Essential idea:
• Photosynthesis uses the energy in sunlight to produce the chemical energy needed for life.

Molecular Biology
2.9- Photosynthesis

$6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

Carbon dioxide Water Sugar Oxygen

Nature of science:
• Experimental design
  – controlling relevant variables in photosynthesis experiments is essential. (3.1)

Equation
• Photosynthesis is the production of carbon compounds in cells using light energy.
  – Compare to cell respiration

$6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

Carbon dioxide Water Sugar Oxygen

Properties of Light
• Visible light has a range of wavelengths with violet the shortest wavelength and red the longest.
  – Remember ROY-G-BIV
  – Visible range is about 400nm-700nm
  – Small wavelength = large energy; large wavelength = low energy

Chlorophyll
• Chlorophyll absorbs red and blue light most effectively and reflects green light more than other colors.
  – Chlorophylls a and b are most prevalent
  – Accessory pigments contribute other colors
Absorbance and Action Spectrum

- An absorbance spectra show what wavelengths are absorbed by pigments.
- An action spectra shows relative rate of photosynthesis for wavelength.

Absorbance and Action Spectrum

- Action spectrum of photosynthesis mimics chlorophyll absorbance.
- Chlorophyll is most important pigment.
- Lack of light in the fall brings causes chlorophyll breakdown.
- Brings out accessory pigments (change colors).

Limiting Factors on Photosynthetic Rates

2.9 UE: Temperature, light intensity and carbon dioxide concentration are possible limiting factors on the rate of photosynthesis.

Light-dependent Reactions

- Energy is needed to produce carbohydrates and other carbon compounds from carbon dioxide.
  - Occur in the thylakoid membranes.
  - Oxygen is produced in photosynthesis from the photolysis of water.
  - ATP and NADPH are produced.
  - Requires two light-gathering units; photosystem I (PS I) and photosystem II (PS II).
**Light-dependent Reactions**

- **Photosystems**
  - A pigment complex and electron acceptor.
  - Pigments transfer energy to chlorophyll reaction center.
  - Chlorophylls absorb free energy from light, boosting electrons to a higher energy level in Photosystems I and II.

**Noncyclic Electron Pathway**
- Photosystem II absorbs solar energy.
- High-energy electrons (e-) leave the reaction-center chlorophyll molecule (P680).
- PS II takes replacement electrons from H₂O, which splits, releasing O₂ and H⁺.
- The H⁺ ions temporarily stay within the thylakoid space.
- High-energy electrons that leave PS II are captured by an electron acceptor, which sends them to an electron transport system.

**ATP Production**
- Electrons from PS II flow to ETC.
- As electrons flow, they give up energy to pump H⁺ from stroma into thylakoid space.
- The thylakoid space acts as a reservoir for H⁺ ions; each time H₂O is split, two H⁺ remain.
- Chemiosmosis occurs forming ATP in the stroma.

**NADPH Production**
- Low-energy electrons enter pigment of complex PS I from ETC and sunlight.
- High-energy electrons leave reaction-center chlorophyll (P700) and are captured by an electron acceptor.
- The electron acceptor passes them on to NADP⁺.
- NADP⁺ becomes NADPH (builds up in the stroma).

**Cyclic Electron Pathway**
- PS I (P700) pigment complex absorbs solar energy.
- High-energy electrons leave PS I reaction-center.
- Build up of NADPH inhibits its production pathway.
- Electrons therefore travel down electron transport system.
- Produces extra ATP in stroma.

**Light-independent Reactions**
- Take place in the stroma.
- Occur in either the light or the dark.
- Use NADPH and ATP to reduce CO₂.
- Called the Calvin Cycle (C₃ Cycle) after Melvin Calvin.
Light-independent Reactions

- Calvin Cycle Has Three Stages
  - Fixing Carbon Dioxide
    - The attachment of CO₂ to RuBP (ribulose bisphosphate)
    - Enzyme RuBP carboxylase (Rubisco) catalyzes reaction

- Light-independent Reactions
  - Reducing PGA
    - Each PGA molecule undergoes reduction to PGAL (glyceraldehyde phosphate)
    - Light-dependent reactions provide NADPH (electrons) and ATP (energy) to reduce PGA to PGAL.

- Light-independent Reactions
  - Regenerating RuBP
    - Every three turns of Calvin cycle, five molecules of PGAL are used to re-form three molecules of RuBP.
    - Every three turns of Calvin cycle, there is net gain of one PGAL molecule; five PGAL regenerate RuBP.

Evolution of Photosynthesis

- Photosynthesis first evolved in prokaryotic organisms
- Scientific evidence supports that prokaryotic (bacterial) photosynthesis was responsible for the production of an oxygenated atmosphere
- Photosynthetic pathways were the foundation of eukaryotic photosynthesis. (Photorespiration, C₄ and CAM Plants)

Effects of Photosynthesis on Earth

- Primordial Earth had a reducing atmosphere that contained very low levels of oxygen gas (approx. 2%). Debatable?
- 2.5 bya Cyanobacteria (prokaryotes) containing chlorophyll first performed photosynthesis

Effects of Photosynthesis on Earth

- Photosynthesis creates oxygen gas as a by-product (by the photolysis of water).
- Oxygen levels remained at 2% until about 700 mya.
- From 700 mya until the now there has been a significant rise to 21%. 
**Effects of Photosynthesis on Earth**

- Oxygen generation also allowed the formation of an ozone layer ($O_3$).
  - Shielded the Earth from damaging levels of UV radiation.
  - Evolution of a wider range of organisms.

**Ozone Layer**

- Shielded the Earth from damaging levels of UV radiation.

**Banded Iron Formations**

- Iron compounds in the oceans were oxidized:
  - The insoluble iron oxides precipitated onto the seabed.
  - Time and further sedimentation has produced rocks with layers rich in iron ore called the banded iron formations.

**Photorespiration**

- In hot weather, stomates close to save water; $CO_2$ concentration decreases in leaves; $O_2$ increases.
- In $C_3$ plants, $O_2$ competes with $CO_2$ for the active site of rubisco.
- Called "photorespiration" since oxygen is taken up and $CO_2$ is produced.
- No sugar or ATP is produced.
- Relic of evolution when $O_2$ was in short supply.

**C$_4$ Plants**

- Sugarcane, Corn, Grasses
- Fix $CO_2$ by first forming a C$_4$ molecule
- Shuttle C$_4$ into Bundle sheath cells
- $CO_2$ is released and used in Calvin Cycle.
- In hot, dry climates, net photosynthetic rate of C$_4$ plants (e.g., corn) is 2-3 times that of C$_3$ plants.

**CAM (Crassulacean-Acid Metabolism) Plants**

- Succulent desert plants, cacti, pineapple
- CAM plants open stomates only at night
- Store $CO_2$ as a C$_4$ molecule
- Release $CO_2$ during the day in Calvin Cycle