SA #33-34	PHOTOSYNTHESIS I: PHOTOCHEMISTRY
BIO 2500	Stern et al., Chapter 10, p 165-176

OVERVIEW: In our introductory study of *plant water relationships* we saw the importance of "water work." Plants benefit from "water work" when water has sufficient free energy (high enough Ψw) to do this work. But this energy of water molecules is *external energy* and does not involve *chemical bond energy* of H_2O directly. We now turn to the topic of photosynthesis, perhaps the most important biological process in support of life on Earth. Photosynthesis is responsible for the conversion of light energy into chemical bond energy (*internal energy*) of molecules such as ATP and $NADPH_2$. The phase of photosynthesis that produces these two energetic molecules is referred to as *photochemistry*.

READING: Stern, *et al.* Chapter 10, pages 165-176. Also, refer to your laboratory notes and labeled diagrams from Lab Ex. #11 "Plant Cells," Lab Ex. #14 "Leaves," and the Lab Inquiry Sheet in which demonstrations of pigment extraction, starch synthesis, and fluorescence were used to give insights into photosynthesis.

PROCEDURE: The **COMPREHENSION QUESTIONS** below and the *Study Outline* will highlight the emphasis on photochemistry in Chapter 10. Peruse the assigned reading, noting the "Chapter Overview", page 166, the major headings, and illustrations. Then, as you read, use the *Study Outline* to guide you in learning the major concepts and processes by filling in the blanks and making additional notes to express your developing understanding of photosynthesis.

COMPREHENSION QUESTIONS: [These reflect the major parts of the Study Outline, p 33.2 ff.]

1. Describe the nature of *light energy* in the broader context of *electromagnetic radiation*. Which wavelengths are most harmful? How do these wavelengths cause the harm?

2. What happens when visible light is absorbed by matter? By chlorophyll in particular?

3. List and discuss the roles of Chlorophyll *a* and *b*, carotenoids, and xanthophylls. Explain how you would distinguish these pigments if given a molecular structure diagram? Describe their solubility in water *versus* organic solvents.

4. Discuss evidence that chlorophyll and carotenoids are really the chief photosynthetic pigments. What is the evidence that chlorophyll *b* and carotenoids are accessory pigments?

5. Write a sentence or two giving an overview of the photochemical and biochemical aspects of photosynthesis.

6. How do the photochemical reactions convert light energy into ATP and NADPH?

7. Why does cyclic photophosphorylation fail to permit the synthesis of NADPH and the hydrolysis of water but allow the synthesis of ATP? Suggest a benefit of this provision.

CONTEMPORARY UNDERSTANDING OF PHOTOSYNTHESIS

I. NATURE OF LIGHT

A. ELECTROMAGNETIC SPECTRUM -- range of wavelengths of solar radiation (Fig. 10-2)

Concept: When electromagnetic radiation is absorbed by matter *photons* (individual packets of energy) each impart one *quantum* of energy which affects the electrons of atoms. The effect upon electrons depends upon wavelength of light absorbed. The energy per photon is inversely related to wavelength as follows:

	Ultraviolet Radiation	**Visible Radiation**	**Infrared Radiation**
λ	<400 nanometers (nm)	400-700 nanometers	>700 nanometers (nm)
quantum energy *(hv)*	HIGH -- called ionizing radiation (expels electrons from atoms)	INTERMEDIATE -- photons of light simply excite electrons without causing ionization	LOW – photons cause rotation and vibrations of molecules; sensed as heat
Signifi-cance	Absorbed by glass and O_3 gas in stratosphere; otherwise can damage cells	Usable in photosynthesis and photosensitive organs/organelles of motile creatures	Insufficient energy to excite electrons of chlorophyll; causes rotation of groups as in IR spectroscopy

II. PIGMENTS

A. Definition: Molecules that preferentially absorb certain wavelengths and reflect others

B. Types of Photosynthetic Pigments – *i.e.* matter designed to convert photon energy to chem. energy
1. Chlorophylls (esp. Chl *a* and Chl *b* in Plantae)
2. Carotenoids -- red-yellow *beta*-carotene in carrot, tomato, etc.
3. Xanthophylls -- similar color and structure as carotenoids

C. Location of Photosynthetic pigments – as you know, leaves are not totally green:

Study Figure 10.8 and complete the following statement: "Of all the cells of a typical dicot leaf, only the G_____ cells and the M_____ cells are green. Then, within these cells, the green is localized in C_____. Within the chloroplasts, only the T_____ membranes are green.

D. Arrangement of Pigments in Photosystems and Their Roles in Light Absorption:

Concept: Chlorophylls and carotenoids are arranged in chloroplast thylakoids (Fig. 10.8 & 9) along with proteins and lipids into photosystems each consisting of a reaction center and antenna complex:

1. **Reaction Center** – arrangement of Chlorophyll ___ (primary pigment) and proteins where light is absorbed and electrons are transferred to electron acceptor molecules.
2. **Antenna Complex** – arrangement of Chlorophyll ___, Chlorophyll ___, C _____, and X_____. These accessory pigments absorb photons and transfer the quanta of energy (but not electrons) to reaction centers.

E. LIGHT ABSORPTION BY MATTER AND PHOTOSYNTHETIC PIGMENTS:

1. Matter (atoms/molecules) in general – _____

2. Chlorophyll extracted in ethanol -- _____

3. Chlorophyll in intact chloroplasts – _____

4. Define *fluorescence* _____

_____

5. Why is fluorescence rare in intact leaves?_____

_____

III. PHOTOSYNTHESIS -- OVERVIEW OF THE PROCESS:

A. NUTSHELL -- in photosynthesis, absorbed *light energy* is used during *photochemical reactions* to form *ATP* and *NADPH* which, in turn, are used in *biochemical reactions* that convert CO_2 to 3-PGA, the building block for all other plant organic matter.

B. Relationship between *photochemical* and *biochemical* reactions -- Study Figure 10.5:

1. Photochemical Reactions -- involve absorption of *photons* which excite electrons.

a. Location -- hollow, chl-containing membrane sacs called _____

b. Two sub-parts -- *electron transport* and *photophosphorylation* (Fig. 10.8)

c. Electrons are removed from _____ , NADPH is formed and _____

is released as a gas. Also, _____ is formed by photophosphorylation.

2. Biochemical Reactions -- products of photochemical react. used in enzyme reactions

a. Location -- the non-pigmented part of the chloroplast called _____

b. NADPH and ATP are utilized to convert (biochemically reduce) CO_2 gas (absorbed by the leaf) into 3-PGA.

IV. PHOTOCHEMICAL REACTIONS -- See Figure 10.8 and 10.9 (two different models)

A. NONCYCLIC ELECTRON FLOW -- NADPH Synthesis

1. What is the origin of each 2 electrons transported? _____

2. When 2 e^- reach $NADP^+$, the product is _____

3. How is H_2O oxidized in Photosystem II? _____

_____

4. What causes electrons to move from Photosystem II to PS I?

_____

5. How many photons are necessary to release one molecule of O_2? _____

B. NONCYCLIC PHOTOPHOSPHORYLATION (ATP Synthesis) – Two views (Figure 10.8)

1. Redox View: ATP is synthesized when coupled to exothermic redox reactions of electron transport

2. Chemiosmotic View: ATP is synthesized during discharge of a pH (or $[H^+]$) gradient which is maintained across the thylakoid membrane by light-driven electron transport.

Evidence: When isolated chloroplasts are illuminated, pH increases in the medium

C. PHOTOCHEMICAL REACTIONS -- Summary Reactions:

1. Electron Transport: $2H_2O + 2NADP^+ \text{---> } 2\ NADPH\ +\ 2H^+ + O_2$

2. Photophosphorylation: $2ADP\ +\ 2Pi\ \text{----> } 2ATP$

D. CYCLIC PHOTOPHOSPHORYLATION -- Figures 10.8

1. The cyclic path of electrons: _____

2. NADPH is not formed since excited electrons return to P*700* (in Photosystem I).

3. Why can't *cyclic electron flow* cause splitting of H_2O? _____

_____

4. Benefit of cyclic photophosphorylation: _____

_____

GENERAL BOTANY **NAME** _____

Take-at-Home Quiz (SA #34) **Lab Section (circle one): T W R**

INSTRUCTIONS: Write the upper case letter representing the correct choice in the blank provided. Work alone to complete the quiz, or you may work with others, but be sure you are mentally involved in answering the questions to assess your progress and to stimulate additional learning.

____ 1. Select the primary event or cause of guard cell "puckering" and stomatal opening:
A. H^+/K^+ ATPase in guard cell membranes
B. light absorption and resultant initiation of photosynthesis
C. lowered solute potential and water potential within guard cells
D. movement of water into guard cells by osmosis, causing increased Ψp
E. decrease in concentration of carbon dioxide within the atmosphere if the leaf mesophyll

____ 2. Which of the following is not essential for plant embryos to "explode" out of seed coats?
A. emergence of lateral roots from the radicle
B. cell division in the apical meristem of the radicle
C. cell enlargement causing elongation of the radicle
D. swelling of starches and protein within the embryo and endosperm
E. imbibition (absorption of water by colloidal substances–*e.g.* starch)

____ 3. All of the following will enable roots to "push" through soil <u>except</u>:
A. cell division
B. uptake of solute ions from the soil
C. maintenance of soil water in a hypertonic state
D. cell elongation via turgor pressure from within cells
E. uptake of water from the higher Ψw of the soil environment

____ 4. What enables roots to bend downward and stems to "bend" upward? [Stern, p. 66-7, and 202-204]
A. turgor pressure within elongating cells
B. movement of amyloplasts, and Ca^{2+}, in direction of gravity
C. the hormone IAA (auxin) unevenly distributed in elongation region
D. cell elongation is inhibited on the underside of the root and stimulated on underside of the stem
E. All of the above processes contribute.

____ 5. Theoretically, a water molecule diffusing from the soil to the root xylem must at some point pass through all of the following <u>except</u>:
A. cytoplasm of cortical cells
B. symplast of the endodermis
C. cell walls of epidermal cells
D. plasma membrane and/or plasmodesmata

____ 6. All of the following are related to the phloem tissues and their function <u>except</u>:
A. broad rays
B. sieve tubes
C. turgor pressure within symplast
D. active transport of sugars, causing Ψw gradients
E. a negative Ψp (*i.e.* tension) during sunny afternoons