

# Chapter 11: Photosynthesis in Higher Plants

## Comprehensive Study Notes

Class 11 Biology - NCERT Based

EXAM SPRINT - Complete Coverage for NEET and Board Examinations

### Introduction

Photosynthesis is the fundamental process that sustains life on Earth. Green plants, as autotrophs, synthesize their own food through this physico-chemical process, converting light energy into chemical energy. All heterotrophic organisms, including humans, depend directly or indirectly on the products of photosynthesis for their survival.

#### Significance of Photosynthesis:

1. **Primary food source:** Foundation of all food chains on Earth
2. **Oxygen production:** Releases  $O_2$  into the atmosphere for aerobic life
3. **Energy conversion:** Transforms solar energy into usable chemical energy
4. **Carbon fixation:** Removes  $CO_2$  from atmosphere, mitigating greenhouse effect

### 11.1 FOUNDATIONAL KNOWLEDGE

#### Basic Requirements for Photosynthesis

Early experiments established three essential requirements:

#### Essential Components

1. **Chlorophyll:** Green pigment in leaves
2. **Light:** Energy source for the process

3. **Carbon dioxide:** Raw material for carbohydrate synthesis

## Classical Experiments

### Starch Test Experiment

**Procedure:** Variegated leaves or leaves partially covered with black paper exposed to light

**Observation:** Starch formation occurs only in green parts exposed to light **Conclusion:** Both chlorophyll and light are essential for photosynthesis

### CO<sub>2</sub> Requirement Experiment

**Setup:** Leaf partially enclosed in test tube with KOH-soaked cotton **Result:**

- Exposed portion: Starch positive
- Enclosed portion (CO<sub>2</sub> absent): Starch negative **Conclusion:** CO<sub>2</sub> is essential for photosynthesis

## 11.2 HISTORICAL EXPERIMENTS

### Joseph Priestley's Experiments (1770)

#### The Bell Jar Series

#### Observations:

- Candle extinguishes in closed bell jar
- Mouse suffocates in closed space
- **Crucial discovery:** Plant restores air quality, allowing candle to burn and mouse to survive

**Hypothesis:** *"Plants restore to the air whatever breathing animals and burning candles remove"*

**Significance:** First evidence that plants purify air by releasing oxygen

### Jan Ingenhousz's Contributions (1730-1799)

## Light Dependency Discovery

**Experiment:** Priestley's setup tested in sunlight vs. darkness **Results:**

- **Sunlight:** Oxygen bubble formation around green plant parts
- **Darkness:** No bubble formation

**Conclusions:**

1. Sunlight is essential for the purifying process
2. Only green parts of plants release oxygen
3. Established light-dependent nature of photosynthesis

## Julius von Sachs (1854)

### Glucose Production Evidence

**Discoveries:**

- Provided evidence for glucose production during plant growth
- Identified glucose storage as starch
- Located chlorophyll in special bodies (chloroplasts) within plant cells
- Established that glucose synthesis occurs in green parts

## T.W. Engelmann's Spectrum Experiment (1843-1909)

### Action Spectrum Discovery

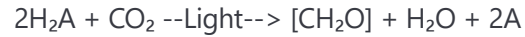
**Method:** Used prism to split light into spectral components, illuminated *Cladophora* in bacterial suspension **Results:** Bacteria accumulated in blue and red light regions **Significance:** First action spectrum of photosynthesis, correlating with chlorophyll absorption

## Cornelius van Niel's Revolutionary Work (1897-1985)

### Universal Photosynthesis Equation

**Discovery:** Photosynthesis is essentially a light-dependent reduction reaction

**General equation:**



**For green plants:**

- $\text{H}_2\text{A} = \text{H}_2\text{O}$  (hydrogen donor)
- $\text{A} = \text{O}_2$  (oxidation product)

**Key insight:**  $\text{O}_2$  evolved comes from  $\text{H}_2\text{O}$ , not  $\text{CO}_2$

### Modern Photosynthesis Equation



**Note:** 12  $\text{H}_2\text{O}$  molecules required because:

- 6  $\text{H}_2\text{O}$  for hydrogen atoms in glucose
- 6  $\text{H}_2\text{O}$  for oxygen evolution
- Net water consumption = 6  $\text{H}_2\text{O}$

## 11.3 LOCATION OF PHOTOSYNTHESIS

### Structural Organization

**Tissue Level**

**Primary sites:** Green leaves and other photosynthetic parts **Cellular level:** Mesophyll cells containing numerous chloroplasts

### **Chloroplast Orientation**

- **Optimal light:** Chloroplasts align parallel to cell walls
- **Intense light:** Chloroplasts orient perpendicular to reduce damage

### **Chloroplast Structure and Function**

#### **Membranous System**

- **Grana:** Stacked thylakoids
- **Stroma lamellae:** Interconnecting unstacked thylakoids
- **Stroma:** Fluid matrix surrounding membrane system

#### **Division of Labor**

#### **Membrane system (Thylakoids):**

- Light energy trapping
- ATP and NADPH synthesis
- Location of light reactions (photochemical reactions)

#### **Stroma:**

- CO<sub>2</sub> fixation
- Sugar synthesis
- Location of dark reactions (carbon reactions/Calvin cycle)

**Important Note:** "Dark reactions" don't occur in darkness - they're light-independent but depend on light reaction products.

## 11.4 PHOTOSYNTHETIC PIGMENTS

### Pigment Diversity and Function

#### Chromatographic Separation

Paper chromatography reveals four main pigments:

1. **Chlorophyll a**: Bright/blue-green (most abundant plant pigment globally)
2. **Chlorophyll b**: Yellow-green
3. **Xanthophylls**: Yellow
4. **Carotenoids**: Yellow to yellow-orange

#### Absorption and Action Spectra

##### Chlorophyll a Absorption

##### Peak absorption:

- Blue region (~430-450 nm)
- Red region (~660-680 nm)
- Minimal green light absorption (explains green appearance)

##### Action Spectrum Analysis

**Correlation:** Maximum photosynthesis occurs in blue and red regions **Conclusion:** Chlorophyll a is the chief photosynthetic pigment

##### Accessory Pigments

##### Function:

- **Light harvesting:** Absorb different wavelengths and transfer energy to chlorophyll a

- **Photoprotection:** Protect chlorophyll a from photo-oxidation
- **Efficiency enhancement:** Utilize broader spectrum of light

**Significance:** Enable photosynthesis across wider range of light conditions

## 11.5 LIGHT REACTIONS

### Photochemical Phase Overview

#### Components:

- Light absorption
- Water splitting
- Oxygen release
- Formation of ATP and NADPH

### Photosystem Organization

#### Light Harvesting Complexes (LHC)

**Structure:** Hundreds of pigment molecules bound to proteins **Function:** Capture light energy and funnel to reaction center

#### Photosystem I (PS I)

**Reaction center:** P700 (chlorophyll a absorbing at 700 nm) **Location:** Both grana and stroma lamellae

#### Photosystem II (PS II)

**Reaction center:** P680 (chlorophyll a absorbing at 680 nm) **Location:** Primarily in grana

**Note:** Named in order of discovery, not functional sequence

## Antenna Complex Function

**Components:** All pigments except one chlorophyll a molecule per photosystem **Purpose:** Maximize light capture efficiency **Mechanism:** Energy transfer to reaction center chlorophyll

## 11.6 ELECTRON TRANSPORT CHAIN

### The Z-Scheme

#### Photosystem II Pathway

1. **Excitation:** P680 absorbs 680 nm light
2. **Electron elevation:** Electrons move to higher energy orbital
3. **Electron transport:** Transfer through cytochrome complex
4. **Energy release:** Downhill movement in redox potential

#### Photosystem I Pathway

1. **Excitation:** P700 absorbs 700 nm light
2. **Further elevation:** Electrons reach even higher potential
3. **NADP+ reduction:** Final electron acceptor becomes NADPH + H+

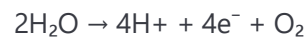
### Z-Scheme Characteristics

**Shape origin:** Characteristic zigzag pattern when carriers plotted on redox potential scale **Electron**

**flow:** PS II → Electron transport → PS I → NADP+ reduction

### 11.6.1 Water Splitting Complex

#### Photolysis Reaction





## Location and Significance

**Position:** Inner side of thylakoid membrane (lumen side) **Function:** Replenish electrons lost from PS

**Product release:**

- H<sup>+</sup> ions: Released into lumen
- O<sub>2</sub>: Diffuses out of chloroplast
- Electrons: Replace those lost from P680

## 11.6.2 Phosphorylation Types

### Non-cyclic Photophosphorylation

**Process:** Both PS I and PS II function in series **Products:** ATP + NADPH + O<sub>2</sub> **Electron flow:** PS II → ETC → PS I → NADP<sup>+</sup> **Significance:** Provides both energy currency and reducing power

### Cyclic Photophosphorylation

**Process:** Only PS I functions, electrons return to PS I **Products:** ATP only (no NADPH or O<sub>2</sub>)

**Location:** Primarily stroma lamellae **Conditions:**

- When PS II is non-functional
- Light wavelengths > 680 nm available
- When additional ATP needed

**Purpose:** Supplements ATP production to meet Calvin cycle requirements

## 11.6.3 Chemiosmotic Hypothesis

### Proton Gradient Development

**Mechanism:** Three processes create H<sup>+</sup> gradient across thylakoid membrane:

1. **Water splitting:** H<sup>+</sup> released into lumen
2. **Proton pumping:** Electron transport moves H<sup>+</sup> from stroma to lumen
3. **NADP<sup>+</sup> reduction:** H<sup>+</sup> consumed from stroma

### **ATP Synthesis Mechanism**

#### **ATP synthase structure:**

- **CF<sub>0</sub>:** Transmembrane channel for proton passage
- **CF<sub>1</sub>:** Catalytic unit protruding into stroma

#### **Process:**

1. Proton gradient creates electrochemical potential
2. H<sup>+</sup> flows through CF<sub>0</sub> down concentration gradient
3. Energy released causes CF<sub>1</sub> conformational change
4. ATP synthesis from ADP + Pi

### **Requirements for Chemiosmosis**

1. **Membrane:** Thylakoid membrane
2. **Proton pump:** Electron transport chain
3. **Proton gradient:** Higher [H<sup>+</sup>] in lumen than stroma
4. **ATP synthase:** CF<sub>0</sub>-CF<sub>1</sub> complex

## **11.7 CALVIN CYCLE (DARK REACTIONS)**

### **Products of Light Reactions**

**Energy currency:** ATP **Reducing power:** NADPH **By-product:** O<sub>2</sub> (diffuses out)

## Calvin's Radiotracer Experiments

**Method:** Used radioactive  $^{14}\text{C}$  to trace  $\text{CO}_2$  incorporation **Discovery:** First stable product is 3-phosphoglyceric acid (PGA) **Significance:** Established 3-carbon pathway ( $\text{C}_3$  pathway)

### 11.7.1 $\text{CO}_2$ Acceptor Identification

#### The 5-Carbon Mystery

**Question:** What molecule accepts  $\text{CO}_2$  to form 3-carbon PGA? **Expected:** 2-carbon compound

**Reality:** Ribulose 1,5-bisphosphate (RuBP) - a 5-carbon sugar

**Reaction:**



### 11.7.2 Calvin Cycle Stages

#### Stage 1: Carboxylation

**Process:**  $\text{CO}_2$  fixation into stable organic intermediate **Reaction:**  $\text{RuBP} + \text{CO}_2 \rightarrow 2 \text{PGA}$  **Enzyme:** RuBP carboxylase-oxygenase (RuBisCO) **Significance:** Most crucial step; RuBisCO is world's most abundant enzyme

#### Stage 2: Reduction

**Process:** Conversion of PGA to triose phosphate **Requirements per  $\text{CO}_2$ :**

- 2 ATP (for phosphorylation)
- 2 NADPH (for reduction) **Product:** Glyceraldehyde 3-phosphate (G3P)

#### Stage 3: Regeneration

**Process:** Regeneration of RuBP from triose phosphates **Requirement:** 1 ATP per RuBP regenerated

**Significance:** Maintains cycle continuity

## Calvin Cycle Stoichiometry

**Per CO<sub>2</sub> molecule:**

- **Input:** 3 ATP + 2 NADPH
- **Output:** 1/6 glucose + 3 ADP + 2 NADP+

**For one glucose molecule (6 CO<sub>2</sub>):**

**Input:**

- 6 CO<sub>2</sub>
- 18 ATP
- 12 NADPH

**Output:**

- 1 C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>
- 18 ADP + 18 Pi
- 12 NADP+

**ATP:NADPH ratio requirement:** 3:2 **Explanation for cyclic phosphorylation:** Compensates for higher ATP requirement

## 11.8 C<sub>4</sub> PATHWAY

### C<sub>4</sub> Plant Characteristics

### Environmental Adaptations

- **Climate:** Dry tropical regions
- **Temperature tolerance:** Higher than C<sub>3</sub> plants
- **Light response:** Better performance under high light intensity
- **Productivity:** Greater biomass production
- **Photorespiration:** Absent

### 11.8.1 Kranz Anatomy

#### Structural Features

##### Bundle sheath cells:

- Large cells surrounding vascular bundles
- Multiple layers around vascular tissue
- Numerous chloroplasts
- Thick, impermeable walls
- No intercellular spaces

**Kranz meaning:** "Wreath" - describes cell arrangement pattern

#### Microscopic Identification

**Method:** Cut vertical sections of suspected C<sub>4</sub> plants **Observation:** Look for prominent bundle sheath cells **Examples:** Maize, sorghum, sugarcane

### 11.8.2 Hatch-Slack Pathway

#### Spatial Separation of Reactions

##### Mesophyll cells:

- **Primary acceptor:** Phosphoenolpyruvate (PEP) - 3-carbon

- **Enzyme:** PEP carboxylase (PEPcase)
- **Product:** Oxaloacetic acid (OAA) - 4-carbon
- **Absence:** No RuBisCO enzyme

#### **Bundle sheath cells:**

- **Process:** Calvin cycle operates here
- **Enzyme:** RuBisCO present, PEPcase absent
- **Function:** Sugar synthesis from concentrated CO<sub>2</sub>

#### **C<sub>4</sub> Cycle Steps**

1. **CO<sub>2</sub> fixation:** PEP + CO<sub>2</sub> → OAA (in mesophyll)
2. **C<sub>4</sub> acid transport:** OAA → Malic acid/Aspartic acid → Bundle sheath
3. **Decarboxylation:** C<sub>4</sub> acid → CO<sub>2</sub> + 3-carbon compound (in bundle sheath)
4. **Regeneration:** 3-carbon compound → PEP (in mesophyll)

#### **C<sub>4</sub> Advantage Mechanism**

**CO<sub>2</sub> concentration:** C<sub>4</sub> acid breakdown concentrates CO<sub>2</sub> around RuBisCO **Result:** Favors carboxylase activity over oxygenase activity **Benefit:** Eliminates photorespiration, increases efficiency

## **11.9 PHOTORESPIRATION**

### **RuBisCO Dual Function**

#### **Competitive Binding**

**Carboxylase activity:** RuBP + CO<sub>2</sub> → 2 PGA (productive) **Oxygenase activity:** RuBP + O<sub>2</sub> → PGA + Phosphoglycolate (wasteful)

## Binding Affinity

**CO<sub>2</sub> preference:** Higher affinity when CO<sub>2</sub>:O<sub>2</sub> ratio favors CO<sub>2</sub> **Competition:** Relative concentrations determine which substrate binds

## Photorespiration Process

### Oxygenation Reaction



### Characteristics of Photorespiration

- **No sugar synthesis**
- **No ATP production**
- **ATP consumption** (wasteful)
- **CO<sub>2</sub> release** (counterproductive)
- **Biological function:** Unknown

## C<sub>3</sub> vs C<sub>4</sub> Photorespiration

### C<sub>3</sub> Plants

**Occurrence:** Significant photorespiration **Reason:** No CO<sub>2</sub> concentrating mechanism **Impact:** Reduced photosynthetic efficiency

### C<sub>4</sub> Plants

**Occurrence:** Negligible photorespiration **Reason:** CO<sub>2</sub> concentrating mechanism via C<sub>4</sub> acid breakdown **Result:** Higher productivity and yield

## 11.10 FACTORS AFFECTING PHOTOSYNTHESIS

## Factor Categories

### Internal (Plant) Factors

- Number, size, age, orientation of leaves
- Mesophyll cell organization
- Chloroplast number and arrangement
- Internal CO<sub>2</sub> concentration
- Chlorophyll content
- Genetic predisposition

### External (Environmental) Factors

- Light (quality, intensity, duration)
- Temperature
- CO<sub>2</sub> concentration
- Water availability

## Blackman's Law of Limiting Factors (1905)

### Principle Statement

*"If a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value"*

### Practical Application

**Scenario:** Despite optimal light and CO<sub>2</sub>, low temperature prevents photosynthesis **Implication:**

Rate determined by most limiting factor at any given time

### 11.10.1 Light as a Limiting Factor



## Light Intensity Relationship

**Low intensities:** Linear relationship between light and CO<sub>2</sub> fixation **High intensities:** Rate plateaus as other factors become limiting **Light saturation:** Occurs at ~10% of full sunlight

## Light Quality Effects

**Optimal wavelengths:** Blue (430-450 nm) and red (660-680 nm) **Photosynthetic efficiency:** Matches chlorophyll absorption spectrum

## Light Duration (Photoperiod)

**Effect:** Influences overall daily photosynthetic output **Seasonal variation:** Affects annual productivity

## Excessive Light

**Consequence:** Chlorophyll breakdown (photoinhibition) **Result:** Decreased photosynthetic rate  
**Plant response:** Various photoprotective mechanisms

## 11.10.2 Carbon Dioxide Concentration

### Atmospheric Limitation

**Current levels:** 0.03-0.04% (300-400 ppm) **Optimal range:** Up to 0.05% can increase rates **Toxic levels:** Beyond 0.05% causes long-term damage

### C<sub>3</sub> vs C<sub>4</sub> Response Patterns

#### C<sub>3</sub> plants:

- Respond to CO<sub>2</sub> increase beyond 450 μL L<sup>-1</sup>
- Current atmospheric levels are limiting
- Used in greenhouse cultivation (tomatoes, bell peppers)

### **C<sub>4</sub> plants:**

- Saturate at ~360  $\mu\text{L L}^{-1}$
- Less responsive to CO<sub>2</sub> enrichment
- Already adapted to low CO<sub>2</sub> conditions

## **11.10.3 Temperature Effects**

### **Reaction Sensitivity**

**Dark reactions:** Highly temperature sensitive (enzymatic) **Light reactions:** Less temperature sensitive

### **Optimal Temperature Ranges**

**C<sub>3</sub> plants:** 20-25°C optimum **C<sub>4</sub> plants:** 30-40°C optimum

### **Habitat Adaptation**

**Tropical plants:** Higher temperature optimum **Temperate plants:** Lower temperature optimum

**Adaptation significance:** Reflects evolutionary climate history

## **11.10.4 Water Stress Effects**

### **Direct vs Indirect Effects**

**Direct effect:** Water is a reactant in light reactions (minimal impact) **Indirect effects:** More significant impact on plant physiology

### **Physiological Responses**

**Stomatal closure:** Reduces CO<sub>2</sub> availability **Leaf wilting:** Decreases photosynthetic surface area

**Metabolic stress:** Reduces overall cellular activity

# COMPARATIVE ANALYSIS: C<sub>3</sub> vs C<sub>4</sub> PLANTS

## Structural Differences

Feature	C <sub>3</sub> Plants	C <sub>4</sub> Plants
Leaf anatomy	No Kranz anatomy	Kranz anatomy present
Bundle sheath	Thin-walled, few chloroplasts	Thick-walled, many chloroplasts
Cell types for CO <sub>2</sub> fixation	One (mesophyll)	Two (mesophyll + bundle sheath)

## Biochemical Differences

Aspect	C <sub>3</sub> Plants	C <sub>4</sub> Plants
Primary CO <sub>2</sub> acceptor	RuBP (5-carbon)	PEP (3-carbon)
First stable product	PGA (3-carbon)	OAA (4-carbon)
Calvin cycle location	Mesophyll cells	Bundle sheath cells
Initial fixation enzyme	RuBisCO	PEPcase
RuBisCO presence	Yes (mesophyll)	Yes (bundle sheath only)
PEPcase presence	No	Yes (mesophyll)

## Physiological Differences

Characteristic	C <sub>3</sub> Plants	C <sub>4</sub> Plants
Photorespiration	High	Negligible
CO <sub>2</sub> fixation rate (high light)	Lower	Higher
Temperature optimum	20-25°C	30-40°C
Water use efficiency	Lower	Higher
Light saturation point	Lower	Higher

## Ecological and Economic Significance

### C<sub>3</sub> Plants

**Examples:** Rice, wheat, barley, cotton **Habitat:** Temperate regions, moderate temperatures

**Advantage:** Efficient under moderate conditions **Limitation:** Photorespiration reduces efficiency

### C<sub>4</sub> Plants

**Examples:** Maize, sugarcane, sorghum, amaranth **Habitat:** Tropical regions, high temperatures

**Advantages:** Higher productivity, drought tolerance **Applications:** Important crop plants in tropical agriculture

## EVOLUTIONARY AND ECOLOGICAL SIGNIFICANCE

### Evolutionary Perspectives

#### C<sub>3</sub> Pathway

- **Origin:** Ancient, evolved when atmospheric CO<sub>2</sub> was higher
- **Distribution:** Widespread, majority of plant species
- **Adaptation:** Suited for ancestral atmospheric conditions

#### C<sub>4</sub> Pathway

- **Origin:** More recent evolutionary adaptation
- **Selection pressure:** Response to declining atmospheric CO<sub>2</sub>
- **Convergent evolution:** Evolved independently multiple times
- **Specialization:** Adaptation to specific environmental conditions

### Ecological Roles

#### Primary Productivity

**Global impact:** Photosynthesis drives virtually all ecosystems **Energy flow:** Foundation of all food webs **Biomass production:** Determines ecosystem carrying capacity

### Environmental Services

**Oxygen production:** Maintains atmospheric O<sub>2</sub> levels **Carbon sequestration:** Removes CO<sub>2</sub> from atmosphere **Climate regulation:** Influences local and global climate patterns

## EXAM-ORIENTED KEY POINTS

### High-Yield Topics for NEET

#### Historical Experiments

1. **Priestley's bell jar:** Plant-animal interaction
2. **Ingenhousz light dependency:** Sunlight requirement
3. **Van Niel's equation:** Universal photosynthesis concept
4. **Calvin's <sup>14</sup>C experiment:** CO<sub>2</sub> fixation pathway discovery

#### Photosynthesis Equation



#### Key points:

- O<sub>2</sub> comes from water, not CO<sub>2</sub>
- 12 H<sub>2</sub>O required (6 net consumption)
- Light energy converted to chemical energy

#### Light Reactions

1. **Photosystem organization:** PS I (P700) and PS II (P680)
2. **Electron transport:** Z-scheme pathway
3. **Water splitting:** Source of replacement electrons
4. **ATP synthesis:** Chemiosmotic mechanism
5. **Products:** ATP, NADPH, O<sub>2</sub>

### Calvin Cycle

1. **Location:** Stroma of chloroplasts
2. **Phases:** Carboxylation, Reduction, Regeneration
3. **Key enzyme:** RuBisCO (most abundant enzyme)
4. **Stoichiometry:** 3 ATP + 2 NADPH per CO<sub>2</sub> fixed
5. **Product:** Glucose (6 turns of cycle)

### C<sub>4</sub> Pathway

1. **Anatomy:** Kranz structure with bundle sheath cells
2. **Spatial separation:** Different cell types for different reactions
3. **Advantage:** Eliminates photorespiration
4. **Efficiency:** Higher productivity under stress conditions

### Limiting Factors

1. **Blackman's law:** Rate limited by most deficient factor
2. **Light:** Rarely limiting except in shade
3. **CO<sub>2</sub>:** Major limiting factor for C<sub>3</sub> plants
4. **Temperature:** Affects enzymatic reactions
5. **Water:** Indirect effects through stomatal closure

## **Common NEET Question Patterns**

### **Process-Based Questions**

- Explain light reaction mechanism
- Describe Calvin cycle steps
- Compare C<sub>3</sub> and C<sub>4</sub> pathways
- Analyze photorespiration effects

### **Quantitative Problems**

- Calculate ATP and NADPH requirements
- Determine glucose production from CO<sub>2</sub> input
- Analyze limiting factor scenarios

### **Comparative Analysis**

- C<sub>3</sub> vs C<sub>4</sub> plant characteristics
- Cyclic vs non-cyclic phosphorylation
- Light reaction vs dark reaction features

### **Application Questions**

- Greenhouse CO<sub>2</sub> enrichment benefits
- Crop productivity optimization
- Environmental factor manipulation

# Memory Aids and Mnemonics

## Light Reaction Products

\*\*\***A**TP **N**ADPH **O**xygen"

- **A**TP (energy currency)
- **N**ADPH (reducing power)
- **O**xygen (by-product)

## Calvin Cycle Stages

\*\*\***C**an **R**eally **R**eproduce **G**lucose"

- **C**arboxylation (CO<sub>2</sub> fixation)
- **R**eduction (ATP + NADPH usage)
- **R**egeneration (RuBP renewal)
- **G**lucose (final product)

## Photosystem Wavelengths

\*\*\***S**even **H**undred, **S**ix **E**ighty"

- **S**even hundred (700 nm - PS I)
- **S**ix eighty (680 nm - PS II)

## C<sub>4</sub> Plant Examples

\*\*\***M**aize **S**ugarcane **S**orghum **A**maranth"

- **M**aize (corn)
- **S**ugarcane



- Sorghum
- Amaranth

### Limiting Factors

\*\*\*"Light CO<sub>2</sub> Temperature Water"

- Light intensity/quality
- Carbon dioxide concentration
- Temperature
- Water availability

### Practice Questions for NEET

#### Multiple Choice Questions

1. **The oxygen evolved during photosynthesis comes from:** a) CO<sub>2</sub> only b) H<sub>2</sub>O only c) Both CO<sub>2</sub> and H<sub>2</sub>O d) Chlorophyll breakdown
2. **In C<sub>4</sub> plants, the Calvin cycle occurs in:** a) Mesophyll cells b) Bundle sheath cells c) Guard cells d) Epidermal cells
3. **The first stable product of Calvin cycle is:** a) RuBP b) OAA c) PGA d) Glucose
4. **Which of the following is the most abundant enzyme in the world:** a) PEPcase b) RuBisCO c) ATP synthase d) Cytochrome oxidase
5. **Photorespiration is absent in C<sub>4</sub> plants because:** a) They lack RuBisCO b) They have PEPcase c) CO<sub>2</sub> concentration is high around RuBisCO d) They lack chlorophyll

#### Short Answer Questions

1. **Explain the significance of the light and dark reactions in photosynthesis.**
2. **Why is RuBisCO called a bifunctional enzyme?**

3. How does the C<sub>4</sub> pathway eliminate photorespiration?
4. Describe the chemiosmotic mechanism of ATP synthesis in chloroplasts.
5. Explain why C<sub>4</sub> plants are more efficient than C<sub>3</sub> plants in tropical conditions.

### Long Answer Questions

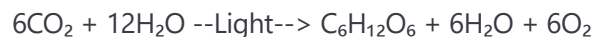
1. Describe the complete Calvin cycle with proper equations and energy requirements.
2. Explain the structure and function of photosystems in light reactions.
3. Compare and contrast C<sub>3</sub> and C<sub>4</sub> pathways of photosynthesis.
4. Analyze the various factors affecting the rate of photosynthesis.

### Numerical Problems

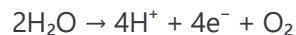
1. Calculate the number of ATP and NADPH molecules required to produce 5 molecules of glucose through Calvin cycle.
2. If 18 CO<sub>2</sub> molecules are fixed through Calvin cycle, how many RuBP molecules will be regenerated?
3. Determine the net gain of glucose molecules when 72 ATP and 48 NADPH are available for Calvin cycle.

### Important Equations and Formulas

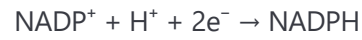
#### Overall Photosynthesis



#### Water Splitting



## NADP<sup>+</sup> Reduction



## Calvin Cycle Carboxylation



## C<sub>4</sub> Initial Fixation



## Photorespiration



## Current Research Applications

### Biotechnology Applications

**Genetic engineering:** Improving RuBisCO efficiency **C<sub>4</sub> rice:** Introducing C<sub>4</sub> pathway into rice

**Artificial photosynthesis:** Solar energy conversion systems

### Environmental Solutions

**Carbon capture:** Enhanced CO<sub>2</sub> fixation **Biofuels:** Photosynthetic organism cultivation **Climate change mitigation:** Increased carbon sequestration

### Agricultural Improvements

**Crop enhancement:** Higher photosynthetic efficiency **Stress tolerance:** Better performance under

adverse conditions **Yield optimization:** Maximizing productivity through understanding limiting factors

**EXAM SPRINT** - Master photosynthesis through systematic study of historical discoveries, reaction mechanisms, pathway comparisons, and limiting factor analysis. Focus on quantitative relationships, comparative features, and practical applications for comprehensive NEET preparation.

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*Source: NCERT Biology Class 11, Chapter 11 - Complete coverage for NEET and Board examination success*