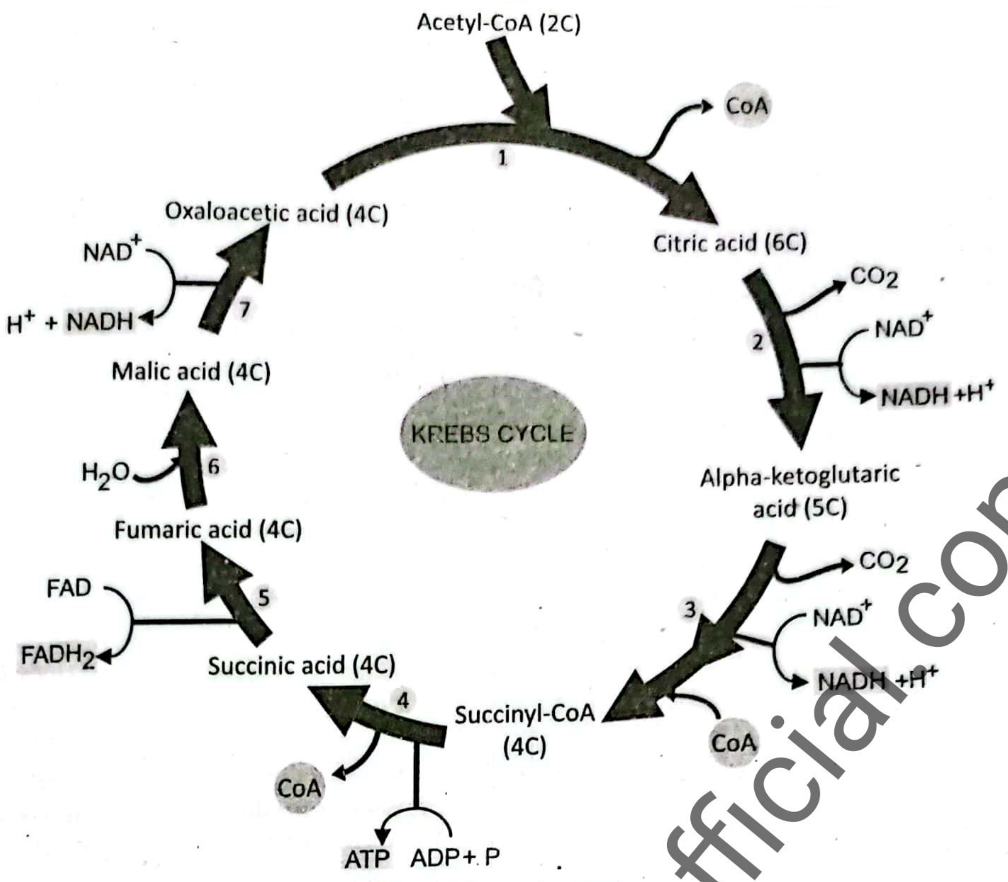

Fig. 6.17: Krebs cycle

mQs ✓

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1. **What is the primary function of cellular respiration?**
   A) Produce glucose
   B) Break down carbon dioxide
   C) Generate usable energy ✓
   D) Form nucleic acids

2. **What is the respiratory fuel in most cells?**
   A) Oxygen B) Glucose ✓
   C) Carbon dioxide D) Fatty acids

3. **What is the general chemical equation for cellular respiration?**
   A) $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
   B) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Energy ✓
   C) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
   D) $C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$

4. **Which of the following does NOT contain C-H bonds?**
   A) Glucose B) Alcohol
   C) CO_2 ✓ D) Fatty acids

5. **In which organelle does aerobic respiration mostly occur?**
   A) Nucleus B) Cytoplasm
   C) Mitochondria ✓ D) Ribosome

6. **Which process occurs in the cytosol of the cell?**
   A) Krebs cycle B) Glycolysis ✓
   C) Pyruvic acid oxidation D) Alcoholic fermentation

7. **What is the first step in both aerobic and anaerobic respiration?**
   A) Krebs cycle B) Glycolysis ✓
   C) Alcoholic fermentation
   D) Oxidative phosphorylation

8. **How many ATP molecules are produced in anaerobic respiration per glucose molecule?**
   A) 36 B) 34
   C) 2 ✓ D) 4

9. **What is pyruvic acid converted to in lactic acid fermentation?**
   A) Ethanol B) CO_2
   C) Acetyl-CoA D) Lactic acid ✓

10. **Where does lactic acid fermentation occur in humans?**
    A) Brain cells B) Liver cells
    C) Muscle cells ✓ D) Red blood cells

11. **What is the product of alcoholic fermentation?**
    A) Lactic acid B) Glucose
    C) Alcohol and CO_2 ✓ D) Acetyl-CoA

12. **What is the full form of ATP?**
    A) Adenine Triphosphate
    B) Adenosine Triphosphate ✓
    C) Alpha Tetra Phosphate

D) Adenine Tetraphosphate

13. **What does NAD^+ get reduced to during glycolysis?**
A) FAD B) CO_2
C) NADH ✓ D) ATP

14. **What is the first compound formed in the Krebs cycle?**
A) Malic acid B) Citric acid ✓
C) Succinic acid D) Acetaldehyde

15. **What enzyme helps acetyl group combine with Coenzyme A?**
A) Hexokinase B) Dehydrogenase
C) Acetyl transferase
D) Pyruvate dehydrogenase complex ✓

16. **How many carbon atoms are in citric acid?**
A) 4 B) 5
C) 6 ✓ D) 3

17. **What is the function of FAD in the Krebs cycle?**
A) Enzyme activator B) Substrate
C) Electron acceptor ✓ D) Product

18. **What happens when succinic acid is oxidized?**
A) Water is produced B) FAD is reduced ✓
C) CO_2 is released D) ATP is formed

19. **What is the final product that regenerates the cycle in the Krebs process?**
A) Succinic acid B) Malic acid
C) Oxaloacetic acid ✓ D) Citric acid

20. **What is the energy yield from 1 glucose in anaerobic respiration?**
A) 36 ATP B) 2 ATP ✓
C) 18 ATP D) 6 ATP

21. **In which phase of glycolysis is energy invested?**
A) Oxidative phase B) Recovery phase
C) Preparatory phase ✓ D) Terminal phase

22. **What is the first stable intermediate in glycolysis?**
A) Fructose-6-phosphate B) Glucose-6-phosphate ✓
C) Glyceraldehyde-3-phosphate
D) Dihydroxyacetone phosphate

23. **Which coenzyme is used in oxidative decarboxylatio of pyruvic acid?**
A) FAD B) NAD^+ ✓
C) Biotin D) ATP

24. **What enzyme adds water to fumaric acid?**
A) Fumarase ✓ B) Hydratase
C) Decarboxylase D) Oxidase

25. **What molecule donates phosphate to ADP durin glycolysis?**
A) Fructose-1,6-biphosphate
B) G3P
C) 1,3-BPGA ✓ D) PEP

26. **What does PEP stand for?**
A) Phosphoethyl pyruvate
B) Phosphoenol pyruvate ✓
C) Pyruvic Enol Phosphate
D) Phosphate Electron Pyruvate

27. **What is released when acetyl-CoA splits in Krebs cycle?**
A) CO_2 B) ATP
C) Coenzyme A ✓ D) NAD^+

28. **What is produced when malic acid is oxidized?**
A) Oxaloacetic acid ✓ B) Succinic acid
C) Citric acid D) Fumaric acid

29. **What kind of reaction is involved in converting 2-PGA to PEP?**
A) Hydrolysis B) Oxidation
C) Dehydration ✓ D) Phosphorylation

30. **What is the total number of carbon atoms in one glucose molecule?**
A) 3 B) 4
C) 5 D) 6 ✓

SQ

1. **What is cellular respiration?**
Ans. Cellular respiration is a universal process in organisms through which complex carbon compounds like glucose are broken down to release usable energy. It occurs in almost all living cells.

2. **What is the general equation of cellular respiration?**
Ans: The equation is:
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}.$$
This shows that glucose and oxygen are converted into carbon dioxide, water, and energy.

3. **Why is glucose considered to have more stored energy than CO_2 and H_2O?**
Ans: Glucose contains many C-H bonds which store a significant amount of energy. In contrast, CO_2 and H_2O lack these bonds, and therefore, have much less stored energy.

4. **What is meant by "respiratory fuel"?**
Ans: Glucose is referred to as the respiratory fuel because almost all cells use it as the primary source of energy during respiration. It serves as the substrate for glycolysis and other respiration steps.

5. **What are the two main types of cellular respiration?**
Ans: The two main types are **aerobic respiration**, which requires oxygen, and **anaerobic respiration**, which [occu]rs in the absence of oxygen. Both begin with glycolysis but differ in the breakdown of pyruvic acid.

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6. **What is glycolysis?**

Ans: Glycolysis is the first step of both aerobic and anaerobic respiration where glucose is broken down into two molecules of pyruvic acid. It occurs in the cytosol and is catalyzed by enzymes.

7. **What is anaerobic respiration?**

Ans: Anaerobic respiration is a type of cellular respiration that occurs without oxygen. It results in the partial breakdown of glucose and yields only 2 ATP molecules per glucose.

8. **In which organisms or cells does anaerobic respiration occur?**

Ans: Anaerobic respiration occurs in many microorganisms, some plant cells, and muscle cells of vertebrates under low oxygen conditions. It also occurs in bacteria and yeast.

9. **What is alcoholic fermentation?**

Ans: In alcoholic fermentation, pyruvic acid is broken down into ethanol (C_2H_5OH) and CO_2. This process is seen in yeast and some bacteria.

10. **What is lactic acid fermentation?**

Ans: In lactic acid fermentation, each pyruvic acid molecule is converted into lactic acid ($C_3H_6O_3$) in the absence of oxygen. This happens in muscle cells during intense activity and in some bacteria.

11. **How much energy is released during anaerobic respiration?**

Ans: Anaerobic respiration releases energy equivalent to only two ATP molecules, which is about 2% of the total energy in one glucose molecule. This equals approximately 14.6 kilocalories.

12. **What happens to pyruvic acid in aerobic respiration?**

Ans: In aerobic respiration, pyruvic acid is completely oxidized to carbon dioxide and water. This allows for the full release of energy stored in glucose's C-H bonds.

13. **Where does glycolysis occur in the cell?**

Ans: Glycolysis occurs in the cytosol of the cell. It involves a series of enzyme-catalyzed reactions.

14. **What is the role of NAD^+ in glycolysis?**

Ans: NAD^+ acts as an electron carrier by accepting high-energy electrons and hydrogen atoms from glyceraldehyde-3-phosphate (G3P). It gets reduced to NADH in the process.

15. **What are the two phases of glycolysis?**

Ans: The two phases of glycolysis are the **preparatory phase** and the **oxidative phase**. The preparatory phase consumes ATP to prime glucose, while the oxidative phase produces ATP and pyruvic acid.

16. **What is formed after glycolysis in aerobic respiration?**

Ans: After glycolysis, pyruvic acid undergoes oxidative decarboxylation to form **acetyl-CoA**, which enters the Krebs cycle for further breakdown. This process takes place in mitochondria.

17. **What happens to acetyl-CoA in the Krebs cycle?**

Ans: Acetyl-CoA enters the Krebs cycle and combines with oxaloacetic acid to form citric acid. Through a series of reactions, citric acid is oxidized, releasing CO_2 and forming energy carriers like NADH, $FADH_2$, and ATP.

18. **What is the importance of the Krebs cycle?**

Ans: The Krebs cycle is crucial for completely oxidizing the acetyl group to CO_2 and releasing energy. It produces NADH and $FADH_2$, which are later used in the electron transport chain to generate more ATP.

19. **What is the role of FAD in the Krebs cycle?**

Ans: FAD is an electron carrier that gets reduced to $FADH_2$ when succinic acid is oxidized to fumaric acid. It helps transfer electrons to the electron transport chain for ATP production.

20. **How is oxaloacetic acid regenerated in the Krebs cycle?**

Ans: Oxaloacetic acid is regenerated when malic acid is oxidized, releasing hydrogen and electrons. These are accepted by NAD^+ to form NADH, completing the cycle.

Q 21. Describe the Electron Transport Chain and the process of Chemiosmosis in cellular respiration.

Ans. Introduction to Electron Transport Chain (ETC)

The electron transport chain is the fourth and final stage of aerobic respiration. In this stage, the electrons are transferred from reduced coenzymes—NADH and $FADH_2$—to a series of electron carriers embedded in the inner mitochondrial membrane, ultimately ending with oxygen.

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Final Electron Acceptor and Formation of Water

Oxygen acts as the final electron acceptor. It receives the electrons at the end of the chain and combines with hydrogen ions (H^+) to form water. This crucial step prevents the backup of electrons in the chain and keeps the process ongoing.

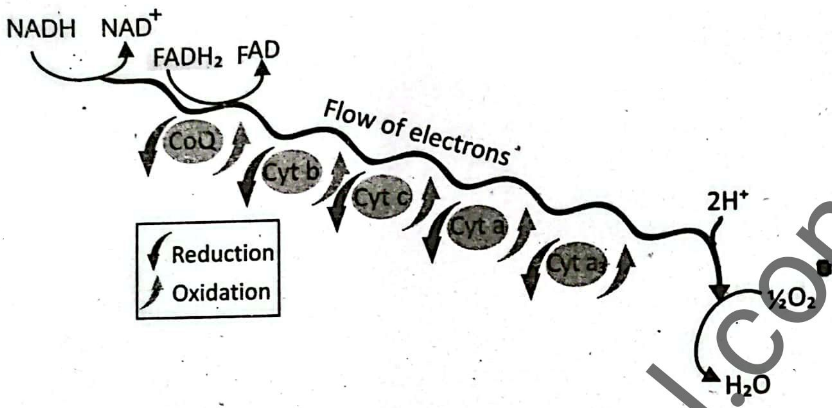

Fig. 6.18: Pathway of electrons

Redox Reactions in the Chain

The electron transport chain works through a series of oxidation and reduction (redox) reactions. A carrier molecule gets oxidized when it loses electrons, and the next one in the chain gets reduced upon gaining those electrons. As electrons move from one carrier to the next, they lose energy.

> You have seen that in redoxreactions electrons and hydrogenions are removed from substratesand transferred to coenzymes NAD+and FAD.

Role of Chemiosmosis

Chemiosmosis is the mechanism that couples these redox reactions to the synthesis of ATP using membrane-bound enzymes. The released energy during electron transfer is used to actively transport hydrogen ions across the inner mitochondrial membrane, from the matrix to the intermembrane space. This movement builds a gradient, storing potential energy.

22. Explain the pathway of electrons in the Electron Transport Chain and describe how ATP is synthesized during this process.

Ans. Electron Pathway in ETC

The electron transport chain is located in the inner membrane of the mitochondrion. Initially, NADH is oxidized, releasing electrons that are picked up by coenzyme Q (CoQ). $FADH_2$, when oxidized, also transfers its electrons to CoQ. The reduced CoQ passes the electrons to cytochrome 'b', which then transfers them to cytochrome 'c'. Cytochrome 'c' passes them to cytochrome 'a' complex (a combination of two cytochromes). Finally, electrons are transferred to an oxygen atom at the end of the chain.

ATP Synthesis through ATP Synthase

The redox reactions release energy that is used for the active transport of H^+ ions from the mitochondrial matrix into the intermembrane space. This results in a high concentration of H^+ ions in the intermembrane space, creating a proton gradient. These ions then diffuse back into the matrix through a special protein complex called ATP synthase.

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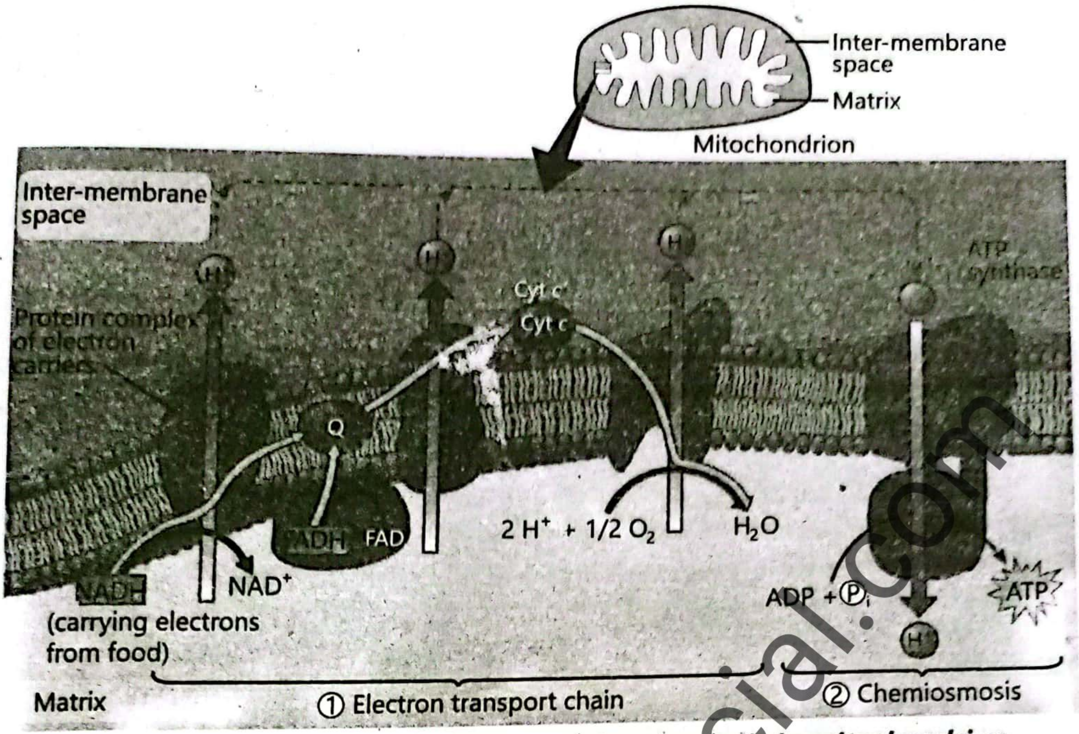


Fig. 6.19: Electron transport chain and chemiosmosis in mitochondrion

As H^+ ions move through ATP synthase, their kinetic energy is harnessed to convert ADP and inorganic phosphate into ATP. This is the process of oxidative phosphorylation.

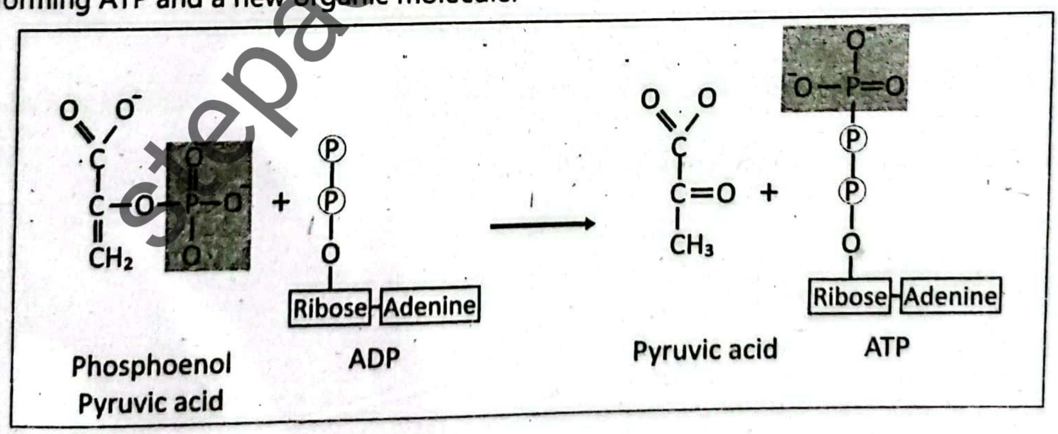
ATP Yield

- Oxidation of one NADH in the ETC yields **3 ATP molecules**.
- Oxidation of one $FADH_2$ yields **2 ATP molecules.**
- At the end, oxygen combines with two electrons and two H^+ ions to form water.

23. What is substrate-level phosphorylation and how does it differ from chemiosmotic phosphorylation?

Ans. Definition of Substrate-Level Phosphorylation

Substrate-level phosphorylation is a simpler way of ATP generation that occurs without the need for membranes or an electron transport chain. In this method, an enzyme transfers a phosphate group from an organic substrate directly to ADP, forming ATP and a new organic molecule.



Example in Glycolysis

An example of substrate-level phosphorylation is observed during the last step of glycolysis. Here, an enzyme transfers a phosphate group from phosphoenolpyruvic acid (PEP) to ADP, resulting in the formation of ATP and pyruvic acid.

Comparison with Chemiosmotic Phosphorylation

- **Substrate-level phosphorylation** is a direct enzymatic reaction and contributes only a small amount of ATP.

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- **Chemiosmotic phosphorylation** is membrane-based and involves the electron transport chain and ATP synthase, generating the bulk of ATP in aerobic respiration.

24. Provide an overview of energy extraction from glucose oxidation and compare aerobic and anaerobic respiration.

Ans. Energy Yield from NADH and $FADH_2$

NADH and $FADH_2$ produced in glycolysis and the Krebs cycle donate high-energy electrons to the electron transport chain. During chemiosmosis:

- Each **NADH from Krebs cycle** leads to the production of **3 ATP**.
- Each **$FADH_2$** results in **2 ATP**.

NADH from Glycolysis and Transport Cost

Glycolysis occurs in the cytoplasm, and NADH generated here must be transported into the mitochondria. This transport costs one ATP per NADH, reducing its net yield from 3 ATP to 2 ATP.

Net ATP Production

- Total ATP from **aerobic respiration: 36 ATP molecules** per glucose.
- Total ATP from **anaerobic glycolysis: 2 ATP molecules** per glucose.

Thus, aerobic respiration is **18 times more efficient** than anaerobic respiration.

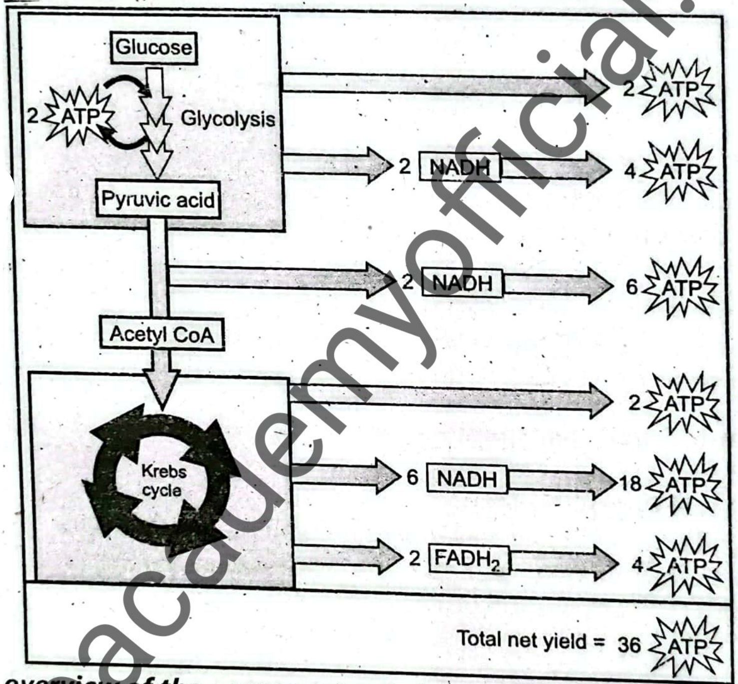

Fig. 6.20: An overview of the energy extracted from the aerobic oxidation of glucose

25. How are other organic molecules used as fuel in cellular respiration?

Ans. Carbohydrates Other Than Glucose

In the diet, free glucose is rare. Instead, sucrose, starch, and other disaccharides serve as carbohydrate sources. These are broken down into glucose or its equivalents before entering glycolysis or the Krebs cycle.

Proteins as Fuel

Proteins are broken down into amino acids. While most amino acids are used to build body proteins, some undergo deamination (removal of the amino group) and are converted into intermediates such as:

- Pyruvic acid
- Acetyl CoA
- Organic acids of the Krebs cycle

These intermediates enter the respiration pathways and contribute to ATP production.

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Fats and Lipids as Fuel

Lipids are potent energy sources because of their high carbon-hydrogen bond content. They are hydrolyzed into:

- **Glycerol**, which is converted to glyceraldehyde-3-phosphate (a glycolysis intermediate)
- **Fatty acids**, which are converted to acetyl CoA

Both products enter the respiration pathway and help in ATP synthesis.

MCQs ✓

1. **Where is the electron transport chain located in the cell?**
A) Cytoplasm
B) Outer mitochondrial membrane
C) Inner mitochondrial membrane ✓
D) Ribosome

2. **Which coenzymes donate electrons to the electron transport chain?**
A) NAD+ and ATP
B) NADH and $FADH_2$ ✓
C) FAD and ADP
D) NADPH and GTP

3. **What is the final electron acceptor in the electron transport chain?**
A) Water
B) NAD+
C) Oxygen ✓
D) Hydrogen

4. **What happens to oxygen after it accepts electrons in the electron transport chain?**
A) It forms carbon dioxide
B) It forms water ✓
C) It releases hydrogen
D) It turns into ozone

5. **What is chemiosmosis?**
A) Movement of glucose across membranes
B) Redox reaction without ATP
C) Coupling redox reactions with ATP synthesis via membranes ✓
D) Passive diffusion of water

6. **Which molecule receives electrons directly from NADH or $FADH_2$?**
A) Cytochrome b
B) Coenzyme Q ✓
C) Oxygen
D) Cytochrome a

7. **Which cytochrome receives electrons directly from cytochrome b?**
A) Cytochrome a
B) Coenzyme Q
C) Cytochrome c ✓
D) NAD+

8. **What role does ATP synthase play in chemiosmosis?**
A) Breaks down glucose
B) Pumps hydrogen ions
C) Synthesizes ATP using H^+ ion flow ✓
D) Transfers electrons

9. **How many ATP molecules are produced by the oxidation of one NADH molecule?**
A) 1
B) 2
C) 3 ✓
D) 4

10. **How many ATP molecules are produced by one $FADH_2$?**
A) 4
B) 3
C) 2 ✓
D) 1

11. **What is substrate-level phosphorylation?**
A) ATP synthesis via light energy
B) ATP synthesis without membranes or ETC ✓
C) Use of oxygen in respiration
D) Passive transport of phosphates

12. **Which process does NOT require a membrane or electron transport chain?**
A) Chemiosmosis
B) Oxidative phosphorylation
C) Substrate-level phosphorylation ✓
D) Aerobic respiration

13. **Which molecule donates a phosphate group to ADP during the last step of glycolysis?**
A) Glucose
B) Pyruvic acid
C) Phosphoenol pyruvic acid (PEP) ✓
D) Acetyl CoA

14. **How many net ATP molecules are produced in complete aerobic respiration of one glucose?**
A) 28
B) 36 ✓
C) 12
D) 2

15. **Why does NADH from glycolysis produce fewer ATPs?**
A) It is converted to CO_2
B) It costs ATP to enter mitochondria ✓
C) It breaks down in the cytoplasm
D) It becomes $FADH_2$

16. **How many ATP molecules are generated from each NADH of glycolysis after mitochondrial transport?**
A) 4
B) 3
C) 2 ✓
D) 1

17. **How many ATP molecules are produced in anaerobic respiration of one glucose?**
A) 36
B) 18
C) 6
D) 2 ✓

18. **Which nutrient class yields the most energy during cellular respiration?**
A) Carbohydrates
B) Proteins
C) Lipids ✓
D) Vitamins

19. **What is the first step in lipid metabolism for respiration?**
A) Dehydration
B) Hydrolysis into glycerol and fatty acids ✓
C) Glycolysis
D) Conversion to glucose

20. **What happens to amino acids before they enter cellular respiration?**
A) They are fermented
B) They are phosphorylated
C) They are deaminated ✓
D) They are stored as fat

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SQ

1. **What is the role of oxygen in the electron transport chain?**

Ans. Oxygen acts as the final electron acceptor in the electron transport chain. It combines with hydrogen ions and electrons to form water.

2. **What happens during redox reactions in the electron transport chain?**

Ans: A carrier molecule is oxidized when it loses electrons, and the next carrier is reduced when it gains electrons. This transfer releases energy used in ATP synthesis.

3. **What is chemiosmosis in cellular respiration?**

Ans: Chemiosmosis is the process of using a membrane to couple redox reactions with ATP synthesis. It uses a proton gradient to drive the production of ATP through ATP synthase.

4. **Where is the electron transport chain located in the cell?**

Ans: The electron transport chain is located in the inner membrane of the mitochondrion. This location allows the formation of a proton gradient across the membrane.

5. **What is the first step in the electron transport chain involving NADH?**

Ans: NADH is oxidized and its electrons are transferred to coenzyme Q. This initiates the flow of electrons through the electron transport chain.

6. **What happens to electrons from $FADH_2$ in the electron transport chain?**

Ans: Electrons from $FADH_2$ are transferred to coenzyme Q. From there, they follow the same pathway as electrons from NADH.

7. **Which carriers transport electrons after coenzyme Q?**

Ans: After coenzyme Q, electrons are passed to cytochrome 'b', then to cytochrome 'c', and finally to the cytochrome 'a' complex. This leads them to the final electron acceptor, oxygen.

8. **How does the electron transport chain contribute to the proton gradient?**

Ans: The redox reactions pump hydrogen ions from the mitochondrial matrix to the intermembrane space. This creates a proton gradient across the membrane.

9. **What is the role of ATP synthase in chemiosmosis?**

Ans: ATP synthase is a membrane protein that allows hydrogen ions to flow back into the matrix. The energy from this flow drives the synthesis of ATP.

10. **How many ATP molecules are produced from one NADH?**

Ans: One NADH molecule produces three ATP molecules during oxidative phosphorylation. This occurs via the electron transport chain.

11. **How many ATP molecules are produced from one $FADH_2$?**

Ans: One $FADH_2$ molecule leads to the formation of two ATP molecules in the electron transport chain. This is slightly less efficient than NADH.

12. **What is substrate-level phosphorylation?**

Ans: Substrate-level phosphorylation is a simpler way of making ATP without using membranes. An enzyme transfers a phosphate group from a substrate molecule to ADP, forming ATP.

13. **How is ATP produced during the last step of glycolysis?**

Ans: In the final step of glycolysis, an enzyme transfers a phosphate from phosphoenol pyruvic acid (PEP) to ADP. This forms ATP and pyruvic acid.

14. **How does substrate-level phosphorylation differ from chemiosmosis?**

Ans: Substrate-level phosphorylation occurs directly by enzyme action without a membrane. Chemiosmosis uses a proton gradient and membrane proteins to generate ATP.

15. **Why does NADH from glycolysis produce fewer ATPs than NADH from the Krebs cycle?**

Ans: NADH from glycolysis must be transported into the mitochondria, which costs one ATP per NADH. Therefore, it yields only two ATP instead of three.

16. **What is the total ATP yield from aerobic respiration of one glucose molecule?**

Ans: Aerobic respiration of one glucose molecule yields a net of 36 ATP molecules. This includes ATP from glycolysis, Krebs cycle, and oxidative phosphorylation.

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17. **How many ATP molecules are produced in anaerobic respiration?**
Ans: Anaerobic respiration produces only 2 ATP molecules from glycolysis. It is significantly less efficient than aerobic respiration.

18. **Why is aerobic respiration more efficient than anaerobic respiration?**
Ans: Aerobic respiration produces 36 ATP molecules, while anaerobic respiration produces only 2. Thus, aerobic respiration is 18 times more efficient.

19. **How are proteins used in cellular respiration?**
Ans: Proteins are broken into amino acids, which are mostly used for protein synthesis. Some are deaminated and converted to intermediates like pyruvic acid or acetyl CoA.

20. **How do lipids contribute to cellular respiration?**
Ans: Lipids are broken down into glycerol and fatty acids. Glycerol enters glycolysis, while fatty acids are converted to acetyl CoA for the Krebs cycle.

6.3 PHOTORESPIRATION

INTRODUCTION

Photorespiration is a respiratory process that takes place in green cells of plants in the presence of light, where carbon dioxide (CO_2) is released. It requires oxygen (O_2) and produces CO_2 and water (H_2O), similar to aerobic respiration. However, unlike aerobic respiration, photorespiration does not produce ATP. Instead, it results in the consumption of energy and loss of fixed carbon, which can reduce the efficiency of photosynthesis.

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26. Describe the mechanism of photorespiration including the role of RuBisCO.

Ans. In normal photosynthesis, the enzyme RuBP carboxylase (RuBisCO) catalyzes the fixation of CO_2 to ribulose bisphosphate (RuBP) to form phosphoglyceric acid (phosphoglycerate), which is then reduced to produce glucose. However, when the CO_2 concentration in the leaf cells decreases and oxygen concentration rises, RuBisCObinds O_2 instead of CO_2 to RuBP. This oxygenation reaction breaks RuBP into two molecules: one molecule of phosphoglycerate and one molecule of phosphoglycolate (a two-carbon compound).

> **Recalling:**
> During carbon fixation, RuBisCO combinesthree molecules of CO2 with threemolecules of RuBP and makes six moleculesof 3–phosphoglyceric acid (3-PGA).

Phosphoglycolate is converted into glycolate, which leaves the chloroplast and enters the peroxisome. In the peroxisome, glycolate is metabolized into glyoxylate using O_2, generating toxic hydrogen peroxide (H_2O_2) as a byproduct. Glyoxylate is then converted to glycine, which moves into mitochondria. In mitochondria, two glycine molecules combine to form serine. Serine is then transported back to the peroxisome, where it is converted into glycerate. The glycerate returns to the chloroplast, where it is converted into phosphoglycerate, allowing it to re-enter the Calvin cycle.

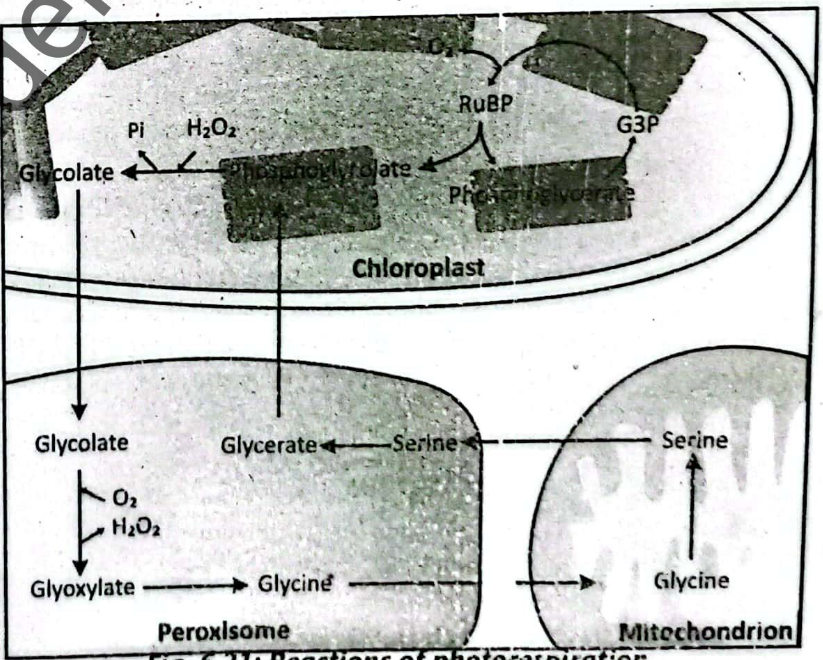
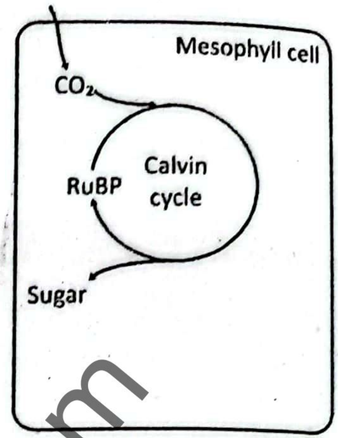


Fig. 6.21: Reactions of photorespiration

27. What are the disadvantages of photorespiration for C-3 plants, and how does temperature affect the process?

Ans. C-3 plants, which rely solely on the Calvin cycle for carbon fixation, suffer significant losses due to photorespiration. They can lose between 25% to 50% of their fixed carbon through this process, which reduces their overall productivity and yield. The rate of photorespiration is also temperature-dependent. At higher temperatures, the oxygenase activity of RuBisCO (which causes photorespiration) increases relative to its carboxylase activity (carbon fixation). This makes photorespiration a severe problem in tropical climates where temperatures frequently exceed 28°C, negatively impacting agricultural yields.



C-3 Photosynthesis

Fig. 6.22a: C-3 photosynthesis

28. How did photorespiration evolve and why is it a problem now?

Ans. Photorespiration was not a problem when photosynthesis first evolved because the Earth's atmosphere contained very little oxygen. Therefore, RuBisCO primarily fixed carbon dioxide without interference. Over millions of years, as photosynthetic organisms produced oxygen, the concentration of free oxygen in the atmosphere increased. This led to competition between oxygen and carbon dioxide at RuBisCO's active site, resulting in photorespiration. Hence, photorespiration is a byproduct of evolutionary changes in atmospheric composition and now poses a challenge to efficient photosynthesis.

> C-4 plants carry out C-4 as well asC-3 photosynthesis.

29. Explain the C-4 photosynthesis pathway as an adaptation to photorespiration.

Ans. C-4 photosynthesis is a specialized pathway found in plants such as corn, sugarcane, and sorghum. In C-4 plants, the leaf anatomy differs from C-3 plants: mesophyll cells have fewer air spaces, and Calvin cycle enzymes are concentrated in specialized bundle-sheath cells, which are relatively impermeable to CO_2.

In the mesophyll cells, CO_2 is initially fixed by combining with a three-carbon compound called phosphoenol pyruvic acid (PEP) to form a four-carbon compound called oxaloacetic acid. This is why the process is termed "C-4 photosynthesis." Oxaloacetic acid is then converted into malic acid using NADH. Malic acid is transported to bundle-sheath cells, where it breaks down to release CO_2 and pyruvic acid. The bundle-sheath cells have high CO_2 concentrations, allowing the Calvin cycle to proceed efficiently with minimal photorespiration. The pyruvic acid returns to the mesophyll cells and is converted back to PEP using ATP, completing the cycle.

> In C-4 photosynthesis, theenergy cost for making aglucose molecule is almostdouble. However, in hotclimates, in whichphotorespiration wouldotherwise remove more thanhalf of the carbon fixed, it is bestcompromise available.

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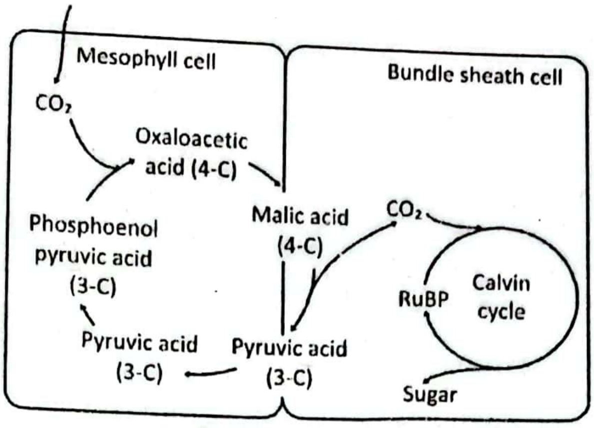


C-4 Photosynthesis

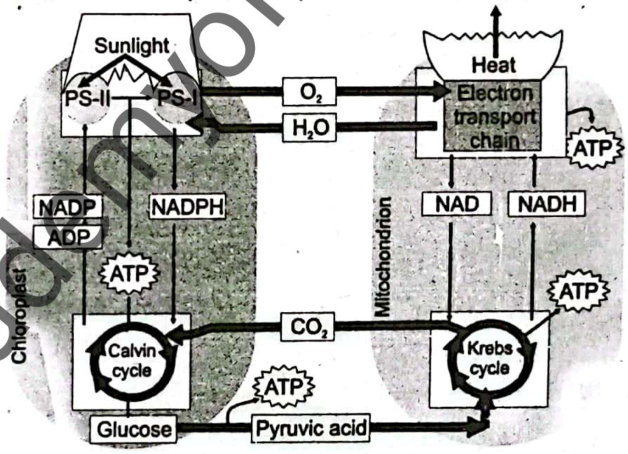
Fig. 6.22b: C-4 photosynthesis

30. Describe CAM metabolism and how it helps plants in hot climates deal with photorespiration.

Ans. Crassulacean Acid Metabolism (CAM) is another adaptation found in succulent plants such as cacti and pineapples. These plants open their stomata at night to take in CO_2 and close them during the day to reduce water loss. The CO_2 absorbed at night is fixed into organic acids, which are stored until daytime. During the day, when the stomata are closed, the CO_2 is released from these organic acids for use in photosynthesis.

This temporal separation of gas exchange reduces photorespiration because the CO_2 concentration inside the leaf remains high during daylight, preventing RuBisCO from binding oxygen. Like C-4 plants, CAM plants use both C-4 and C-3 pathways, enabling them to conserve water and minimize photorespiration under hot, arid conditions.

From the givenflowchart, build aparagraph that candescribe a comparisonbetween photosynthesisand respiration in termsof reactants andproducts of major steps.



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MCQs

Photorespiration

1. **What is photorespiration?**
   a) Respiration occurring in the dark
   b) Respiration in green cells in presence of light producing CO_2 ✓
   c) Anaerobic respiration in roots
   d) ATP-producing respiration in mitochondria

2. **Which enzyme catalyzes the fixation of CO_2 during photosynthesis?**
   a) ATP synthase b) RuBisCO ✓
   c) NADH reductase d) Phosphoglycerate kinase

3. **What happens when RuBisCO binds oxygen instead of CO_2?**
   a) Production of glucose
   b) Breakdown of RuBP into phosphoglycerate and phosphoglycolate ✓
   c) Increase in ATP production
   d) Direct synthesis of glycerate

4. **What toxic byproduct is produced during photorespiration in the peroxisome?**
   a) Carbon dioxide Hydrogen peroxide ✓
   c) Methane Nitric oxide

5. **Where in the cell is glycine onverted to serine during photorespiration?**
   a) Chloroplast b) Cytoplasm
   c) Mitochondrion ✓ d) Peroxisome

6. **What percentage of fixed carbon can be lost due to photorespiration in C-3 plants?**

a) 5-10% b) 15-20%
c) 25-50% ✓ d) 60-70%.

7. **How does temperature affect the rate of photorespiration?**
a) Rate decreases with increasing temperature
b) Rate increases with increasing temperature ✓
c) Rate remains constant
d) Rate fluctuates unpredictably

8. **Why was photorespiration not a problem when photosynthesis first evolved?**
a) Low oxygen levels in atmosphere ✓
b) Higher CO_2 concentration than today
c) Lack of RuBisCO enzyme
d) Presence of alternate enzymes

9. **Which plants perform C-4 photosynthesis as an adaptation to photorespiration?**
a) Wheat and rice
b) Corn, sugarcane, and sorghum ✓
c) Pineapple and cacti d) Mosses and ferns

10. **What is the first product formed in C-4 photosynthesis when CO_2 is fixed?**
a) Phosphoglycerate b) Malic acid
c) Oxaloacetic acid ✓ d) Pyruvic acid

11. **Where in C-4 plants does the Calvin cycle primarily occur?**
a) Mesophyll cells b) Bundle sheath cells ✓
c) Peroxisomes d) Mitochondria

12. **What happens to pyruvic acid produced in the bundle sheath cells of C-4 plants?**
a) Converted to glucose
b) Returns to mesophyll cells and converted to PEP ✓
c) Used to produce oxygen
d) Degraded in mitochondria

13. **What does CAM metabolism stand for and in what kind of plants is it found?**
a) Crassulacean Acid Metabolism; found in succulents like cacti ✓
b) Carbon Assimilation Mechanism; found in all trees
c) Cellular Aerobic Metabolism; found in aquatic plants
d) Chloroplast Assimilation Model; found in mosses

14. **When do CAM plants open their stomata?**
a) During the day b) During the night ✓
c) Continuously d) Only in the morning

15. **How do CAM plants reduce photorespiration?**
a) By increasing oxygen concentration
b) By keeping stomata closed during the day and using stored CO_2 ✓
c) By increasing water uptake
d) By producing more RuBisCO enzyme

16. **Which pathway(s) do CAM plants use for photosynthesis?**
a) Only C-3 pathway b) Only C-4 pathway
c) Both C-3 and C-4 pathways ✓
d) Neither C-3 nor C-4 pathways

17. **What molecule does RuBisCO add to RuBP during normal photosynthesis?**
a) Oxygen b) Carbon dioxide ✓
c) ATP d) NADPH

18. **Which molecule is formed when phosphoglycolate is converted in the peroxisome?**
a) Glycolate b) Glyoxylate ✓
c) Glycerate d) Serine

19. **What is the ultimate fate of glycerate formed in photorespiration?**
a) It is discarded as waste
b) It re-enters the Calvin cycle as phosphoglycerate ✓
c) It converts into glucose directly
d) It accumulates in the mitochondria

20. **Why is photorespiration considered inefficient for plants?**
a) It produces too much glucose
b) It consumes energy and releases fixed carbon without producing ATP ✓
c) It requires no oxygen
d) It enhances plant growth at low CO_2

Photorespiration

SQ

1. **What is photorespiration?**

Ans. Photorespiration is a process in green cells where respiration occurs in the presence of light, releasing carbon dioxide. Unlike normal respiration, it requires oxygen but does not produce ATP.

2. **Which enzyme is responsible for fixing CO_2 during photosynthesis?**

Ans: RuBisCO, also called RuBP carboxylase, fixes carbon dioxide by attaching it to RuBP during the Calvin cycle. However, it can also react with oxygen, leading to photorespiration.

3. **What happens when RuBisCO binds oxygen instead of carbon dioxide?**

Ans: RuBisCO adds oxygen to RuBP, causing it to break down into phosphoglycerate and phosphoglycolate. This reaction initiates the photorespiration pathway.

4. **Where does phosphoglycolate go after its formation?**

Ans: Phosphoglycolate is converted into glycolate, which moves from the chloroplast to the peroxisome. In the peroxisome, glycolate is further metabolized.

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5. **What toxic substance is produced in the peroxisome during photorespiration?**

Ans: During the conversion of glycolate to glyoxylate in the peroxisome, hydrogen peroxide (H_2O_2) is produced. This compound is toxic and needs to be detoxified by the plant.

6. **How is glycine converted during photorespiration?**

Ans: Glyoxylate is converted into glycine, which then moves to the mitochondrion. In the mitochondrion, two glycine molecules combine to form one molecule of serine.

7. **What happens to serine in photorespiration?**

Ans: Serine is transported back to the peroxisome, where it is converted into glycerate. Glycerate then returns to the chloroplast to re-enter the Calvin cycle.

8. **What is the main disadvantage of photorespiration in C-3 plants?**

Ans: Photorespiration causes C-3 plants to lose between 25% to 50% of their fixed carbon. This reduces the overall efficiency of photosynthesis and decreases plant yield.

9. **How does temperature affect photorespiration?**

Ans: At higher temperatures, RuBisCO's oxygenase activity increases relative to its carboxylase activity. This leads to higher rates of photorespiration, especially in tropical climates.

10. **Why was photorespiration not a problem in early Earth's atmosphere?**

Ans: Initially, the atmosphere had very little oxygen, so RuBisCO mostly fixed carbon dioxide. The accumulation of oxygen over millions of years created competition between CO_2 and O_2 for RuBisCO's active site.

11. **What is the key adaptation in C-4 plants to reduce photorespiration?**

Ans: C-4 plants fix CO_2 into a four-carbon compound called oxaloacetic acid in mesophyll cells. This compound is transported to bundle sheath cells where CO_2 is released and used in the Calvin cycle.

12. **What type of cells contain most Calvin cycle enzymes in C-4 plants?**

Ans: The Calvin cycle enzymes are concentrated in bundle sheath cells in C-4 plants. These cells are less permeable to gases, allowing CO_2 to accumulate and reduce photorespiration.

13. **What happens to malic acid in C-4 plants?**

Ans: Malic acid is transported from mesophyll cells to bundle sheath cells. In the bundle sheath, it is broken down into pyruvic acid and CO_2, providing high CO_2 levels for the Calvin cycle.

14. **How is pyruvic acid recycled in C-4 plants?**

Ans: Pyruvic acid moves back to mesophyll cells where it is converted to phosphoenol pyruvic acid (PEP) using ATP. This regeneration is essential for continuing the C-4 pathway.

15. **What is CAM metabolism and which plants use it?**

Ans: CAM metabolism is an adaptation found in succulent plants like cacti and pineapples. These plants open their stomata at night to fix CO_2 and close them during the day to conserve water.

16. **How do CAM plants reduce photorespiration?**

Ans: By fixing CO_2 at night and storing it as organic acids, CAM plants maintain high internal CO_2 during the day. This reduces oxygen competition at RuBisCO's active site and lowers photorespiration.

17. **When do CAM plants open and close their stomata?**

Ans: CAM plants open their stomata during the night to take in carbon dioxide. They close their stomata during the day to prevent water loss in hot climates.

18. **What is the first product formed when CO_2 is fixed in C-4 photosynthesis?**

Ans: The first product is oxaloacetic acid, a four-carbon compound formed by attaching CO_2 to phosphoenol pyruvic acid. This is why the process is called C-4 photosynthesis.

19. **What role does the peroxisome play in photorespiration?**

Ans: The peroxisome metabolizes glycolate to glyoxylate and converts serine to glycerate. It also produces and detoxifies hydrogen peroxide during these processes.

20. **Why do C-3 plants suffer greater losses due to photorespiration compared to C-4 plants?**

Ans: C-3 plants lack the mechanism to concentrate CO_2 around RuBisCO, leading to oxygen competing with CO_2. This results in a higher rate of photorespiration and loss of fixed carbon.

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SOLVED EXERCISE

MULTIPLE CHOICE QUESTIONS

Tick (✓) the correct answer.

1. **What main process occurs during the dark reaction of photosynthesis?**
(a) Release of oxygen (b) Energy absorption by chlorophyll
(c) Adding of hydrogen to CO_2 ✓ (d) Formation of ATP
2. **What is TRUE about glycolysis?**
(a) It produces no ATP
(b) It takes place only in aerobic respiration
(c) It takes place in the mitochondrion
(d) It reduces 2 molecules of NAD^+ for every glucose molecule processed ✓
3. **Which of the following are produced by the reactions that occur in the thylakoid and consumed by the reactions that occur in the stroma?**
(a) CO_2 and H_2O (b) Glucose and O_2 (c) $NADP^+$ and ADP (d) ATP and NADPH ✓
4. **When deprived of oxygen, yeast cells obtain energy by fermentation, producing CO_2, ATP and;**
(a) Acetyl CoA (b) Ethyl alcohol ✓ (c) Lactic acid (d) Pyruvic acid
5. **Conversion of Glucose 6-phosphate into Fructose 6-phosphate is;**
(a) Isomerization ✓ (b) Polymerization (c) Condensation (d) Phosphorylation
6. **In which of the following conversions is ATP produced?**
(a) Alpha ketoglutaric acid into succinyl CoA (b) Succinyl CoA into succinic acid ✓
(c) Succinic acid into fumaric acid (d) Fumaric acid into malic acid
7. **In the electron transport chain, $FADH_2$ produces how many ATPs?**
(a) One (b) Two ✓ (c) Three (d) Four
8. **Which of these is CO_2 acceptor during photosynthesis?**
(a) Malic acid (b) Ribulose biphosphate ✓ (c) Oxaloacetic acid (d) Phosphoglyceric acid
9. **Which of the following takes the electrons lost by Photosystem I on absorption of light energy?**
(a) Ferredoxin ✓ (b) Cytochrome (c) Cytochrome a_3 (d) Plastocyanin
10. **Photosystem-II makes up the electrons lost due to light excitation by taking up the electrons released from,**
(a) Ferredoxin (b) $NADPH.H^+$ (c) Plastocyanin (d) Photolysis of water ✓

SHORT ANSWER QUESTIONS

1. **Differentiate between action spectrum and absorption spectrum.**

Ans: The **absorption spectrum** shows the wavelengths of light absorbed by pigments like chlorophyll. The **action spectrum** indicates the rate of photosynthesis at different wavelengths and shows which wavelengths are most effective for the process.

2. **How is photosynthesis a redox reaction?**

Ans: Photosynthesis involves the **reduction** of carbon dioxide into glucose and the **oxidation** of water into oxygen. Since it involves both reduction and oxidation processes, it is classified as a redox reaction.

3. **Which molecule contributes oxygen in glucose? Water or carbon dioxide!**

Ans: The **oxygen atoms in glucose** ($C_6H_{12}O_6$) come from **carbon dioxide (CO_2)**. Water contributes the oxygen that is released as O_2 during the light reaction.

4. **State the role of CO_2 in photosynthesis.**

Ans: Carbon dioxide acts as a **raw material** in the dark reactions (Calvin cycle) of photosynthesis. It is **fixed into organic molecules**, eventually forming glucose.

5. **Define electron transport chain.**

Ans: The electron transport chain (ETC) is a series of protein complexes in the **inner mitochondrial membrane** or thylakoid membrane. It transfers electrons and **produces ATP** through oxidative phosphorylation.

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6. **What do you mean by glycolysis?**

Ans: Glycolysis is the process of breaking down **glucose into two molecules of pyruvic acid**, releasing energy. It occurs in the **cytoplasm** and produces ATP and NADH.

7. **What is the main structural difference between chlorophyll-a and chlorophyll-b?**

Ans: The difference lies in a **functional group** attached to the porphyrin ring: chlorophyll-a has a **methyl group** **($-CH_3$)**, while chlorophyll-b has an **aldehyde group (-CHO)**. This difference slightly alters their light absorption properties.

8. **How can a cell synthesize ATP through substrate-level phosphorylation?**

Ans: In substrate-level phosphorylation, a **phosphate group is directly transferred** from a phosphorylated compound to ADP to form ATP. This occurs during **glycolysis and the Krebs cycle** without the involvement of the electron transport chain.

9. **Can pyruvic acid enter Krebs cycle as such? If not, what changes are made to it before Krebs cycle?**

Ans: No, pyruvic acid cannot enter the Krebs cycle directly. It is first **converted into Acetyl-CoA** by losing a carbon dioxide molecule and combining with coenzyme A.

10. **Differentiate between C-3 and C-4 photosynthesis.**

Ans: In **C-3 photosynthesis**, the first stable product is a **3-carbon compound** (3-phosphoglycerate), and it occurs directly in mesophyll cells. In **C-4 photosynthesis**, a **4-carbon compound** (oxaloacetate or malate) is formed first and CO_2 fixation occurs in **bundle sheath cells**, helping reduce photorespiration.

LONG ANSWER QUESTIONS

Q1. What are photosynthetic pigments and what role they play in the absorption andconversion of light energy?

Ans: See question Q5.

Q2. How are the absorption spectra of chlorophyll 'a' and 'b' different?

Ans: See question Q6.

Q3. Describe and illustrate how photosynthetic pigments are organized in thylakoidmembrane?

Ans: See Question Q7.

Q4. Describe how the role of water in photosynthesis can be explained throughexperiment.

Ans: See Question Q4

Q5. What are the events that capture light and convert it into chemical energy duringlight dependent reactions?

Ans: see Question 10 and 11.

Q6. Illustrate the cyclic photophosphorylation.

Ans: See Question Number 12.

Q7. Describe light independent reactions of photosynthesis in terms of paragraph andillustrate in terms of Calvin cycle.

Ans: See question 14

Q8. What happens with glucose in anaerobic respiration and how different organismsmodify the end products?

Ans: See Question 16

Q9. How is glucose broken down to pyruvic acid in glycolysis?

Ans: See Question 18

Q10. Describe how Krebs cycle is the completion of the oxidation of glycolytic products.

Ans: See Question 20

Q11. Explain the passage of electron through electron transport chain.

Ans: See Question 21

Q12. Define chemiosmosis. How would you relate it with electron transport chain?

Ans: See Question 22

Q13. Through which ways proteins and fats enter cellular respiration?

Ans: see question 25

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Q14. Define photorespiration and present it in proving that "photosynthesis is notperfect".

Ans: see question 26

Q15. What are the effects of temperature on the oxidative activity of RuBisCO?

Ans: See question 29

Q16. How is the process of C4 photosynthesis an adaptation to deal with the problemof photorespiration?

Ans: See question 30

INQUISITIVE QUESTIONS

1. Why does cellular respiration release energy more efficiently than fermentation?

Ans: Cellular respiration releases energy more efficiently because it completely oxidizes glucose into carbon dioxide and water, producing up to 36–38 ATP molecules per glucose. In contrast, fermentation only partially breaks down glucose, yielding just 2 ATP per glucose, making it far less efficient.

2. Why is the conversion of glucose into ATP during cellular respiration considered a more efficient use of energy than burning glucose directly?

Ans: In cellular respiration, the energy from glucose is released gradually through controlled enzymatic steps and stored in the form of ATP, which the cell can use directly. Burning glucose releases energy all at once as heat, which is wasted and cannot be used by biological systems for cellular work.

3. Why might a disruption in either photosynthesis or respiration processes affect global carbon and oxygen cycles?

Ans: Photosynthesis and respiration are interconnected processes that regulate the levels of carbon dioxide and oxygen in the atmosphere. Disruption in either process would cause an imbalance, leading to excess CO_2 or reduced O_2 levels, ultimately impacting climate, ecosystems, and life on Earth.

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Self-Assessment Unit 6

Max. Marks: 28 Time allowed 60 Mins

Q1. Each of the following question has four options. Select the correct answer. (10x1=10)

1. **Which key event takes place during the dark phase of photosynthesis?**
   (a) Oxygen is liberated (b) Chlorophyll absorbs light energy
   (c) Hydrogen is added to carbon dioxide (d) ATP is synthesized
2. **Which statement correctly describes glycolysis?**
   (a) It generates zero ATP
   (b) It happens only under aerobic conditions
   (c) It occurs within the mitochondria
   (d) It involves the reduction of two NAD^+ molecules per glucose
3. **Which substances are formed in the thylakoid reactions and utilized in the stroma during photosynthesis?**
   (a) Carbon dioxide and water (b) Glucose and oxygen (c) $NADP^+$ and ADP (d) ATP and NADPH
4. **In the absence of oxygen, yeast cells derive energy through fermentation, producing ATP, CO_2, and:**
   (a) Acetyl coenzyme A (b) Ethanol (c) Lactic acid (d) Pyruvate
5. **The transformation of glucose-6-phosphate into fructose-6-phosphate is an example of:**
   (a) Isomerization (b) Polymerization (c) Condensation (d) Phosphorylation
6. **In which step of the Krebs cycle is ATP (or GTP) directly produced?**
   (a) Alpha-ketoglutarate to succinyl-CoA
   (b) Succinyl-CoA to succinate
   (c) Succinate to fumarate
   (d) Fumarate to malate
7. **During the electron transport chain, the oxidation of one $FADH_2$ molecule results in the production of how many ATP molecules?**
   (a) 1 (b) 2 (c) 3 (d) 4
8. **Which molecule acts as the carbon dioxide acceptor in the Calvin cycle?**
   (a) Malate (b) Ribulose bisphosphate (RuBP)
   (c) Oxaloacetate (d) 3-phosphoglycerate
9. **After Photosystem I loses electrons due to light excitation, which molecule receives them?**
   (a) Ferredoxin (b) Cytochrome complex
   (c) Cytochrome a3 (d) Plastocyanin
10. **Photosystem II compensates for its lost electrons by accepting new ones released from:**
    (a) Ferredoxin (b) NADPH
    (c) Plastocyanin (d) Splitting of water

Q2. Write short answers to the following questions. (5x2=10)

1. Differentiate between action spectrum and absorption spectrum.
2. State the role of CO_2 in photosynthesis.
3. Define electron transport chain.
4. What do you mean by glycolysis?
5. Differentiate between C-3 and C-4 photosynthesis.

Q3. Write detailed answer to the following question. (4+4=8)

1. Illustrate the cyclic photophosphorylation.
2. Describe how Krebs cycle is the completion of the oxidation of glycolytic products.

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