Photosynthesis

3: Photosynthesis

- $6\ CO_2 + 6\ H_2O$ + light energy → $C_6H_{12}O_6 + 6\ O_2$
- Photosynthesis is a complex biochemical pathway.
- Photosynthesis consists of two independent pathways called the **light-dependent reaction** (light reaction) and the **light-independent reaction** (dark reaction).
  - Light Reactions: the energy in sunlight is trapped, O_2 is released, and both ATP and NADPH + H^+ (hydrogen-carrier molecule) are formed
  - Dark Reactions: the ATP and NADPH + H^+ react with CO_2 from the atmosphere and form glucose
- The entire process results in the transformation of light energy from the sun into energy stored in the bonds of the glucose molecule.

Structure of a Chloroplast

- double membrane
- thylakoid: a flattened sac that contains chlorophyll
- lumen: an internal reservoir in a thylakoid
- granum: a stack of thylakoids in a chloroplast
- stroma: a solution surrounding the grana

The light reactions take place in the thylakoid membrane

The dark reactions take place in the stroma

Chlorophyll & Accessory Pigments

- Photosynthesis requires the presence of pigments that are acted upon by sunlight.
  - Sunlight consists of particles of energy that move in waves of different wavelengths (visible light is part of the electromagnetic spectrum).
    - Wavelength (λ) is the distance between the crests of successive waves.
    - The shorter the wavelength, the more energy the light has.
    - Therefore, violet light (shorter λ) has more energy than red light (longer λ).
  - Pigments are light-absorbing compounds.
    - Pigments appear colored because they absorb light of certain wavelengths and reflect that of others.
    - Chlorophyll *a* is the primary pigment in green plants that absorbs red and blue/violet light and reflects green light.
    - Chloroplasts also contain other pigments called accessory pigments.
      - Accessory pigments trap wavelengths of light that cannot be absorbed by chlorophyll *a* and then transfer the energy to chlorophyll *a* molecules for use in photosynthesis. In this way, accessory pigments enable plants to use a greater amount of the sun's energy than is available to chlorophyll alone.
      - The most common accessory pigments in green plants are chlorophyll *b* (green), carotenes (orange), xanthophylls (yellow), and anthocyanins (red)

Light Reaction (Light-Dependent Reaction)

- Pigments that are in the chloroplasts intercept light and begin the light reactions of photosynthesis.
- The light reactions occur in two photosystems (located in the thylakoid membrane):

-photosystem I (**PSI**) -photosystem II (**PSII**)

  - Photosystem: a unit of several hundred chlorophyll *a* molecules and associated acceptor molecules

- **Steps:**
  1. Sunlight strikes PSII. The light energy boosts the energy level of the electrons in the chlorophyll molecules to such a high level that the electrons can escape the chlorophyll.
  2. When light struck PSII, a water molecule split into 2 H^+, 1 O, and 2 electrons. These electrons pay back the two electrons that PSII lost in Step 1. The hydrogen ions join other hydrogen ions in the lumen. The oxygen unites with another oxygen atom and O_2 is released into the atmosphere.
  3. Two excited electrons pass down the electron transport chain (a series of electron carrier molecules) to PSI.
  4. As the electrons move along the electron transport chain, hydrogen ions (H^+) are pumped across the thylakoid membrane from the stroma. The energy that the electrons release as they flow down the ETC is used to power this H^+ pump.
  5. Sunlight strikes PSI (remember that PSI has two extra electrons from PSII). The two excited electrons pass through a series of molecules until they reach an electron acceptor called $NADP^+$. Two electrons and two hydrogen ions (H^+) then attach to $NADP^+$ to form NADPH + H^+ (a product of the light reaction).
  6. The pumping of hydrogen ions into the lumen of the thylakoid creates an electrochemical gradient. As the hydrogen ions flow down the gradient from the lumen to the stroma, ADP is phosporylated to ATP by ATP synthase (enzyme/channel). This process is called **chemiosmosis**.
- Products: ATP, NADPH + H^+, and O_2
- ATP and NADPH + H^+ are released into the stroma, and are used to power the dark reaction.

Dark Reaction (Light Independent Reaction)

- The dark reaction is also known as the Calvin Cycle, after an American scientist (Melvin Calvin) who figured out the pathway.
- The dark reaction is also known as the C_3 Cycle because the first stable products of this pathway are molecules that contain three carbon atoms.
- The Calvin Cycle occurs in the stroma.
- **Steps:**
  1. *CO_2 is fixed by ribulose biphosphate (RuBP)*
     CO_2 enters the plant from the atmosphere. RuBP (a five-carbon sugar molecule) binds to CO_2. This is called CO_2 fixation. RuBP carboxylase catalyzes this reaction. The addition of CO_2 to RuBP forms an unstable six-carbon sugar molecule that immediately splits into two molecules of phosphoglyceric acid (PGA), a three-carbon molecule.
  2. *Phosphoglyceraldehyde (PGAL) is formed*
     PGAL is formed through the following 2 step process:
     -A PGA molecule binds with a phosphate group supplied by ATP.
     PGA + ATP → PGA~P + ADP
     -Then the molecule reacts with NADPH + H^+, breaking the phosphate bond and forming PGAL (three-carbon molecule).
     PGA~P + NADPH + H^+ → PGAL + $NADP^+$ + H^+
  3. *Glucose is formed*
     2 molecules of PGAL combine to form a molecule of glucose.
  4. *RuBP is regenerated*
     The remaining 10 molecules of PGAL are used to regenerate more RuBP, using energy supplied by ATP.

- Six turns of the Calvin Cycle are required to produce one molecule of glucose.
- Product: Glucose

C4 and CAM Pathways

- The Calvin Cycle is the most common method of fixing carbon. The two other pathways (C_4 and CAM) have an adaptive value to the plants that use them.

- Plants adapted to hot, dry climates use the C_4 Pathway.
  - In C_4 photosynthesis, a molecule of CO_2 binds, in a special leaf cell, to a three-carbon compound rather than to the five-carbon RuBP. This fixation results in a four-carbon compound. The compound is then transported to an adjacent cell. When released inside the cell, the CO_2 is trapped. Here it is fixed by RuBP and travels through the Calvin Cycle.
  - The advantage of C_4 Photosynthesis is that C_4 plants make efficient use of CO_2 by fixing carbon up to four times as fast as C_3 plants do. This allows them to grow in higher temperatures and at much faster rates.
  - This requires more energy than C_3 Photosynthesis, but C_4 plants grow in abundant light where extra energy is readily available.

- Cactuses and other plants adapted to dry habitats have **C**rassulacean **A**cid **M**etabolism (**CAM**).
  - In CAM Photosynthesis, the plant absorbs CO_2 at night and fixes it in the form of a four-carbon compound. During the day CO_2 is released and refixed by RuBP. It then enters the Calvin Cycle.
  - Plant pores called stomata regulate the movement of CO_2 and water vapor in and out of leaves. For carbon fixation to occur the stomata must be open. However, plants lose water when their stomata are open (transpiration). Since heat and sunlight increase water loss, plants lose less water by opening their stomata only at night.