Biology Chapter 7
Photosynthesis

Introduction

Nearly all living things depend on the cellular process called photosynthesis. Each year this process produces more than 150 billion metric tons of sugar (carbohydrate). Almost all plants and animals, you and I included, depend on this sugar for sustenance. Visible light provides the energy for photosynthesis. Plants tend to appear green because of chlorophyll, which reflects green light and absorbs other wavelengths. Light excites electrons of pigments in cellular organelles called chloroplasts. The movement of these electrons through various substances in the membranes of chloroplasts results in formation of energy-rich molecules (ATP). These energy-rich molecules provide power for the set of photosynthetic reactions resulting in formation of carbohydrate molecules using carbon from atmospheric carbon dioxide. The summary chemical equation for this process is:

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

Being alive is work. Cells organize small organic molecules into polymers such as the proteins, carbohydrates, and so forth you studied last week. Cells move substances across membranes, change shape, grow and reproduce. Cells have complex structures that are intrinsically unstable; work is required to maintain this structure and order. To do work, cells must extract energy from nutritive molecules. Plants and animals both utilize the process of cellular respiration to obtain energy from complex molecules. The chemical reactions involved in this process release energy which is harnessed at the cellular level in the form of ATP. The summary chemical equation for this process is:

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

Note the relationship of this equation to the photosynthesis equation. One is the reverse of the other. This relationship expresses the fact that these two processes are inextricably linked in the living world. Aerobic cellular respiration is dependent on the products of photosynthesis and photosynthesis utilizes the products of cellular respiration. We will explore this relationship in more detail when we examine ecological issues later in the course. For now, the focus is on the processes themselves.

Course Outcomes

Describe photosynthesis including its biological importance to life on this planet.

Learning Goals

- Describe the chloroplast and parts
- Describe the flow of electrons from water through the electron transport system to their final disposition (the Z-scheme)
- Understand and relate how a pH gradient between the thylakoid membrane and stroma is utilized by the ATPase channel protein in the production of ATP.
- Describe the Light Dependent and Light Independent Reactions where each takes place and the produce from each reaction
Assignments:

1. Go to the following Web site:

   http://photoscience.la.asu.edu/photosyn/study.html

   This is an essay on the importance of photosynthesis. Read this to get a sense of the many ways we are dependent on this process.

2. Go to the following Web site:

   http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookPS.html

I. Photosynthesis

A. Energy and materials for the reaction

   1. The light-dependent reaction (Rxn) converts light energy to chemical energy (which is then stored in ATP)
      a. Liberated electrons and protons (H+) from water are picked up by NADP++

   2. The light-independent Rxn assemble sugars and other organic molecules
      a. Using ATP, NAPDH and CO₂

   3. Overall for Rxn for the synthesis of sugar:

      \[ H_2O + CO_2 \rightarrow 6O_2 + C_nH_{2n}O_n \]

B. Where the Rxn takes place

   1. The two stages of photosynthesis take place in the chloroplast

   2. Light dependent Rxn occur in the thylakoid membrane system
      a. The thylakoids are folded into grana (stacks of disks) with channels.
      b. The interior spaces or lumen of the thylakoid disks and channels are continuous.

   3. Carbohydrate formation occurs in the stroma (semifluid) area that surrounds the grana

II. Light-Trapping pigments

A. Light energy is packaged as photons, which vary in energy as a function of wavelength
1. Plants use only a small range (400 - 750 nm) of wavelength for photosynthesis

2. Most of these wavelengths are the ones we see as visible colors

B. Pigments absorb light energy and give up electrons

1. Chlorophyll pigments absorb blue and red
   a. Reflect green (the color of leaves).

2. Carotenoid pigments absorb violet and blue
   a. Reflect yellow, orange, and red.

III. Light-dependent Rxn

A. Three events occur:

1. Pigments absorb sun light energy and give up electrons

2. The pigments that gave up the electrons in the first place get electron replacements

3. Electron and hydrogen transfers from water leads to ATP and NADPH formation

B. Photosystems

1. A photosystem is a cluster of 200 to 300 light-absorbing pigments located in the thylakoid

2. The pigments ‘harvest’ sunlight
   a. Absorbed photons of energy boost electrons to a higher energy level
   b. The electrons quickly return to the lower level and release energy
   c. Released energy is trapped by chlorophylls, which act as a sink for energy harvested by all pigments
   d. The trapped energy is then used to transfer a chlorophyll electron to an acceptor molecule

C. ATP and NADPH loading up energy, hydrogen and electrons

1. Electron transport system are organized in a sequences of enzymes and other proteins bound in thylakoid membrane
   a. Electrons extracted from H₂O by the chlorophyll molecule pass through one or two electron transport systems in the thylakoid membrane to produce NADPH from NADP⁺
   b. The flow of H⁺ through the thylakoid membrane drives the formation of ATP
2. Cyclic pathway - photosystem I only
   a. In the cyclic pathway of ATP formation, electrons are first excited, pass through and
electron transport system, and then return to the original photo-system
   b. The cyclic pathway is an ancient way to make ATP from ADP; used by early bacteria.
3. Noncyclic pathway -- photosystem II
   a. The noncyclic pathway of ATP formation transfers electrons through two photosystems
and two electron transport systems in the thylakoid membranes
   b. The pathway begins when photosystem II absorbs energy splitting water to harvest electrons
and hydrogen releasing $O_2$
      1) Boosted electron moves through a transport system that releases energy from
         \[ \text{ADP} + P_i \rightarrow \text{ATP} \]
      2) An electron fills “hole” left by an electron in photosystem I
   c. Pathway continues when Photosystem I absorbs sun light energy
      1) Energy hole is filled by electron from photosystem II
      2) Boosted electron from Photosystem I passes to acceptor, through the electron
transport system and finally the electron joins NADP$^+$ to form NADPH (which along
with ATP can be used in the synthesis of organic compounds)
D. Oxygen
   1. Oxygen is a by product of the noncyclic pathway
IV. Dark (Light-Independent) Rxn
A. Overview
   1. The participants and their roles in the synthesis of carbohydrate are
      a. ATP, which provides energy
      b. NADPH, which provides hydrogen atoms and electrons
      c. Atmospheric air, which provides the carbon and oxygen from carbon dioxide.
   2. These reactions are not dependent on sunlight directly (hence, light independent reaction)
B. Capturing carbon

1. Carbon dioxide diffuses from the air through the leaf’s stomates, across the
   plasma membrane of the plant cell, and into the stroma.

2. Carbon fixation occurs when CO₂ becomes attached to ribulose bisphosphate (RuBP) to
   form a six-carbon intermediate.

C. Building the Glucose subunits

1. The attachment of CO₂ to RuBP is the first step in the cyclic Calvin-Benson pathway:
   a. The six-carbon intermediate, an unstable produce, splits at once to form two PGA
      (phosphoglycerate) molecules
   b. Each PGA then receives a phosphate from ATP plus H⁺ and electrons from NADPH to
      form PGAL (phosphoglyceraldehyde)
   c. Most of the PGAL molecules continue in the cycle to fix more carbon dioxide but two
      PGAL join to form a sugar phosphate, which will be modified to sucrose, starch and
      cellulose

2. Final PRODUCT

\[ \text{H}_2\text{O} + \text{CO}_2 + \text{ATP} + \text{NADPH} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{ADP} + \text{Pi} + \text{NADP}^+ + \text{H}_2\text{O} + \text{H}^+ \]