**Earth’s Timeline**

Humans have only existed for 1 second of Earth’s 24 hour clock.

Phototrophic bacteria (and photosynthesis) evolved close to the beginning of life.

**Pre-Biotic Earth**

The very early atmosphere of the earth contained mostly CO$_2$, about 80%.

The concentration of CO$_2$ gradually dropped to about 20% by 3,500 Ma (million years ago).

The evolution of the first bacteria occurred about 3,500 Ma.

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**Photosynthesis**

- The process of converting light energy into chemical energy.
- Nourish most living organisms directly or indirectly.
- Plants are autotrophs, self feeders, producers of organic molecules from CO$_2$. 

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**Capturing Solar Energy:** Photosynthesis

Chapter 7
### Earliest Evidence of Microbial Life

- **Graphite** bands found 3.8 billion years ago.
  - Graphite is a material that can be produced when organic carbon, found in all living organisms, is altered by heat and pressure over time.

(i.e. evidence of Biogenic Carbon)

- **Stromatolites** found 2.7 billion years ago.
  - Stromatolites formed when sediments accumulated over sticky colonies of underwater cyanobacteria.
    - After buried by sediment, the bacteria moved upward toward needed sunlight.
    - The cycle begins again with the accumulation of more sediment, forming layers over time.

---

#### Atmospheric Composition %

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<th>Time (m.y.)</th>
<th>Carbon Dioxide (ppm)</th>
<th>Nitrogen (ppm)</th>
<th>Oxygen (ppm)</th>
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</tr>
<tr>
<td>5000</td>
<td>20</td>
<td>79</td>
<td>21</td>
</tr>
</tbody>
</table>

**No Oxygen present in the early atmosphere.**

**Oxygen generated after life began.**

#### Earliest Evidence of Life

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Earliest Evidence of Microbial Life

- **Banded iron formations** (BIFs) found between 3.5 billion and two billion years ago.
  - BIFs are formed when oxygen released by photosynthetic bacteria create rust, oxidized iron, in shallow ocean shores.

- **The Cambrian Explosion**, 543 million years ago
  - Nearly all the major animal groups we are familiar with first appeared in this period.
Photosynthesis

$$6\text{CO}_2 + 6\text{H}_2\text{O} + \text{light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$$

Photosynthetic Organisms

Photosynthetic Adaptations

- Leaves
  - Designed to Capture Sunlight
    - Thin (only a few cells thick)
    - Large surface area (to expose all cells to the sun)
  - Designed to Prevent Water Loss and allow Gas Exchange
- Mesophyll Cells
- Chloroplasts

Leaf Adaptations

1. Capturing Sunlight
2. Prevention of Water Loss

- Cuticle
  - Waxy waterproof covering that reduces evaporation
- Upper & Lower Epidermis
Leaf Adaptations

1. Capturing Sunlight
2. Prevention of Water Loss
3. Gas Exchange

- Stoma
  - Pores, open & close

- Guard Cells
  - Move to open & close the ‘stoma’

Stoma open when humidity is high. Guard cells absorb water and swell. Open stoma let CO₂ in and O₂ out. Stoma deflate and close when humidity is low to prevent loss of water.

Internal leaf structure

- cuticle
- upper epidermis
- lower epidermis
- stoma
- mesophyll cells
- bundle sheath vascular bundle (vein)
- chloroplasts
Vascular Bundle and Sheath

- Veins of plants.
- Supply water and minerals to mesophyll cells.
- Carry sugar from mesophyll cells to other parts of the plant.

Mesophyll Cells

- “Middle of the Leaf”
- Major site of photosynthesis in the leaf.
- A single cell contains 40-200 chloroplasts.

Chloroplasts

- Organelles where photosynthesis takes place.
- Contain dish-shaped, interconnected membranous sacs called thylakoid disks where the light-dependent photosynthetic reactions take place.
- Light-independent photosynthetic reactions take place in the stroma.

Chloroplasts

- Light Dependent Reaction
- Light Independent Reaction
The **cuticle** is a waxy layer that prevents water loss.

The **upper and lower epidermis** are thicker cells that protect the interior leaf structure and prevent water and gas exchange with the atmosphere.

The **stoma** are pores in the lower epidermis that allow gas exchange. They are regulated by **guard cells** which open and close according to local humidity and gas needs.

The **Vascular Bundle** transports water to the leaves and sugars away from the leaves to other parts of the plant. **Bundle Sheath** cells protect the vascular bundle and regulate water and sugar movement from the vascular bundle.

**Mesophyll cells** make up most of the interior of the leaf. **Palisades mesophyll** cells (top) carry out most of the photosynthesis. **Spongy mesophyll** cells (bottom) store gases and water for palisades cells.

**Chloroplasts** are the eukaryotic organelles where photosynthesis takes place within the plant cell.

The **Thylakoid** disks are packed full of chlorophyll (or other photosynthetic pigment). The location of the **light dependent reaction** of photosynthesis.

The **Stroma** makes up the remaining interior space. The location of the **light independent reaction** of photosynthesis.

**Reactions of Photosynthesis**

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

- **Light-Dependent Reaction**
  - Takes place within the thylakoid membrane.
  - Generates energy-carrier molecules (ATP, NADPH)

\[ \text{H}_2\text{O} + \text{light} + \text{ADP} \rightarrow \text{O}_2 + \text{H}^+ + \text{ATP} \]

- **Light-Independent Reaction**
  - Takes place in the stroma.

\[ \text{CO}_2 + \text{H}^+ + \text{ATP} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{ADP} \]
Light Captured by Pigments

- The visible spectra of energy is quite narrow.
- Light is composed of individual packets of energy, photons.
- The shorter the wavelength, the more energetic the light.

Photosynthetic Pigments

- Photosynthetic pigments absorb light energy in the very high and low wavelengths.
- Light that is not absorbed is reflected and gives the object its color.

Not all light is the same color or wavelength.

**Chlorophyll a** absorbs in the violet and red wavelengths.

**Chlorophyll b** absorbs in the blue and orange wavelengths.

**Carotenoids** absorb in the violet to green wavelengths.

Most photosynthesis utilizes the violet, blue, and red wavelengths of light.

**Chlorophyll** absorbs violet, blue, and red light.
- Two types of chlorophyll:
  - Chlorophyll A, absorbs violet and red.
  - Chlorophyll B, absorbs blue and orange.

- Additional accessory pigments, **carotenoids**, absorb blue and green light while reflecting red and yellow.
- Chlorophyll breaks down in the cold before carotenoids, giving leaves red and yellow hues in autumn.
**Photosystems of Photosynthesis**

- Photosynthetic pigment proteins, chlorophyll and carotenoids, cluster together along the thylakoid membrane creating **photosystems**.
- Two photosystems, **PS I** and **PS II**, contain clusters of chlorophyll and carotenoids at reaction centers.

Electrons generated from light energy are passed from the reaction center along an **electron transport chain (ETC)**, a series of electron-carrying molecules in the membrane, to proteins to generate ATP and NADPH.

Light energy (1) excites electrons in the reaction center of chloroplasts (2) sending them down an electron transport chain (3,4) to generate ATP (5). Excited electrons are further excited (6) and sent down a second ETC (7,8) to form NADPH (9).
Excitation of PS II generates $H^+$ and electrons.

High $H^+$ concentration is used to synthesize ATP.
Excitation of PS I generates electrons for NADPH synthesis.

Energy-carrier molecules (ATP and NADPH) are used to drive light independent reactions.

Photosynthetic Light-Dependent Reaction

Generates a lot of ATP.

ATP Synthesis in Chloroplasts

- A gradient of H+ ions is built up through active transport across the ETC of PS II.
ATP Synthesis in Chloroplasts

- A gradient of H⁺ ions is built up through active transport across the ETC of PS II.
- Passive transport of H⁺ across the membrane is coupled with ATP synthesis.

Light-Independent Reactions of Photosynthesis

- Generation of glucose and other large carbon-storage molecules from CO₂ and energy generated in PS II and PS I is called the **Calvin-Bensen cycle**.
- **Carbon fixation** is the process of capturing CO₂ from the atmosphere and incorporating (fixing) it into larger molecules.

Key:
- RuBP: ribulose bisphosphate
- PGA: phosphoglyceric acid
- G3P: glyceraldehyde-3-phosphate
Bioflix on Photosynthesis

Adaptations of the Calvin Cycle

- **Rubisco**, the enzyme that catalyzes the reaction of RuBP and CO\(_2\) is not selective.
- **Photorespiration** occurs when O\(_2\) is combined with RuBP instead of CO\(_2\), generating CO\(_2\) and no additional energy.
- Plants in hot, dry climates have adapted a two-stage carbon-fixation pathway, the C\(_4\) pathway.

C\(_3\) Pathway used by most plants
Photosynthetic Light Independent Reaction

Takes place in the stroma of the chloroplast.

Stores the energy generated in the light reaction in the form of glucose.

Rubisco requires CO$_2$. Because of the non-specificity of rubisco, cells undergo wasteful photorespiration when CO$_2$ is not available.

Homework

Chapter 7
Thinking Through the Concepts,
Review Questions 1 and 5.