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CUET · BIOLOGY · CLASS XI · CODE 304

# Photosynthesis in Higher Plants

CUET unit: Plant Physiology → Photosynthesis in Higher Plants

By **UniDrill** · NCERT-grounded study material

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# 📌 Snapshot

- Photosynthesis is the physico-chemical process by which green (autotrophic) plants use light energy to synthesise organic compounds from CO2 and water, releasing O2 — the primary basis of food and atmospheric oxygen on earth.
- A series of historical experiments (Priestley, Ingenhousz, von Sachs, Engelmann, van Niel) established the role of air, light, chlorophyll and water in photosynthesis.
- It dissects the site (chloroplast — grana, stroma lamellae, stroma), the pigments (chlorophyll a, b, xanthophylls, carotenoids), the light reactions (PS I, PS II, Z-scheme, water splitting, chemiosmotic ATP synthesis) and the dark/biosynthetic reactions (Calvin C3 cycle, C4 Hatch-Slack pathway, photorespiration).
- Factors affecting photosynthesis (light, CO2, temperature, water) are framed by Blackman's Law of Limiting Factors — high-yield CUET territory.

# 📖 Detailed Notes

## 2.1 Core concepts

- Green plants are autotrophs that synthesise food via photosynthesis; all heterotrophs ultimately depend on them. Photosynthesis is important because it is the primary source of food and releases O2 into the atmosphere (NCERT §11.1, p. 133).
- Classroom experiments (variegated leaf / partially-covered leaf; KOH-tube experiment) establish that chlorophyll, light and CO2 are required for starch formation in green parts of the leaf (NCERT §11.1, pp. 133–134).
- Joseph Priestley (1770) showed with bell-jar experiments using a candle and a mouse that plants "restore to the air whatever breathing animals and burning candles remove" — establishing the role of air (NCERT §11.2, p. 134).
- Jan Ingenhousz (using a similar setup in dark vs sunlight, and an aquatic plant releasing bubbles in bright light) showed that sunlight is essential and only the green parts of plants release oxygen (NCERT §11.2, p. 134).
- Julius von Sachs (1854) provided evidence that glucose is produced when plants grow, that it is usually stored as starch, and that the green chlorophyll is located in special bodies (later called chloroplasts) within plant cells (NCERT §11.2, p. 135).

- T. W. Engelmann split light with a prism, illuminated Cladophora in a suspension of aerobic bacteria, and described the first action spectrum of photosynthesis — bacteria (and hence O2 evolution) accumulated in the blue and red regions, matching the absorption spectra of chlorophyll a and b (NCERT §11.2, p. 135).
- Cornelis van Niel, from studies of purple and green sulphur bacteria, demonstrated photosynthesis as a light-dependent reaction in which hydrogen from an oxidisable compound (H2O in green plants, H2S in sulphur bacteria) reduces CO2 to carbohydrate; he inferred that the O2 released by green plants comes from water, later proved by radioisotope techniques (NCERT §11.2, p. 135).
- Photosynthesis occurs in green leaves and other green parts; mesophyll cells contain large numbers of chloroplasts aligned along cell walls to capture optimum incident light (NCERT §11.3, p. 136).
- Chloroplasts have a membranous system of grana and stroma lamellae plus the matrix stroma. Membrane system traps light energy and synthesises ATP and NADPH (light reactions / photochemical); stroma carries out enzymatic synthesis of sugars / starch (dark reactions / carbon reactions) (NCERT §11.3, p. 136).
- Paper chromatography of leaf pigments reveals four pigments: chlorophyll a (bright/blue-green), chlorophyll b (yellow-green), xanthophylls (yellow), carotenoids (yellow to yellow-orange) (NCERT §11.4, p. 137).
- Chlorophyll a is the chief pigment, with maximum absorption in the blue and red regions — matching the action spectrum of photosynthesis. Accessory pigments (chl b, xanthophylls, carotenoids) widen the usable wavelength range and protect chlorophyll a from photo-oxidation (NCERT §11.4, pp. 137–138).
- Pigments are organised into two light-harvesting complexes (LHC) — Photosystem I (PS I) and Photosystem II (PS II) — named in order of discovery, not function. Each LHC has hundreds of pigment molecules acting as antennae and a single chlorophyll a reaction-centre molecule: P700 in PS I, P680 in PS II (NCERT §11.5, p. 138).
- In the Z-scheme: PS II's P680 absorbs 680 nm red light, electrons are excited, picked up by an electron acceptor, passed downhill through cytochromes to PS I; P700 in PS I absorbs 700 nm light, electrons are re-excited and finally reduce NADP+ to NADPH + H+ (NCERT §11.6, p. 139).
- Water splitting (associated with PS II, on the inner side of the thylakoid) replenishes PS II's electrons: 2H2O → 4H+ + O2 + 4e−. This is the source of O2 in photosynthesis (NCERT §11.6.1, p. 139).
- Non-cyclic photophosphorylation: both PS II and PS I operate in series via the Z-scheme; produces ATP and NADPH + H+. Cyclic photophosphorylation: only PS I is functional, the electron is cycled back to PS I via the ETS; produces only ATP (no NADPH); occurs in stroma lamellae (which lack PS II and NADP reductase) and at wavelengths beyond 680 nm (NCERT §11.6.2, p. 140).
- Chemiosmotic hypothesis explains ATP synthesis: a proton gradient develops across the thylakoid membrane because (a) water splitting releases protons into the lumen,

(b) electron carriers shuttle protons from stroma to lumen, and (c) NADP+ reduction in stroma consumes stromal protons. Protons accumulate in lumen (high H+, low pH); breakdown of the gradient through ATP synthase (CF0 transmembrane channel + CF1 catalytic head facing stroma) drives ATP synthesis (NCERT §11.6.3, pp. 140–142).

- ATP and NADPH from light reaction power the biosynthetic (dark) reactions in stroma, fixing CO2 to sugars. Melvin Calvin, using radioactive 14C in algal photosynthesis, showed that the first stable CO2-fixation product is a 3-carbon acid, 3-phosphoglyceric acid (PGA); this pathway is the Calvin / C3 cycle (NCERT §11.7, p. 142).
- The primary CO2 acceptor in the Calvin cycle is the 5-carbon ketose sugar ribulose-1,5-bisphosphate (RuBP), not a 2-carbon compound as initially expected (NCERT §11.7.1, p. 143).
- Calvin cycle has three stages: (1) Carboxylation — CO2 + RuBP → 2 × 3-PGA, catalysed by RuBP carboxylase-oxygenase (RuBisCO); (2) Reduction — 2 ATP and 2 NADPH used per CO2 fixed to form triose phosphate; (3) Regeneration — RuBP is regenerated using 1 ATP. For one glucose: 6 turns of the cycle, 6 CO2, 18 ATP and 12 NADPH are required (NCERT §11.7.2, pp. 143–145).
- C4 / Hatch-Slack pathway: in plants of dry tropical regions (e.g., maize, sorghum), the first CO2-fixation product is the 4-carbon oxaloacetic acid (OAA). The primary acceptor is the 3-carbon phosphoenolpyruvate (PEP); the enzyme is PEP carboxylase (PEPcase), present in mesophyll cells which lack RuBisCO (NCERT §11.8, pp. 145–146).
- C4 leaves show Kranz ('wreath') anatomy — large bundle-sheath cells around vascular bundles, packed with chloroplasts, having thick walls impervious to gases and no intercellular spaces. OAA → malate/aspartate (C4) is transported to bundle-sheath cells where decarboxylation releases CO2 for the Calvin cycle; the resulting C3 compound returns to mesophyll to regenerate PEP (NCERT §11.8, pp. 145–147).
- C4 plants tolerate higher temperatures, respond to high light, lack photorespiration and have greater biomass productivity. The Calvin cycle is common to all photosynthetic plants — in C3 plants it occurs in mesophyll, in C4 plants only in bundle sheath cells (NCERT §11.8, pp. 145–147).
- Photorespiration: RuBisCO's active site can bind both CO2 and O2 (competitive binding governed by their relative concentrations). When O2 binds RuBP, one molecule of phosphoglycerate (3C) and one phosphoglycolate (2C) form. The photorespiratory pathway releases CO2, uses ATP, and produces no sugar, no ATP, no NADPH. Its biological function is not yet known (NCERT §11.9, p. 147).
- C4 plants avoid photorespiration because decarboxylation of C4 acids in bundle-sheath cells raises intracellular CO2, ensuring RuBisCO functions as a carboxylase, minimising oxygenase activity (NCERT §11.9, p. 147).

- Factors affecting photosynthesis are internal (number/size/age/orientation of leaves, mesophyll/chloroplast number, internal $CO_2$, chlorophyll content) and external (light, $CO_2$, temperature, water). Blackman's (1905) Law of Limiting Factors: when more than one factor affects a process, its rate is determined by the factor nearest its minimal value (NCERT §11.10, p. 149).
- Light: linear response at low intensity; saturation at ~10% of full sunlight; light is rarely limiting in nature (except shade/dense forests); excess light causes chlorophyll breakdown (NCERT §11.10.1, pp. 149–150).
- $CO_2$: major limiting factor (atmospheric 0.03–0.04%); rates rise up to 0.05%; C4 plants saturate near 360 μL $L^{-1}$ while C3 saturate beyond 450 μL $L^{-1}$ — current atmospheric $CO_2$ is limiting for C3 plants. Used commercially in $CO_2$-enriched greenhouses (tomato, bell pepper) (NCERT §11.10.2, p. 150).
- Temperature: dark (enzymatic) reactions are temperature-controlled; C4 plants thrive at higher temperatures than C3 plants; tropical plants have higher optima than temperate-adapted plants (NCERT §11.10.3, p. 150).
- Water: water stress closes stomata (reducing $CO_2$ entry) and wilts leaves — its effect on photosynthesis is largely indirect via the plant (NCERT §11.10.4, p. 150).

## 2.2 Definitions to memorise

| Term | Definition | Page |
|---|---|---|
| Photosynthesis | Physico-chemical process by which green plants use light energy to drive the synthesis of organic compounds | 133 |
| Autotrophs | Organisms that synthesise their own food (green plants) | 133 |
| Heterotrophs | Organisms that depend on green plants (or other organisms) for food | 133 |
| Action spectrum | Plot of rate of photosynthesis vs wavelength of light | 135, 137 |
| Absorption spectrum | Plot of light absorbed by a pigment vs wavelength | 137 |
| Light reactions (photochemical) | Light-driven reactions of the thylakoid membrane — light absorption, water splitting, $O_2$ release, formation of ATP and NADPH | 136, 138 |
| Dark reactions (carbon reactions) | Stromal enzymatic reactions that synthesise sugars using ATP and NADPH; not directly light-driven | 136 |
| Light Harvesting Complex (LHC) | Photosystem assembly of hundreds of pigment molecules bound to proteins, acting as antennae feeding a reaction centre | 138 |
| P700 | Reaction-centre chlorophyll a of PS I, absorption peak at 700 nm | 138 |
| P680 | | 138 |

| Term | Definition | Page |
|---|---|---|
| | Reaction-centre chlorophyll a of PS II, absorption peak at 680 nm | |
| Z-scheme | Sequence of electron transfer PS II → acceptor → ETS → PS I → acceptor → NADP+; named for its zig-zag shape on a redox-potential scale | 139 |
| Photophosphorylation | Synthesis of ATP from ADP + Pi in presence of light (in chloroplasts) | 140 |
| Non-cyclic photophosphorylation | Electron flow through PS II + PS I in series; produces ATP and NADPH | 140 |
| Cyclic photophosphorylation | Electron flow only through PS I (cycled back via ETS); produces ATP only | 140 |
| Chemiosmotic hypothesis | Mechanism explaining ATP synthesis through breakdown of a proton gradient across the thylakoid membrane via ATP synthase | 140 |
| ATP synthase (CF0–CF1) | Enzyme of thylakoid membrane: CF0 is the transmembrane H+ channel, CF1 protrudes into stroma and catalyses ATP synthesis | 142 |
| Calvin cycle / C3 pathway | CO2 fixation pathway whose first stable product is 3-carbon PGA; occurs in all photosynthetic plants | 143 |
| RuBP | Ribulose-1,5-bisphosphate; 5-carbon ketose sugar; primary CO2 acceptor in Calvin cycle | 143 |
| RuBisCO | Ribulose bisphosphate carboxylase-oxygenase; catalyses both carboxylation and oxygenation of RuBP; most abundant enzyme in the world | 143, 147 |
| C4 / Hatch-Slack pathway | Pathway in tropical plants where first CO2-fixation product is 4-carbon OAA, primary acceptor is PEP, enzyme is PEP carboxylase | 145–146 |
| PEP carboxylase (PEPcase) | Mesophyll-cell enzyme that fixes CO2 onto PEP to form OAA in C4 plants | 146 |
| Kranz anatomy | 'Wreath'-like arrangement of large, chloroplast-rich bundle-sheath cells around vascular bundles in C4 leaves; thick walls, no intercellular spaces | 145 |
| Photorespiration | RuBisCO-catalysed oxygenation of RuBP in C3 plants — releases CO2, consumes ATP, produces no sugar, no ATP, no NADPH | 147 |
| Blackman's Law of Limiting Factors | If a chemical process is affected by more than one factor, its rate is determined by the factor nearest its minimal value | 149 |

## 2.3 Diagrams / processes to remember

- **Figure 11.1 — Priestley's experiment (p. 134):** bell-jar setups (a) burning candle alone, (b) candle extinguished/mouse dead, (c–d) mint plant restores air so candle burns and mouse survives.
- **Figure 11.2 — Chloroplast diagrammatic electron micrograph (p. 136):** outer membrane, inner membrane, grana (stacked thylakoids), stromal lamellae, stroma, ribosomes, starch granule, lipid droplet.
- **Figure 11.3 (a, b, c) — Absorption vs action spectra (p. 137):** (a) absorption spectra of chl a, chl b, carotenoids; (b) action spectrum of photosynthesis; (c) overlap of action spectrum on absorption of chl a.
- **Figure 11.4 — Light Harvesting Complex (p. 138):** photon striking antenna pigments, energy funnelled to reaction centre, electron passed to primary acceptor.
- **Figure 11.5 — Z-scheme of light reaction (p. 139):** PS II (P680) → e– acceptor → ETS (ADP+Pi → ATP) → PS I (P700) → e– acceptor → NADPH; water splitting feeds PS II.
- **Figure 11.6 — Cyclic photophosphorylation (p. 140):** PS I (P700) only; electron returns via ETS, ATP produced, no NADPH.
- **Figure 11.7 — ATP synthesis through chemiosmosis (p. 141):** PS II → plastoquinone (PQ) → cytochrome b6f → plastocyanin (PC) → PS I → ferredoxin (Fd) → FNR → NADPH; H+ pumped into lumen; ATP synthase (CF0/CF1) makes ATP as H+ flows back into stroma.
- **Figure 11.8 — Calvin cycle (p. 144):** carboxylation (RuBP + CO2 → 3-PGA), reduction (using ATP + NADPH → triose phosphate → sucrose/starch), regeneration (RuBP reformed using ATP).
- **Figure 11.9 — Hatch and Slack pathway (p. 146):** mesophyll cell — PEP + HCO3– → OAA (C4) → transport via plasmodesmata to bundle-sheath cell — decarboxylation → CO2 enters Calvin cycle, C3 acid returns to mesophyll → regenerates PEP.
- **Figure 11.10 — Light intensity vs rate of photosynthesis (p. 149):** linear rise (region A), saturation (B–C plateau), saturation level E at full sunlight ~10%.

## 2.4 Common confusions / NTA trap points

- "Dark reactions" is a misnomer — they are not light-independent absolutely; they depend on ATP and NADPH from light reactions and continue briefly in the dark after illumination stops (NCERT §11.3, p. 136; §11.7, p. 142).
- PS I and PS II are numbered by order of discovery, NOT by the sequence in which they function. In the Z-scheme, PS II acts first, then PS I (NCERT §11.5, p. 138).
- Primary CO2 acceptor in Calvin cycle is the 5-carbon RuBP — not a 2-carbon compound (a historical wrong guess) and not the 3-carbon PGA (which is the first product) (NCERT §11.7.1, p. 143).

- Cyclic photophosphorylation produces ONLY ATP (no NADPH and no O2). It occurs in stroma lamellae (which lack PS II and NADP reductase) and when light beyond 680 nm is available (NCERT §11.6.2, p. 140).
- O2 evolved in photosynthesis comes from H2O, not CO2 (van Niel inference, later confirmed by radioisotope studies) (NCERT §11.2, p. 135).
- C4 plants still use the Calvin cycle — it just happens in bundle-sheath cells, not mesophyll. C4 is an "add-on" CO2-concentrating route, not a replacement for Calvin (NCERT §11.8, pp. 146–147).
- Per CO2 fixed in the Calvin cycle: 3 ATP and 2 NADPH; per glucose (6 turns): 18 ATP and 12 NADPH — easy to misremember (NCERT §11.7.2, p. 145).

## 🎯 Practice MCQs

**Q1. Joseph Priestley's bell-jar experiment (1770), in which a mint plant kept a mouse alive and a candle burning, established that:**

**A.** Sunlight is essential for the plant process that purifies foul air

**B.** Plants restore to the air whatever breathing animals and burning candles remove

**C.** Oxygen released by green plants comes from water, not CO2

**D.** Glucose produced by green plants is stored as starch

**Q2. T. W. Engelmann's experiment with a prism, Cladophora and aerobic bacteria described, for the first time, the:**

**A.** Absorption spectrum of chlorophyll a

**B.** Absorption spectrum of carotenoids

**C.** Action spectrum of photosynthesis

**D.** Emission spectrum of chlorophyll b

**Q3.** **Which scientist demonstrated, on the basis of studies of purple and green sulphur bacteria, that the O2 released during photosynthesis in green plants comes from water?**

- **A.** Julius von Sachs
- **B.** T. W. Engelmann
- **C.** Jan Ingenhousz
- **D.** Cornelis van Niel



## 📊 PYQ Alignment

Photosynthesis is among the highest-yield chapters in CUET Biology Plant Physiology, contributing roughly 8–12 MCQs across the 2023–25 cycles. Typical question types include direct factual recall on early experiments (Priestley/Ingenhousz/van Niel), pigment-spectrum interpretation, sequence of carriers in the Z-scheme, P700/P680 absorption maxima, ATP/NADPH stoichiometry in the Calvin cycle, RuBP/PEP/OAA/PGA carbon counts, Kranz anatomy and C3 vs C4 comparative tables, photorespiration mechanism, and Blackman's Law / limiting-factor graph interpretation.