PHOTOSYNTHESIS

7.1 PHOTOSYNTHETIC ORGANISMS

- Photosynthetic organisms (algae, plants & cyanobacteria) transform solar energy into chemical energy (carbohydrates). *Autotrophs*: produce their own food.

Flowering Plants as Photosynthesizers

- **Leaves**: mesophyll tissue contains specialized cells for photosynthesis.
- **Roots**: absorb H_2O that moves up vascular tissue in stem until it reaches leaf veins.
- **CO_2:** enters leaf through small openings *(stomata – sing. stoma).*
  - **CO_2 & H_2O:** diffuse into *chloroplasts.*
- **Chlorophyll** & other pigments (in thylakoid membrane) absorb solar energy.

Process of Photosynthesis

- O_2 (^{18}O isotope, can be traced) given off by photosynthesis comes from H_2O & **not** from CO_2.
- **Net equation** of photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$.
- Involves **oxidation-reduction**: CO_2 reduced by H atoms + energy, & H_2O oxidized.

2 Sets of Reactions

- Light reactions: take place only in presence of light; *energy-capturing reactions.*
  - **Chlorophyll** (thylakoid membranes) absorbs solar energy & energizes e^-.
  - **Energized e^-** move down electron transport chain, energy is captured & used for ATP production.
  - **Energized e^-** also taken up by $NADP^+$, converting it to NADPH (coenzyme).

solar energy → chemical energy (ATP, NADPH)

- Calvin cycle reactions: take place in stroma; occur in *either* presence or absence of light.
  - Use **NADPH & ATP** produced in light reactions to reduce CO_2 to carbohydrate.

chemical energy → chemical energy

(ATP, NADPH) (carbohydrates)

Plants as Solar Energy Converters

- Higher energy wavelengths screened out by ozone layer.
- Lower energy wavelengths screened out by water vapour & CO_2.
- ***Absorption spectrum:*** pigments in chlorophyll absorb various portions of *visible light.*

  - **Chlorophyll *a* + *b:*** absorb violet, blue, and red wavelengths best.
  - *Very little* green light is absorbed; most is reflected (∴ leaves appear green).
  - ***Carotenoids:*** yellow-orange pigments that absorb light in violet, blue & green regions.
    - ✓ Noticeable in fall when chlorophyll breaks down.

Absorption & action spectrum

- Purified sample exposed to different wavelengths of light inside ***spectrophotometer:*** measures amount of light that passes through a sample.
- **Some** wavelengths absorbed & others pass through sample.
- **Graph** of percent of light absorbed at each wavelength is pigment's ***absorption spectrum.***
- ***Action spectrum:*** uses O_2 production to measure rate of photosynthesis at each wavelength of light.

- This light reaction requires participation of two light-gathering units: **photosystem I (PS I)** and **photosystem II (PS II)**.
  2. A.

Light Reactions

- **Photosystem:** comprised of pigment complex in thylakoid membrane (molecules of chlorophyll a & b and cartenoids), & an electron acceptor; solar energy is absorbed & high-energy electrons are generated.

- Noncyclic Electron Pathway…
  - **Electrons** flow from H_2O through **PS II** to **PS I** and then on to **$NADP^+$.**
  - **PS II** pigment complex absorbs solar energy; high-energy electrons (e^-) leave reaction-center chlorophyll *a* & are captured by electron acceptor.
  - **PS II** takes replacement electrons from H_2O, which splits, releasing O_2 (as gas) and H^+ ions.
  - **Electron acceptor** sends energized e– to *electron transport system*, e– pass from 1 carrier to another, energy released is used to move H^+ ions from stroma *(low H^+ conc.)* to thylakoid space *(high H^+ conc.)* by **active transport.**
  - **H^+ accumulated** in thylakoid space flow into stroma through ATP synthase complex in thylakoid membrane **(protein carrier, facilitated transport).**
  - H^+ movement provide energy for ATP synthase to produce ATP from ADP + P **(**chemiosmosis).

  - **PS I** pigment complex absorbs solar energy; high-energy electrons leave reaction-center chlorophyll *a* & are captured by **electron acceptor.**

  - Electron acceptor passes them on to $NADP^+$ in stroma, which takes on 2 e− from electron transport system & 1 H^+ from stroma to become NADPH:

$$\mathbf{NADP^+ + 2\,e^- + H^+ \rightarrow NADPH}$$

  - NADPH & ATP used by enzymes in stroma during Calvin cycle.

Organization of Thylakoid Membrane

- **PS II** consists of *pigment complex* & *electron-acceptor molecules*; it oxidizes H_2O & **produces O_2.**
- **Electron transport system** consists of *cytochrome complexes, Pq (plastoquinone)* & transports electrons to PS II & pumps H^+ ions into **thylakoid space.**
- **PS I** has pigment complex & electron-acceptor molecules; adjacent to **$NADP^+$.**
- ***ATP synthase complex*** has an H^+ channel & a protruding ATP synthase, an enzyme that joins **ADP + P.**

ATP Production

1. The thylakoid space acts as a reservoir for H^+ ions; each time H_2O is split, two H^+ remain.
2. Electrons move carrier-to-carrier, giving up energy used to pump H^+ from the stroma into the thylakoid space.
3. Flow of H^+ from high to low concentration across thylakoid membrane provides energy to produce ATP from ADP + P by using an ATP synthase enzyme.
4. This is called **chemiosmosis** because ATP production is tied to an electrochemical (H^+) gradient.

E. Tropical Rain Forest Destruction and Global Warming (*Ecology Focus Box*)

1. **Global warming** is an unexpected rise in the average global temperature during the 21st century due to the introduction of certain gases into the atmosphere.
2. For more than 1000 years before 1850, carbon dioxide levels remained fairly constant at 0.028%.
3. Following the 1850s (marked by the industrial revolution), the amount of carbon dioxide in the atmosphere increased to 0.038%.
4. Role of Carbon Dioxide
    a. Carbon dioxide, as well as other gases, traps radiant heat from the sun.
    b. Factors adding carbon dioxide to the atmosphere include: burning of fossil fuels, and destructing tropical rain forests.
5. Role of Tropical Rain Forests
    a. Ten – 30 million hectares of rain forests are lost every year due to ranching, logging, and mining.
    b. Each year, tropical rain forest deforestation accounts for 20-30% of all carbon dioxide in the atmosphere.

  - c. Destruction of tropical rain forests is also troublesome because burning a forest add carbon dioxide to the atmosphere, and also removes trees that normally would absorb carbon dioxide.

6. The Argument for Preserving Forests
   - a. Tropical rain forests contribute to the uptake of carbon dioxide, and the productivity of photosynthesis.
   - b. Tropical rain forests exist between the Tropic of Cancer and Tropic of Capricorn, temperatures about 26 C, and where rainfall is 100-200 cm and regular.
   - c. Tropical rain forest tree characteristics include: large trees, buttressed trunks, broad, simple dark-green leaves, and vines (lianas).
   - d. Researchers suggest that as temperatures rise, tropical rain forests may add to atmospheric carbon dioxide accumulation and accelerate global warming rather than the reverse.
   - e. To combat deforestation, some countries, such as Costa Rica, have developed national park systems and reserves to protect the forests from destruction. .

7.4 Calvin Cycle Reactions

1. The Calvin cycle is a series of reactions producing carbohydrates; these reactions follow the light reactions.
2. The cycle is named for Melvin Calvin who used a radioactive isotope of carbon to trace the reactions.
3. The Calvin cycle includes carbon dioxide fixation, carbon dioxide reduction, and regeneration of ribulose 1,5-bisphosphate (RuBP).

A. Fixation of Carbon Dioxide

1. **CO_2 fixation** is the attachment of CO_2 to an organic compound called **RuBP**.
2. **RuBP (ribulose bisphosphate)** is a five-carbon molecule that combines with carbon dioxide; the resulting 6-carbon molecule then splits into two 3-carbon molecules.
3. The enzyme **RuBP carboxylase** (**rubisco**) speeds this reaction; this enzyme comprises 20–50% of the protein content of chloroplasts--it is an unusually slow enzyme.

B. Reduction of Carbon Dioxide

1. With the reduction of carbon dioxide, a 3PG (3-phosphoglycerate) molecule forms.
2. Each of two 3PG molecules undergoes reduction to G3P (glyceraldehyde-3-phosphate) in two steps.
3. Light-dependent reactions provide NADPH (electrons) and ATP (energy) to reduce 3PG to G3P.

C. Regeneration of RuBP

1. For every three turns of the Calvin cycle, five molecules of G3P are used to re-form three molecules of RuBP.
2. This reaction also uses ATP produced by the light reactions.

D. The Importance of the Calvin Cycle

1. G3P, the product of the Calvin Cycle can be converted into many other molecules.
2. Glucose phosphate is one result of G3P metabolism; it is a common energy molecule.
3. Glucose phosphate can bond with *fructose* to form *sucrose*.
4. Glucose phosphate is the starting point for synthesis of *starch* and *cellulose*.
5. The hydrocarbon skeleton of G3P is used to form fatty acids and glycerol; the addition of nitrogen forms various amino acids.

7.5 Other Types of Photosynthesis

1. In C_3 plants, the Calvin cycle fixes CO_2 directly; the first molecule following CO_2 fixation is 3PG.
2. In hot weather, stomata close to save water; CO_2 concentration decreases in leaves; O_2 increases.
3. This is called **photorespiration** since oxygen is taken up and CO_2 is produced; this produces only one 3PG.

A. C_4 Photosynthesis

1. In a C_3 plant, mesophyll cells contain well-formed chloroplasts, arranged in parallel layers.
2. In C_4 plants, bundle sheath cells as well as the mesophyll cells contain chloroplasts.
3. In C_4 leaf, mesophyll cells are arranged concentrically around the bundle sheath cells.
4. C_3 plants use RuBP carboxylase to fix CO_2 to RuBP in mesophyll; the first detected molecule is G3P.
5. C_4 plants use the enzyme PEP carboxylase (PEPCase) to fix CO_2 to PEP (phosphoenolpyruvate, a C3 molecule); the end product is oxaloacetate (a C_4 molecule).
6. In C_4 plants, CO_2 is taken up in mesophyll cells and malate, a reduced form of oxaloacetate, is pumped into the bundle-sheath cells; here CO_2 enters Calvin cycle.
7. In hot, dry climates, net photosynthetic rate of C_4 plants (e.g., corn) is 2–3 times that of C_4 plants.
8. Photorespiration does not occur in C_4 leaves because PEPCase does not combine with O_2; even when stomates are closed, CO_2 is delivered to the Calvin cycle in bundle sheath cells.
9. C_4 plants have advantage over C_3 plants in hot and dry weather because photorespiration does not occur; e.g., bluegrass (C_3) dominates lawns in early summer, whereas crabgrass (C_4) takes over in the hot midsummer.

B. CAM Photosynthesis

1. **CAM (crassulacean-acid metabolism)** plants form a C_4 molecule at night when stomates can open without loss of water; found in many succulent desert plants including the family *Crassulaceae*.
2. At night, CAM plants use PEPCase to fix CO_2 by forming C_4 molecule stored in large vacuoles in mesophyll.
3. C_4 formed at night is broken down to CO_2 during the day and enters the Calvin cycle within the same cell, which now has NADPH and ATP available to it from the light-dependent reactions.
4. CAM plants open stomates only at night, allowing CO_2 to enter photosynthesizing tissues; during the day, stomates are closed to conserve water but CO_2 cannot enter photosynthesizing tissues.
5. Photosynthesis in a CAM plant is minimal, due to limited amount of CO_2 fixed at night; but this does allow CAM plants to live under stressful conditions.

C. Photosynthesis and Adaptation to the Environment

1. Each method of photosynthesis has its advantages, depending on the environment.
2. C_4 plants are adapted to areas of high light intensities, high temperatures, and limited rainfall.
3. C_3 plants do better in cooler climates.
4. CAM plants do well in an arid environment.