PHOTOSYNTHESIS
Photosynthesis

- An **anabolic, endergonic, carbon dioxide** \((\text{CO}_2)\) requiring process that uses **light energy** (photons) and **water** \((\text{H}_2\text{O})\) to produce **organic macromolecules** (glucose).

\[
6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]
Question:

- Where does photosynthesis take place?
Plants

- **Autotrophs**: self-producers.
- Location:
  1. Leaves
    a. stoma
    b. mesophyll cells
Stomata (stoma)

• **Pores** in a plant’s cuticle through which **water** and **gases** are exchanged between the plant and the atmosphere.
Mesophyll Cell

- Cell Wall
- Central Vacuole
- Nucleus
- Chloroplast
Chloroplast

- **Organelle** where **photosynthesis** takes place.
Thylakoid

Granum

Thylakoid Membrane

Thylakoid Space
Question:

• Why are plants green?
Chlorophyll Molecules

• Located in the **thylakoid membranes**.

• Chlorophyll have **Mg**\(^+\) in the center.

• **Chlorophyll pigments** harvest energy (photons) by **absorbing** certain **wavelengths** (blue-420 nm and red-660 nm are most important).

• **Plants** are **green** because the **green wavelength** is **reflected**, **not absorbed**.
Wavelength of Light (nm)

Short wave (more energy)  Long wave (less energy)
Absorption of Chlorophyll

Absorption

violet  blue  green  yellow  orange  red
wavelength
Question:

- During the fall, what causes the leaves to change colors?
Fall Colors

• In addition to the chlorophyll pigments, there are other **pigments** present.

• During the fall, the **green chlorophyll** pigments are **greatly reduced** revealing the other **pigments**.

• **Carotenoids** are pigments that are either **red** or **yellow**.
Redox Reaction

• The transfer of one or more electrons from one reactant to another.

• Two types:
  1. Oxidation
  2. Reduction
Oxidation Reaction

- The **loss** of electrons from a **substance**.
- Or the **gain** of **oxygen**.

\[
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\]

**glucose**
Reduction Reaction

- The **gain** of **electrons** to a **substance**.
- Or the **loss** of **oxygen**.

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

**glucose**
Breakdown of Photosynthesis

- Two main parts (reactions).

1. Light Reaction or Light Dependent Reaction

Produces energy from solar power (photons) in the form of ATP and NADPH.
Breakdown of Photosynthesis

2. Calvin Cycle or Light Independent Reaction or Carbon Fixation or C₃ Fixation

Uses **energy (ATP and NADPH)** from **light rxn** to make **sugar (glucose)**.
1. Light Reaction (Electron Flow)

- Occurs in the Thylakoid membranes
- During the light reaction, there are two possible routes for electron flow.

A. Cyclic Electron Flow
B. Noncyclic Electron Flow
A. Cyclic Electron Flow

- Occurs in the thylakoid membrane.
- Uses Photosystem I only
- P700 reaction center- chlorophyll a
- Uses Electron Transport Chain (ETC)
- Generates ATP only

\[
\text{ADP} + \overset{\text{P}}{\text{P}} \rightarrow \text{ATP}
\]
A. Cyclic Electron Flow

SUN

Primary Electron Acceptor

P700

Accessory Pigments

Photosystem I

ATP produced by ETC

Photons
B. Noncyclic Electron Flow

- Occurs in the thylakoid membrane
- Uses PS II and PS I
- P680 rxn center (PSII) - chlorophyll a
- P700 rxn center (PS I) - chlorophyll a
- Uses Electron Transport Chain (ETC)
- Generates O₂, ATP and NADPH
B. Noncyclic Electron Flow

2e\textsuperscript{-} \rightarrow \text{Primary Electron Acceptor} \rightarrow \text{ETC} \rightarrow \text{P700} \rightarrow \text{Enzyme Reaction} \rightarrow \text{NADPH}

\text{SUN} \rightarrow \text{Photon} \rightarrow \text{P680} \rightarrow \text{H}_2\text{O} \xrightarrow{1/2\text{O}_2 + 2\text{H}^+} \text{Photosystem II} \rightarrow \text{ATP} \rightarrow \text{Primary Electron Acceptor} \rightarrow \text{Photosystem I}
B. Noncyclic Electron Flow

- ADP + P → ATP
  (Reduced)

- NADP⁺ + H → NADPH
  (Reduced)

- Oxygen comes from the splitting of H₂O, not CO₂

  H₂O → 1/2 O₂ + 2H⁺
  (Oxidized)
Chemiosmosis

• Powers ATP synthesis.

• Located in the thylakoid membranes.

• Uses ETC and ATP synthase (enzyme) to make ATP.

• Photophosphorylation: addition of phosphate to ADP to make ATP.
Chemiosmosis

Thylakoid

SUN (Proton Pumping)

PS II

E

T

C

PS I

H⁺ H⁺ H⁺ H⁺ high H⁺ concentration

H⁺ H⁺ H⁺ H⁺ Thylakoid Space

ADP + P

H⁺ ATP Synthase

ATP

H⁺ low H⁺ concentration
Calvin Cycle

- **Carbon Fixation (light independent rxn).**

- **C₃ plants** (80% of plants on earth).

  - Occurs in the stroma.

  - Uses **ATP** and **NADPH** from light rxn.

  - Uses **CO₂**.

- To produce **glucose**: it takes **6 turns** and uses **18 ATP** and **12 NADPH**.
Chloroplast

- Inner Membrane
- Outer Membrane
- Stroma
- Thylakoid
- Granum
Calvin Cycle (C₃ fixation)

6CO₂ → 6C-C-C-C-C-C-C (unstable)

RuBP

6C-C-C-C-C-C

6ATP → 6C-C-C

6NADPH → 6C-C-C

12PGA → 6C-C-C

6C-C-C

6C-C-C

6C-C-C

12G₃P

C-C-C-C-C-C

Glucose

6C

(6C)

(30C)

(36C)
Calvin Cycle

- **Remember:** $C_3 = \text{Calvin Cycle}$
Photorespiration

- Occurs on **hot, dry, bright days**.
- **Stomates close**.
- Fixation of **$O_2$** instead of **$CO_2$**.
- Produces **2-C molecules** instead of **3-C sugar molecules**.
- Produces **no sugar molecules or no ATP**.
Because of photorespiration: Plants have special adaptations to limit the effect of photorespiration.

1. C4 plants
2. CAM plants
C4 Plants

- **Hot, moist environments.**
- **15% of plants (grasses, corn, sugarcane).**
- **Divides photosynthesis spatially.**
  - Light rxn - mesophyll cells.
  - Calvin cycle - bundle sheath cells.
C4 Plants

Mesophyll Cell

- CO₂
- C-C-C
- PEP
- ATP

Bundle Sheath Cell

- Malate
- Transported
- CO₂
- C₃
- Glucose
- Vascular Tissue

Pyruvic Acid

C-C-C-C

C₃
CAM Plants

- **Hot, dry environments.**
- **5% of plants (cactus and ice plants).**
- **Stomates closed during day.**
- **Stomates open during the night.**
- Light rxn - occurs during the **day.**
- Calvin Cycle - occurs when CO$_2$ is present.
CAM Plants

Night (Stomates Open)  Day (Stomates Closed)

Vacuole

CO₂  Malate

PEP  ATP

C₃  glucose

C₃  CO₂
Question:

- Why would CAM plants close their stomates during the day?