Chapter 7

Photosynthesis: Using Light to Make Food

Biology and Society: Biofuels

- Wood has historically been the main fuel used to produce
  - heat and
  - light.

Figure 7.0

- Industrialized societies replaced wood with fossil fuels including
  - coal,
  - gas, and
  - oil.
- To limit the damaging effects of fossil fuels, researchers are investigating the use of biomass (living material) as efficient and renewable energy sources.
- There are several types of biofuels.
  - Bioethanol is a type of alcohol produced by the fermentation of glucose made from starches in crops such as grains, sugar beets, and sugar cane.
  - Bioethanol may be used
    - directly as a fuel source in specially designed vehicles or
    - as a gasoline additive.
  - Cellulosic ethanol is a type of bioethanol made from cellulose in nonedible plant material such as wood or grass.
  - Biodiesel is made from plant oils or recycled frying oil.

THE BASICS OF PHOTOSYNTHESIS

- **Photosynthesis**
  - is used by plants, algae (protists), and some bacteria,
  - transforms light energy into chemical energy, and
  - uses carbon dioxide and water as starting materials.
- The chemical energy produced via photosynthesis is stored in the bonds of sugar molecules.
- Organisms that use photosynthesis are
  - photosynthetic autotrophs and
  - the producers for most ecosystems.

Figure 7.1
Figure 7.1a
Figure 7.1b
Figure 7.1c

Chloroplasts: Sites of Photosynthesis

- **Chloroplasts** are
  - the site of photosynthesis and
  - found mostly in the interior cells of leaves.
- Inside chloroplasts are interconnected, membranous sacs called **thylakoids,** which are suspended in a thick fluid called **stroma**.
- Thylakoids are concentrated in stacks called **grana**.
- The green color of chloroplasts is from **chlorophyll**, a light-absorbing pigment that plays a central role in converting solar energy to chemical energy.
- **Stomata** are tiny pores in leaves where
  - carbon dioxide enters and
  - oxygen exits.

Figure 7.2-1
Figure 7.2-2
Figure 7.2-3
Figure 7.2a
Figure 7.2b
Figure 7.2c
Figure 7.2d

The Simplified Equation for Photosynthesis

- In the overall equation for photosynthesis, notice that the reactants of photosynthesis are the waste products of cellular respiration.

Figure 7-UN01

- In photosynthesis,
  - sunlight provides the energy,
  - electrons are boosted "uphill" and added to carbon dioxide, and
  - sugar is produced.

- During photosynthesis, water is split into
  - hydrogen and
  - oxygen.
- Hydrogen is transferred along with electrons and added to carbon dioxide to produce sugar.
- Oxygen escapes through stomata into the atmosphere.

A Photosynthesis Road Map

- Photosynthesis occurs in two multistep stages:
  - the **light reactions** convert solar energy to chemical energy and
  - the **Calvin cycle** uses the products of the light reactions to make sugar from carbon dioxide.

A Photosynthesis Road Map

- The initial incorporation of carbon from the atmosphere into organic compounds is called **carbon fixation**.
  - This lowers the amount of carbon in the air.
  - Deforestation reduces the ability of the biosphere to absorb carbon by reducing the amount of photosynthetic plant life.

Figure 7.3-1
Figure 7.3-2

THE LIGHT REACTIONS: CONVERTING SOLAR ENERGY TO CHEMICAL ENERGY

- Chloroplasts
  - are chemical factories powered by the sun and
  - convert sunlight into chemical energy.

Figure 7-UN02

The Nature of Sunlight

- Sunlight is a type of energy called radiation, or electromagnetic energy.
- The distance between the crests of two adjacent waves is called a **wavelength**.
- The full range of radiation is called the **electromagnetic spectrum**.

Figure 7.4
Figure 7.5
Figure 7.5a
Figure 7.5b

The Process of Science:
What Colors of Light Drive Photosynthesis?

- **Observation**: In 1883, German biologist Theodor Engelmann saw that certain bacteria tend to cluster in areas with higher oxygen concentrations.
- **Question**: Could this information determine which wavelengths of light work best for photosynthesis?
- **Hypothesis**: Oxygen-seeking bacteria will congregate near regions of algae performing the most photosynthesis.
- **Experiment**: Engelmann
  - laid a string of freshwater algal cells in a drop of water on a microscope slide,
  - added oxygen-sensitive bacteria to the drop, and
  - used a prism to create a spectrum of light shining on the slide.
- **Results:** Bacteria
  - mostly congregated around algae exposed to red-orange and blue-violet light and
  - rarely moved to areas of green light.
- **Conclusion**: Chloroplasts absorb light mainly in the blue-violet and red-orange part of the spectrum.

Figure 7.6

Chloroplast Pigments

- Chloroplasts contain several pigments:
  - **Chlorophyll *a***
    - absorbs mainly blue-violet and red light and
    - participates directly in the light reactions.
  - **Chlorophyll *b***
    - absorbs mainly blue and orange light and
    - participates indirectly in the light reactions.
- Carotenoids
  - absorb mainly blue-green light,
  - participate indirectly in the light reactions, and
  - absorb and dissipate excessive light energy that might damage chlorophyll.

- The spectacular colors of fall foliage are due partly to the yellow-orange light reflected from carotenoids.

Figure 7.7

How Photosystems Harvest Light Energy

- Light behaves as **photons**, a fixed quantity of light energy.
- Chlorophyll molecules absorb photons.
  - Electrons in the pigment gain energy.
  - As the electrons fall back to their ground state, energy is released as heat or light.

Figure 7.8
Figure 7.8a
Figure 7.8b

- In the thylakoid membrane, chlorophyll molecules are organized with other molecules into photosystems.
- A **photosystem** is a cluster of a few hundred pigment molecules that function as a light-gathering antenna.
- The **reaction center** of the photosystem consists of chlorophyll *a* molecules that sit next to another molecule called a **primary electron acceptor**, which traps the light-excited electron from chlorophyll *a.*
- Another team of molecules built into the thylakoid membrane then uses that trapped energy to make
  - ATP and
  - NADPH.

Figure 7.9
Figure 7.9a
Figure 7.9b

How the Light Reactions Generate ATP and NADPH

- Two types of photosystems cooperate in the light reactions:
  - the water-splitting photosystem and
  - the NADPH-producing photosystem.

Figure 7.10-1
Figure 7.10-2
Figure 7.10-3

- The light reactions are located in the thylakoid membrane.
- An electron transport chain
  - connects the two photosystems and
  - releases energy that the chloroplast uses to make ATP.

Figure 7.11
Figure 7.11a
Figure 7.11b
Figure 7.12

THE CALVIN CYCLE: MAKING SUGAR FROM CARBON DIOXIDE

- The Calvin cycle
  - functions like a sugar factory within a chloroplast and
  - regenerates the starting material with each turn.

Figure 7-UN03
Figure 7.13-1
Figure 7.13-2
Figure 7.13-3
Figure 7.13-4

Evolution Connection:
Solar-Driven Evolution

- **C_3 plants**
  - use CO_2 directly from the air and
  - are very common and widely distributed.
- **C_4 plants**
  - close their stomata to save water during hot and dry weather and
  - can still carry out photosynthesis.
- **CAM plants**
  - are adapted to very dry climates and
  - open their stomata only at night to conserve water.

Figure 7.14
Figure 7.14a
Figure 7.14b
Figure 7.14c
Figure 7-UN04
Figure 7-UN05
Figure 7-UN06
Figure 7-UN07