

OVERVIEW: Welcome to the last regular assignment in General Botany. It is fitting that we end with a study of how land plants can acquire CO₂ gas from the atmosphere while avoiding the loss of water from the moist mesophyll. As you proceed, you will see how an understanding of *plant physiology* and *biochemistry* can aid our understanding of *ecology* and *vice versa*.

READING: “Carbon Fixation” from an Ecology perspective – Read Molles, Chapter 6, pages 135-138 Next, read Stern, *et al.* Chapter 10, pages 176-180 [some references back to pages 165-176.]

PROCEDURE: The **COMPREHENSION QUESTIONS** below and the *Study Outline* will highlight the emphasis on “Carbon Fixation” in Chapter 10. First, as you read, use the *Study Outline*, page 35.2 ff., for 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 **COMPREHENSION 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.”.

COMPREHENSION QUESTIONS: [These follow the Study Outline to follow.]

1. Principle: *Light is essential to the biochemical reactions of CO₂ 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 CO₂ fixed, how many moles of ATP and NADPH are required and how many moles of O₂ 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 #31 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 Ψ_w 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.

STUDY OUTLINE – Photosynthesis II: Biochemical Reactions (Carbon Fixation)

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 CO₂ to *3-phosphoglyceric acid* (3-PGA) and other organic compounds.

B. CARBOXYLATION -- attachment (fixation) of CO₂ to an organic acceptor molecule, *Ribulose biphosphate* (RuBP), a 5-carbon molecule

1. Enzyme responsible: Ribulose biphosphate carboxylase, or _____
2. Biological and global significance: _____
3. Reaction: CO₂ + 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)?

D. VARIATIONS OF BIOCHEMICAL PATHWAYS

1. "C₃ PLANTS" - species (mostly temperate) in which 3-PGA is first organic product
Example C₃ species: Most tree species, cool season grasses (e.g. bluegrass, rye), legumes, etc.
2. "C₄ PLANTS" - species (mostly tropical, with *Kranz anatomy*) which combine CO₂ 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 x-sec.]

Example C₄ species: _____

On 26 October 2000, *Nature* reported the discovery of both the C₃ and C₄ pathways in a marine diatom (phylum Chromophyta). In this unicellular organism, the two paths are kept separate by having the C₄ path in the cytosol, and the C₃ path confined to the chloroplast. How would presence of a C₄ pathway improve fitness of this diatom in the frequently low [CO₂] in ocean waters? Compare the compartmentation here with that of corn leaves.
Reference: <http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/C4plants.html>

E. PROBLEM WITH RUBISCO IN C₃ PLANTS – “Photorespiration”

1. Low affinity for CO₂ relative to O₂ makes O₂ an effective competitive inhibitor of carboxylation
2. RESULT: C₃ photosynthesis is less efficient than C₄, especially in high temperatures and high light. Explain how the conditions of high temperature and high light intensity affect CO₂ concentration and O₂ concentration. Relate this to the problem of competitive inhibition of Rubisco and resultant *photorespiration*.

3. C₄ PLANTS: In light of your answer to Question #2 above, explain how C₄ plants overcome the problems associated with high temperature and high light intensity with respect to the following:

Leaf Anatomy: _____

Enzyme Pathway: _____

4. Discuss relative “fitness” of C₃ and C₄ plants in different climates. Are C₄ plants always more fit?

F. CAM (crassulacean acid metabolism) plants:

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

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

3. How are CAM plants xeromorphic biochemically speaking? _____

4. How would you distinguish C₄ photosynthesis from CAM photosynthesis?

Take-at-Home Quiz (SA #36)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 HEXOSE SUGAR (6C), OR TO STARCH IN THE STROMA
- D. ____ HEXOSE SUGARS OUTSIDE THE CHLOROPLASTS ARE CONVERTED TO SUCROSE, 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 P680 AND P700, RESPECTIVELY
- G. ____ ELECTRON EXCITATIONS OF CHLOROPHYLL-P680 AND -P700
- H. ____ $RuBP + CO_2 \rightarrow 2 \text{ 3-PGA}$ (3-PHOSPHOGLYCERIC ACID, A 3-C COMPOUND)