

General Botany Study Guide

Chapter 7

BIO 134

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PHOTOSYNTHESIS

PROCEDURE: We will conclude our study of general botany by photosynthesis, perhaps the most important biological process in support of life on Earth. The LECTURE DISCUSSION QUESTIONS below and the *Study Outline* will direct you to the major points of emphasis in Chapter 7.

Peruse Chapter 7, noting the "Chapter Overview", page 131; the major headings; and, illustrations. Then, as you read the chapter, 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.

THEME: Light energy absorption by photosynthetic cells, and its conversion to carbohydrate molecules.

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

1. Describe the nature of *light energy* in the broader context of *electromagnetic radiation*. What difference does wavelength make with respect to how light interacts with matter?
2. 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.
3. Discuss evidence that chlorophyll and carotenoids are really the chief photosynthetic pigments. What is the evidence that chlorophyll *b* and carotenoids are accessory pigments?
4. What happens when visible light is absorbed by matter? By chlorophyll in particular?
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. How does the biochemical phase of photosynthesis use ATP and NADPH to convert CO₂ into PGA and other organic molecules? Why aren't the "dark reactions" really dark reactions?
8. What enzymatic and anatomical adaptations enable C4 plants to avoid photorespiration?

CONTEMPORARY UNDERSTANDING OF PHOTOSYNTHESIS

I. HISTORY OF PHOTOSYNTHESIS: Match the experiments (A.) with contribution (B):

A. EXPERIMENTS:

1. Van Helmont (Belgium, 1648) measured changes in mass of a growing willow tree.
2. Jan Ingenhousz (Holland, 1780) – Plants purify air in light but “injure” it at night.
3. N. de Saussure (1804) *et.al.* – Equal volumes of CO₂ and O₂ are exchanged in photosynthesis.
4. Senebier (France, 1782) – Plants produce “good air” faster in light when “bad air” increases
5. Julius von Sachs (Germany, 1864) – saw white deposits in “chlorophyll corpustles” in light
6. T.W. Engelmann (1883) – bacteria are drawn to only certain regions of *Spirogyra* when the filaments are exposed to a light spectrum generated by a prism.

B. CONTRIBUTION TO OUR UNDERSTANDING: [Match each with the experiment in A.]

- a. ___ Chloroplasts synthesize starch [CH₂O]_n in light as a product of photosynthesis.
- b. ___ Photosynthesis stoichiometry advances: CO₂ + H₂O → [organic matter] + O₂
- c. ___ Water and minerals alone are converted to plant mass. [Is there another contributor?]
- d. ___ Plants require light for photosynthesis. Plants can respire in light and dark.
- e. ___ “Fixed air” (now CO₂) from the atmosphere and water is converted to plant mass.
- f. ___ The action spectrum of photosynthesis indicates that blue and red light are involved.

II. NATURE OF LIGHT

A. ELECTROMAGNETIC SPECTRUM -- range of wavelengths composing solar radiation

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 on electrons depends upon wavelength. The energy per photon is inversely related to wavelength as follows:

	Ultraviolet Radiation	Visible Radiation	Infrared Radiation
Freq.	High frequency	Intermediate Frequency	Low Frequency
λ	<400 nanometers (nm)	400-700 nanometers	>700 nanometers (nm)
quantum energy (<i>hν</i>)	HIGH -- called <u>ionizing radiation</u> (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
Significance	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

III. 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 in close-up view:

Study Figure 7.12 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_____, and only the T_____ membranes of each chloroplast are green.

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

Concept: Chlorophylls and carotenoids are arranged in chloroplast thylakoids (Figure 7.12) 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 to reaction centers.

- E. LIGHT ABSORPTION BY MATTER AND PHOTOSYNTHETIC PIGMENTS:

1. Matter (atoms/molecules) in general (Fig. 7.14) – _____
2. Chlorophyll extracted in ethanol -- _____
3. Chlorophyll in intact chloroplasts - _____
4. Define *fluorescence* _____

5. Why is fluorescence rare in intact leaves? _____

6. Why might fluorescence occur when plants are exposed to certain herbicides or low Q_w which affects the hydration of the thylakoids? _____

IV. 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 7.16:
1. Photochemical Reactions -- involve absorption of *photons* which excite electrons.
 - a. Location -- hollow, chl-containing membrane sacs called _____
 - b. Two subparts -- *electron transport* and *photophosphorylation* (Figure 7.18)
 - c. Electrons are removed from _____ and transported to NADP to form NADPH 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 reduce absorbed gas to 3-PGA_____

V. PHOTOCHEMICAL REACTIONS -- See Figure 7.18 (two different models)

- A. NONCYCLIC ELECTRON FLOW -- NADPH Synthesis
1. What is the origin of each 2 electrons transported? _____
 2. When $2 e^-$ reach $\text{NADP}^+ + \text{H}^+$, the product is $\text{NADPH} + \text{H}^+$ [Can you "find" the added $2 e^-$?]
 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 (Figure 7.18)

1. Two views of *photophosphorylation*

- a. Redox View: ATP is synthesized when coupled to exothermic redox reactions of electron transport
- b. 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: pH increases in medium around illuminated chloroplasts

C. PHOTOCHEMICAL REACTIONS -- Summary Reactions:

1. Electron Transport: $2\text{H}_2\text{O} + 2\text{NADP}^+ \rightarrow 2\text{NADPH} + 2\text{H}^+ + \text{O}_2$
2. Photophosphorylation: $2\text{ADP} + 2\text{P}_i \rightarrow 2\text{ATP}$

D. CYCLIC PHOTOPHOSPHORYLATION -- Figures 7.17, 7.18

1. The cyclic path of electrons: _____
2. NADPH is not formed since excited electrons return to P700 (in Photosystem I).
3. Why can't *cyclic electron flow* cause splitting of H₂O? _____

4. Benefit of cyclic photophosphorylation: _____

VI. BIOCHEMICAL REACTIONS -- See Fig. 7.21 [Fig. 7.20 is detailed to support a general understanding.]

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: $\text{CO}_2 + \text{RuBP} \rightarrow 2\text{ 3-PGA}$

C. CALVIN CYCLE

1. 3-PGA is later reduced by NADPH to ---> glyceraldehyde-3-Phosphate
2. Glyceraldehyde-3-P is then converted to sugar-phosphates (e.g. Fructose-P)
3. How does this pathway compare to *glycolysis* (Fig. 6.4) _____

4. Products of Calvin Cycle
 - a. Product for translocation out of leaf in phloem is _____
 - b. Product for storage during the day within the chloroplast: _____

D. VARIATIONS OF BIOCHEMICAL PATHWAYS

1. "C₃ PLANTS" - species (mostly temperate) in which 3-PGA is first organic product
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]

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

1. Low affinity for CO₂ relative to O₂. The O₂ is competitive inhibitor, causing photorespiration.
2. RESULT: C₃ photosynthesis is less efficient than C₄, especially in high temperatures and 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.

3. C₄ PLANTS: Based upon your answer to #2, why are C₄ plants more efficient than C₃ plants?

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

G. CAM (crassulacean acid metabolism) plants [e.g. cacti and *Bryophyllum* (pregnant plant)]:

1. What about CAM plants is similar to C₄ plants ? _____
2. What about CAM plants is different from C₄ plants? _____
3. How are they xeromorphic biochemically speaking? _____
