Chapter 7
Capturing Solar Energy: Photosynthesis

Overview - the process that feeds the biosphere

**Photosynthesis:** transformation of solar energy into chemical energy.

Responsible for **O**₂ in our atmosphere

<table>
<thead>
<tr>
<th>Carbon source</th>
<th>Energy source</th>
<th>Autotrophs “producers”</th>
<th>Heterotrophs “consumers”</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>sunlight</td>
<td>(phototrophs)</td>
<td>organic molecules</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“food”</td>
<td>“food”</td>
</tr>
</tbody>
</table>

What is Photosynthesis?

**Answer:** The capture of sunlight energy and the subsequent storage of that energy in chemical bonds (glucose)

**Chemical Reaction:**

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

**Autotrophs (“self-feeders”):** Make their own food using sunlight

- Plants (Eukaryotes)
- Algae (Eukaryotes)
- Bacteria (Prokaryotes)

Sunlight wavelengths

- **Short wavelengths:** greater energy
  - UV light has the greatest energy, but cannot be seen by human eye.
- **Visible light (to humans):** 400 – 750
  - These light wavelengths are the only ones used in photosynthesis.
B. The photosynthetic pigments: light receptors

Pigment - molecule that absorbs light in the visible range.
1. wavelengths absorbed - not seen
2. wavelengths transmitted / reflected = pigment color

- Not a pigment
- A red pigment

Leaves and Chloroplasts are Adaptations for Photosynthesis:

Leaf Design:
- Flattened shape (large surface area)
- Thin (light can penetrate entire leaf)
- Surrounded by a Cuticle:
  - Waxy covering that prevents water loss
- Contain Stomata:
  - Adjustable openings that regulate CO₂ uptake and O₂ release
- Filled with Mesophyll Cells:
  - Contain majority of chloroplast organelles
- Contain Vascular Bundles (Veins):
  - Supply water / minerals; Carry away sugars

Leaf Structure:

- Stomata
- Mesophyll cell (with many chloroplasts)
- Vascular bundles

Leaves and chloroplasts are adaptations for photosynthesis:

Chloroplast Design:
- Contain two membranes (inner and outer)
- Filled with Stroma:
  - Semi-fluid medium (light-independent reactions)
- Contain stacks of Thylakoids (Grana):
  - Location of chlorophyll (light dependent reactions)
Chloroplast Structure:

Overview of Photosynthesis:

Two reactions:
1. Light dependent
2. Light independent  AKA dark reactions

Light Dependant Reactions:
The Conversion of Light Energy to Chemical Energy

1) Light is captured by pigments in chloroplast
   • photon: Packet of light energy
     • When photon hits leaf, the light is either:
       1) Absorbed
       2) Reflected (bounced back)
       3) Transmitted (passes through)
     • Chlorophyll and accessory pigments (e.g. carotenoids) absorb specific wavelengths of light

2) Light energy transferred to energy-carrier molecules
   • Reactions clustered in Photosystems (located in Thylakoids)
     1) Light-harvesting Complex (Gathers light)
     2) Electron Transport System (Energy-carrier molecules)
   • Photosystems utilize light energy to produce an energy transport molecule
     • Photosystem II generates ATP
     • Photosystem I generates NADPH

Light Dependent Reactions:
The Conversion of Light Energy to Chemical Energy

Pigment Absorption:

Chlorophyll (a vs. b):
- Blue & red light

Carotenoids:
- Blue & green light

Why do many leaves turn yellow in fall?

A typical photosystem in the thylakoid
Sequence of Events in Light Dependent Reactions:
Photosystem II:
1) Light energy excites electron in light-harvesting complex
2) Electron transport system accepts excited electron
3) ETS uses electron energy to synthesis ATP (chemiosmosis)

Sequence of Events in Light Dependent Reactions:
Photosystem I (same as photosystem II):
1) Light energy excites electron in light-harvesting complex
2) Electron transport system accepts excited electron
3) ETS captures electron to form NADPH

• Electrons lost in Photosystem I are replaced by electrons from Photosystem II:

• Electrons lost from Photosystem II are replaced by splitting water to form oxygen

Light Independent Reactions:
Energy is Stored in Glucose Molecules

\[ \text{CO}_2 + \text{H}_2\text{O} \xrightarrow{\text{ATP, NADPH}} \text{C}_6\text{H}_{12}\text{O}_6 \]

• Energy from ATP & NADPH are necessary to drive process
• Occurs in stroma of the chloroplast
Calvin-Benson Cycle: Set of reactions which capture carbon dioxide (C3 Cycle)

Requires:
1) Carbon Dioxide (from air) (CO₂)
2) Ribulose Bisphosphate (RuBP): A CO₂ capturing sugar
3) Multiple enzymes (to catalyze reactions)
4) Energy (ATP & NADPH)

Sequence of Events in Calvin-Benson (C₃) Cycle:
1) Carbon Fixation
   • CO₂ combines with ribulose bisphosphate (RuBP) to form phosphoglyceric acid (PGA)
2) PGA is converted to glyceraldehyde-3-phosphate (G3P)
   • Requires energy
   • G3P converted into glucose (1 glucose from 6 CO₂)
3) G3P converted back to RuBP (requires energy)

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{RuBP} \rightarrow \text{PGA} \rightarrow \text{ATP} \rightarrow \text{NADPH} \rightarrow \text{G3P} \rightarrow \text{Glucose}
\]

Fate of Glucose:
1) Broken down for energy
2) Stored as starch (energy storage)
3) Converted to cellulose (structure)
4) Other chemical modifications (e.g. glycoprotein)

Plants must balance between obtaining CO₂ and H₂O loss
• Cool, wet conditions → stomata open (plenty CO₂)
• Hot, dry conditions → stomata close (low CO₂)
  • Photosynthesis inefficient (photorespiration)

Plants living in arid conditions (e.g. corn) use C₄ pathway:
• CO₂ initially captured as oxaloacetate (mesophyll cells)
• Oxaloacetate releases CO₂ to bundle-sheath cells where photosynthesis continues as normal \(↑[\text{CO}_2]\)

C₄ Pathway:
(Figure 7.12)

Photosynthesis Review:
(Figure 7.11)