SA #50	PHOTOSYNTHESIS II: BIOCHEMICAL REACTIONS
BIO 2130	Stern et al., Chapter 10 and Molles, Chapter 6

OVERVIEW: Welcome to the last regular assignment in General Botany and Ecology. It is fitting that we end with a study of how plants can acquire CO_2 gas from the atmosphere while avoiding the loss of water from the moist chlorenchyma. Here is an excellent opportunity to observe how an understanding of *ecology* can enhance our understanding of *physiology* and *biochemistry*.

READING: "Carbon Fixation" from an Ecology perspective – Read Molles, Chapter 6, pages 147-150
Next, read Stern, *et al*. Chapter 10, pages 182-186 [some references back to pages 171-180.]

PROCEDURE: The **LECTURE DISCUSSION QUESTIONS** below and the *Study Outline* will highlight the emphasis on "Carbon Fixation" in Chapter 10. First, as you read, use the *Study Outline* below 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. Then, use what you have learned to write answers to the **LECTURE DISCUSSION QUESTIONS.** They will challenge you to apply concepts to the larger context of photosynthesis as a whole process and the related ecological principles of "plant and environment.".

LECTURE DISCUSSION QUESTIONS: [These reflect the major parts of the Study Outline to follow.]

1. Principle: *Light is essential to the biochemical reactions of CO_2 fixation in the Calvin Cycle.*
   a. Use Figures 10.5 and 10.9 (Stern) to explain how light is essential to the function of the Calvin Cycle?
   b. Explain the physical locations of the *photochemical* and *biochemical* reactions within the chloroplast.
   c. What is one additional role of light without which the Calvin Cycle pathway would not function?
   d. Given your answers to a. and b. in what sense is the term "light-independent reactions" a misnomer?

2. Stoichiometry of Photosynthesis: For each mole of CO_2 fixed, how many moles of ATP and NADPH are required and how many moles of O_2 are produced? How is the extra ATP produced if noncyclic photophosphorylation produces ATP and NADPH in a one-to-one ratio?

3. Calvin Cycle Pathway: Use Figure 10.10 to explain three possible fates of soluble carbohydrates such as GA3P in the biochemical reactions.

4. Principle: *Ecology enhances our understanding of physiology and biochemistry and vice versa.* Apply this principle to the following questions:
   a. What is the biochemical role of the Calvin Cycle enzyme *rubisco* in photosynthesis?
   b. In what sense does the fate of whole food webs rest on what happens at the active site of *rubisco*?

5. Stomata and Carbon Fixation: Given the "Principle" in #4 above, explain the following:
   a. When dawn occurs, explain the scenario from SA #48 of how stomata normally "pucker" open.
   b. Propose a likely source of the ATP necessary to cause the "water work" of opening the stomata.
   c. How might reduced leaf Ψw affect the rate of *rubisco* enzyme activity? The rate of NADPH synthesis? Note: Water doesn't limit photosynthesis by being too scarce for photolysis in PS II.
   d. How could chloroplast thylakoids still produce ATP when stomata are closed and NADPH is not used in the Calvin Cycle as readily? Note: Your answer to 5. c. should account for the fact that noncyclic photophosphorylation cannot produce ATP without producing NADPH?

6. Alternate Biochemical Pathways of Photosynthesis:
   a. Explain how the C4 pathway works in C4 plants and how ecology enhances your understanding of it.
   b. Explain how the CAM pathway works and the ecological benefit of it in CAM plants.

I. BIOCHEMICAL REACTIONS -- See Fig. 10.10 [Fig. 10.5 relates biochemical to the photochemical reactions)

A. OVERVIEW: Chemical bond energy of ATP and the reducing power of NADPH are released from the grana to the *stroma* where they are used to drive the Calvin Cycle, an autocatalytic biochemical pathway that converts CO_2 to *3-phosphoglyceric acid* (3-PGA) and other organic compounds.

B. CARBOXYLATION -- attachment (fixation) of CO_2 to an organic acceptor molecule, *Ribulose bisphosphate* (RuBP), a 5-carbon molecule

1. Enzyme responsible: Ribulose bisphosphate carboxylase, or ________________________

2. Biological and global significance: ____

3. Reaction: CO_2 + RuBP ---> 2 3-PGA

C. CALVIN CYCLE

1. 3-PGA is later reduced by NADPH to ---> glyceraldehyde-3-Phosphate (GA3P)

2. Three major destinations of GA3P:

a. Some is used to make intermediates in the pathway to regenerate RuBP

b. Some is converted to sugar-phosphates (*e.g.* Fructose-P) and to the disaccharide

_________________ which is exported via the phloem

c. Some is converted to hexose-P monomers which then form ______________ which is stored in the chloroplast during the day as we demonstrated via the iodine test.

3. How does the above pathway from PGA to Fructose-P compare to *glycolysis* (Fig. 10.14)?

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D. VARIATIONS OF BIOCHEMICAL PATHWAYS

1. "C_3 PLANTS" - species (mostly temperate) in which 3-PGA is first organic product

Example C_3 species: <u>Most tree species, cool season grasses (e.g. bluegrass, rye), legumes, *etc.*</u>

2. "C_4 PLANTS" - species (mostly tropical, with *Kranz anatomy*) which combine CO_2 into a 4-carbon product such as oxalacetate (OAA), in mesophyll cells, and then shuttle the carbon to the bundle sheath cells where *rubisco* converts the carboxyl group into 3-PGA [See Corn leaf]

Example C_4 species: ____

On 26 October 2000, *Nature* reported the discovery of both the C_3 and C_4 pathways in a marine diatom (phylum Chromophyta). In this unicellular organism, the two paths are kept separate by having the C_4 path in the cytosol, and the C_3 path confined to the chloroplast. The presence of a C_4 pathway probably reflects the frequent low concentrations of CO_2 in ocean waters. Reference: http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/C4plants.html

E. PROBLEM WITH RUBISCO IN C_3 PLANTS – "Photorespiration"

1. Low affinity for CO_2 relative to O_2 makes O_2 an effective competitive inhibitor of carboxylation

2. RESULT: C_3 photosynthesis is less efficient than C_4, especially in high temperatures and high light. Explain how the conditions of high temperature and high light intensity affect CO_2 concentration and O_2 concentration. Relate this to the problem of competitive inhibition of Rubisco and resultant *photorespiration*.

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3. C_4 PLANTS: In light of your answer to Question #2 above, explain how C_4 plants overcome the problems associated with high temperature and highlight intensity with respect to the following:

Leaf Anatomy: ____

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Enzyme Pathway: ____

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F. Discuss relative "fitness" of C_3 and C_4 plants in different climates. Are C_4 plants always more fit?

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G. CAM (crassulacean acid metabolism) plants:

1. Name several plant species that possess crassulacean acid metabolism (CAM).

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2. What cellular locations and temporal considerations are involved in crassulacean acid metabolism? ____

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3. How are CAM plants xeromorphic biochemically speaking? ________________________

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GENERAL BOTANY & ECOLOGY **NAME** ________________________________

Take-at-Home Quiz (SA #50) **Lab Section (circle one): T W R**

INSTRUCTIONS: Unscramble the following statements by numbering each event in order from first to last. You should have this quiz completed and ready to hand in when requested during lecture either on or after the date of the assignment to which this quiz is attached. 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.

A. ____ LIGHT ABSORPTION BY ACCESSORY PIGMENTS OF PHOTOSYSTEMS II AND I

B. ____ PRIMARY ACCEPTORS ARE OXIDIZED CAUSING e^- TRANSPORT TO $NADP^+$ + H^+, FORMING NADPH; ATP IS FORMED BY NONCYCLIC PHOTOPHOSPHORYLATION

C. ____ TWO PHOSPHOGLYCERIC ACID MOLECULES ARE REDUCED TO GLYCERALDEHYDE-3-P(GA3P), WHICH IS CONVERTED TO <u>HEXOSE SUGAR</u> (6C), OR TO <u>STARCH</u> IN THE STROMA

D. ____ HEXOSE SUGARS OUTSIDE THE CHLOROPLASTS ARE CONVERTED TO <u>SUCROSE</u>, A DISACCHARIDE WHICH IS EXPORTED IN THE PHLOEM.

E. ____ ATP AND NADPH ARE AVAILABLE FOR BIOCHEMICAL REACTIONS (Calvin Cycle) IN STROMA; "EXTRA ATP" IS SYNTHESIZED BY CYCLIC PHOTOPHORYLATION

F. ____ PRIMARY ACCEPTORS ACCEPT ELECTRONS FROM P*680* AND P*700*, RESPECTIVELY

G. ____ ELECTRON EXCITATIONS OF CHLOROPHYLL-P*68O* AND -P*7OO*

H. ____ RuBP + CO_2 —> 2 3-PGA (3-PHOSPHOGLYCERIC ACID, A 3-C COMPOUND)