KSQUARE CAREER INSTITUTE

PHOTOSYNTHESIS IN HIGHER PLANTS

Class 11 Biology • Lecture 01: Introduction, Early Experiments & Site • NEET Notes

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Lecture at a Glance

1. Introduction — meaning, equation, conditions, features & importance of photosynthesis
2. Melvin Calvin (NCERT box)
3. Early experiments — variegated leaf, half-leaf, Priestley, Ingenhousz, Sachs, Engelmann, van Niel, Ruben & Kamen
4. Site of photosynthesis — leaf section, chloroplast structure, division of labour
5. Added: pigments, light reaction (Z-scheme), chemiosmosis, Calvin cycle, C_4 pathway, photorespiration, factors — overview & practice MCQs

INTRODUCTION

- All animals, including humans, depend on plants for **food**.
- **Photosynthesis** is a **physico-chemical process** by which green plants use **light (solar) energy** to synthesise **organic compounds**.
- Ultimately all living forms depend on **sunlight** for energy — photosynthesis by plants is the **basis of life on earth**.

Overall equation

$$6CO_2 + 12H_2O \xrightarrow{\text{light, chlorophyll}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Importance	Conditions required	Features
Primary source of all food on earth	**Sunlight**	**Physico-chemical** process
Releases oxygen into the atmosphere	**Raw materials** — CO_2 and H_2O	**Endothermic** (endergonic)
	Chlorophyll	**Anabolic** (biosynthetic)
		Oxidation–reduction: water is split (oxidised), CO_2 is reduced

Melvin Calvin (NCERT box)

Born in Minnesota (1911); Ph.D. in Chemistry; Professor of Chemistry at the University of California, Berkeley.

With **J.A. Bassham**, used radioactive **^{14}C**-labelled CO_2 to study how green plants form sugars from CO_2, water and minerals.

Mapped the pathway of **carbon assimilation** — **Nobel Prize in 1961**. His principles are used in research on renewable energy and solar energy.

EARLY EXPERIMENTS RELATED TO PHOTOSYNTHESIS

1. Variegated Leaf Experiment — need for chlorophyll

- A **variegated leaf** (or a leaf partially covered with black paper) exposed to light is tested for **starch** (iodine test).
- Green areas turn **blue-black**; yellow (non-green) areas stay colourless ⇒ photosynthesis occurs **only in green parts in the presence of light**.

2. Half-Leaf Experiment — need for CO_2

- Part of a leaf is enclosed in a test tube containing **KOH-soaked cotton** (KOH **absorbs CO_2**); the other half is exposed to air; the set-up is kept in light.
- The exposed part tests **positive for starch**, the enclosed part **negative** ⇒ **CO_2 is required** for photosynthesis.

Scientists & Their Contributions

Scientist	Experiment	Conclusion
Joseph Priestley (1770)	Candle in a closed bell jar is extinguished; a mouse suffocates. With a **mint plant** inside, the candle keeps burning and the mouse lives	Plants **restore to the air** what burning candles and breathing animals remove; discovered **oxygen (1774)**
Jan Ingenhousz (1730–1799)	Repeated Priestley's set-up in **dark and in sunlight**; with an **aquatic plant** (class note: *Hydrilla*) saw small **bubbles** around green parts in bright light, none in the dark	**Sunlight is essential**; bubbles are **O_2** — only **green parts** release oxygen
Julius von Sachs (1854)	Studied green plants	**Glucose** is produced when plants grow and is stored as **starch**; chlorophyll is located in special bodies (**chloroplasts**); glucose is made in green parts
T.W. Engelmann (1843–1909)	Split light with a **prism**, illuminated the green alga **_Cladophora_** in a suspension of **aerobic bacteria**	Bacteria gathered in **blue and red** light (sites of O_2 evolution) — first **action spectrum**, resembling the absorption spectra of chlorophyll a and b

Scientist	Experiment	Conclusion
Cornelius van Niel (1897–1985)	Studied **purple and green sulphur bacteria** (use **H_2S** as hydrogen donor, release sulphur/sulphate, no O_2)	Photosynthesis is a **light-dependent** reaction in which hydrogen from an oxidisable compound reduces CO_2; in plants **H_2O is the H-donor ⇒ O_2 comes from water, not CO_2**
Ruben, Kamen et al.	Used the heavy, **stable (non-radioactive) isotope ^{18}O**	Proved that O_2 evolved in the light reaction **comes from H_2O**

Equations

Empirical equation (mid-19th century): $CO_2 + H_2O \xrightarrow{\text{light}} [CH_2O] + O_2$

van Niel's general equation: $2H_2A + CO_2 \xrightarrow{\text{light}} 2A + CH_2O + H_2O$

Correct overall equation: $6CO_2 + 12H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6H_2O + 6O_2$

NEET Point / PYQ Alert

By the middle of the 19th century it was known that plants use **light energy** to make **carbohydrates from CO_2 and H_2O**.

$[CH_2O]$ represents a carbohydrate unit (e.g. glucose).

Frequent NEET match: Priestley — O_2; Ingenhousz — sunlight & green parts; Sachs — starch/chloroplasts; Engelmann — action spectrum; van Niel — O_2 from water.

SITE OF PHOTOSYNTHESIS

- Occurs in green **leaves** and also in **other green parts** of the plant.
- Leaf section: upper epidermis → **palisade mesophyll** → **spongy mesophyll** → lower epidermis with **stomata**; mesophyll cells have many **chloroplasts**.
- Chloroplasts **align along the walls** of mesophyll cells to receive the **optimum** amount of incident light.

Chloroplast

Part	Feature
Size & shape	Lens-shaped, freely moving; ~5–10 µm long, 2–3 µm thick (class notes)
Envelope	**Double membrane** — outer membrane semi-porous, permeable to small ions
Inner membrane	Borders the stroma
Stroma (matrix)	Aqueous, **protein-rich, alkaline** fluid; contains **DNA, ribosomes (70S)**, starch grains, plastoglobuli and the thylakoid system
Grana	Stacks of **thylakoids**
Stroma lamellae	Connect thylakoids of different grana

▸ Division of Labour inside the Chloroplast

Membrane system (grana, stroma lamellae)	Stroma
Traps **light energy** and synthesises **ATP and NADPH**	Enzymatic reactions synthesise **sugar**, which forms **starch**
Directly light-driven ⇒ **light reactions (photochemical reactions)**	Not directly light-driven, but depend on products of light reaction (ATP, NADPH) ⇒ **dark reactions (carbon reactions)**

NEET Point / PYQ Alert

"Dark reaction" does **not** mean it occurs in darkness or is light-independent — it simply does not need light directly.

BEYOND THE LECTURE — REST OF THE CHAPTER (ADDITIONAL TOPIC)

Topic	Key facts
Pigments	Paper chromatography: **chlorophyll a** (bright/blue-green, chief pigment, reaction centre), **chlorophyll b** (yellow-green), **xanthophylls** (yellow), **carotenoids** (yellow–orange); accessory pigments widen the absorption range and protect chlorophyll a from photo-oxidation; max absorption in **blue and red**
Light reaction	Light absorption, **photolysis of water** (O_2 released, linked with PS II), ATP & NADPH formation; **LHC** (antenna); **PS I (P700)** and **PS II (P680)**
Electron transport (Z-scheme)	PS II → plastoquinone → cytochrome b_6f → plastocyanin → PS I → ferredoxin → $NADP^+$ → **NADPH**; non-cyclic gives ATP + NADPH; **cyclic** (PS I only, stroma lamellae) gives only ATP
Chemiosmosis	Proton gradient across thylakoid membrane (H^+ accumulate in **lumen**); **ATP synthase (CF_o–CF_1)** makes ATP as H^+ flows to stroma
Calvin cycle (C_3)	In stroma; **RuBisCO** fixes CO_2 with **RuBP (5C)** → **2 PGA (3C)** — first stable product; reduction (ATP, NADPH) and regeneration of RuBP. **For 1 glucose: 6 turns, 18 ATP, 12 NADPH**
C_4 pathway (Hatch–Slack)	Maize, sugarcane, sorghum; **Kranz anatomy**; primary acceptor **PEP (3C)**, enzyme **PEP carboxylase** in mesophyll → **OAA (4C)**; Calvin cycle in **bundle sheath**; no photorespiration, high productivity, tolerate high temperature
Photorespiration	RuBisCO binds O_2 (oxygenase) → wasteful; no ATP/NADPH formed; occurs in chloroplast, peroxisome & mitochondria; absent in C_4 plants
Factors	Light, CO_2 (major limiting factor; C_3 saturate at ~450 µL/L), temperature, water; **Blackman's law of limiting factors**

PRACTICE MCQS

Q1. The half-leaf experiment proves that photosynthesis requires

(a) Chlorophyll

(b) Light
(c) CO_2
(d) Water

Answer: (c) — KOH absorbs CO_2 in the enclosed half.

Q2. Who discovered oxygen in 1774?

(a) Jan Ingenhousz
(b) Joseph Priestley
(c) Julius von Sachs
(d) T.W. Engelmann

Answer: (b)

Q3. Who showed that only the green parts of plants release oxygen in sunlight?

(a) Priestley
(b) Ingenhousz
(c) Sachs
(d) van Niel

Answer: (b)

Q4. The first action spectrum of photosynthesis was described by

(a) Engelmann
(b) Calvin
(c) Sachs
(d) Ruben

Answer: (a) — Using Cladophora and aerobic bacteria.

Q5. The O_2 evolved during photosynthesis comes from water. This was first inferred by

(a) Priestley
(b) van Niel
(c) Calvin
(d) Blackman

Answer: (b) — Later proved with ^{18}O by Ruben and Kamen.

Q6. Which isotope was used to prove that O_2 comes from H_2O?

(a) ^{14}C
(b) ^{32}P
(c) ^{18}O
(d) ^{3}H

Answer: (c)

Q7. Light reactions occur in the

(a) Stroma
(b) Thylakoid/grana membranes
(c) Cytoplasm
(d) Mitochondria

Answer: (b)

Q8. Julius von Sachs showed that

(a) O_2 comes from water
(b) glucose is stored as starch and chlorophyll is in chloroplasts
(c) plants purify air

(d) CO_2 is essential

Answer: (b)

Q9. Melvin Calvin received the Nobel Prize in

(a) 1945
(b) 1961
(c) 1954
(d) 1970

Answer: (b)

Q10. Photosynthesis is a/an

(a) exothermic catabolic process
(b) endothermic anabolic oxidation–reduction process
(c) exothermic anabolic process
(d) endothermic catabolic process

Answer: (b)

QUICK REVISION

- $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$ (light, chlorophyll); physico-chemical, endothermic, anabolic, redox.
- Variegated leaf — chlorophyll needed; half-leaf (KOH) — CO_2 needed.
- Priestley (1770, O_2 1774, mint & mouse), Ingenhousz (sunlight, green parts, aquatic plant), Sachs (1854, starch & chloroplast), Engelmann (Cladophora, action spectrum, blue & red), van Niel (H_2S bacteria; O_2 from H_2O), Ruben & Kamen (^{18}O).
- Calvin & Bassham — ^{14}C, carbon pathway, Nobel 1961.
- Chloroplast: double membrane, stroma (DNA, 70S ribosomes, enzymes), grana (thylakoids), stroma lamellae.
- Membranes → light reactions (ATP, NADPH); stroma → carbon (dark) reactions (sugar/starch).