

Chapter 10- Photosynthesis

(Key Concepts are Underlined)

Photosynthesis in Nature

Plants and other autotrophs are the producers of the biosphere

Autotrophs are also known as *producers*; plants are *photoautotrophs*

Heterotrophs- are also known as *consumers*

Chloroplasts are the sites of photosynthesis in plants

- leaves are the major sites of photosynthesis; about $\frac{1}{2}$ million chloroplasts per square millimeter of leaf surface

- the green pigment **chlorophyll** gives leaves its color

- chloroplasts are found mainly in the cells of the

mesophyll (interior of leaf); typical mesophyll cell contains 30 to 40 chloroplasts

- **stomata** (stoma, singular) is where CO_2 enters leaf

Chloroplast Anatomy: have two membranes in which the *stroma* is enclosed; *thylakoid membrane* (where chlorophyll is located), *thylakoid space*, *grana* (stacked thylakoid sacs)

The Pathways of Photosynthesis

Evidence that chloroplasts split water molecules enabled researchers to track atoms through photosynthesis: *science as a process*

Overall Equation:



- O_2 formed from the splitting of water (confirmed with radioisotope ^{18}O)

The light reactions and the Calvin cycle cooperate in converting light energy to the chemical energy of food: *an overview*

Light reactions- light dependent; water is split and O₂ is formed; ATP is generated via photophosphorylation; energized electrons are accepted by NADP⁺ (see below); no sugar synthesized; occurs in thylakoid of chloroplast

NADP⁺- (nicotinamide adenine dinucleotide phosphate) temporarily stores energized electrons from the excitation of chlorophyll by light; one more phosphate than NAD⁺ in cellular respiration; reduced to NADPH

Calvin cycle- light-independent; synthesis of sugar; where **carbon fixation** takes place (initial incorporation of carbon into an organic compound); the fixed carbon is reduced by NADPH; ATP is required; occurs in stroma

The light reactions convert solar energy to the chemical energy of ATP and NADPH: *a closer look*

Electromagnetic Energy/Radiation/Waves- disturbances of electrical and magnetic fields

Wavelength

Electromagnetic Spectrum

Visible Light

Photons

- proportionality of wavelength, frequency, and energy
- blue and red wavelengths are most effectively absorbed by chlorophyll
- pigments absorb light, as opposed to reflect or transmit
- a spectrophotometer is used to produce a pigment's

absorption spectrum

Action Spectrum- shows the effectiveness of various wavelengths of light in photosynthetic rate

Chlorophyll a- responsible for converting solar energy to chemical energy during the light reactions

Chlorophyll b- *accessory pigment* (transfers energy to chlorophyll a and broadens the spectrum of colors that drive photosynthesis); slightly different than chlorophyll a in structure

Carotenoids- accessory pigment; also protect chlorophyll - pigments absorb those photons with energy equivalent to the difference in energy of the ground and excited state of the molecule (or electron)

Photosystems- have light-gathering “antenna complexes” consisting of cluster of a few hundred chlorophyll a, chlorophyll b, and carotenoid molecules (in thylakoid membrane); chlorophyll a is located within the **reaction center**; chlorophyll a loses its electrons to the **primary electron acceptor** (redox), thus preventing electrons from going back to ground state; two photosystems (Photosystem I and II) differ by associated proteins and numbered by order of discovery

Photosystem I- reaction center chlorophyll is P700

Photosystem II- reaction center chlorophyll is P680

Noncyclic electron flow (predominant): electrons excited in photosystem II are captured by the electron acceptor → water is split, which supplies electrons to P680 and oxygen to form molecular oxygen → excited electrons pass from photosystem II to I via an electron transport chain → the “fall” of electrons produce ATP via chemiosmosis (*noncyclic photophosphorylation*) → P700 of photosystem I accepts the electrons where they are again photoexcited to the primary acceptor → electron acceptor of photosystem I

passes its electrons to a second electron transport chain, which reduces NADP^+ to NADPH

Cyclic electron flow- involves only photosystem I; no NADPH is produced and no O_2 is released; ATP is generated because the primary acceptor loses its electron to the electron transport chain (*cyclic photophosphorylation*); stimulated when ATP is deficient for driving the Calvin cycle

Chemiosmosis compared (Chloroplasts vs. Mitochondria):

- Thylakoid Membrane/Thylakoid Space vs. Mitochondrial Membrane/Intermembrane Space
- Photophosphorylation/Stroma vs. Oxidative Phosphorylation/Matrix

The Calvin cycle uses ATP and NADPH to convert CO_2 to sugar: a closer look

3 Phases:

- 1) *Carbon fixation*- each CO_2 is attached to a five-carbon sugar (abbreviated RuBP) catalyzed by **rubisco** (most abundant protein in plants and on Earth); the six-carbon intermediate splits into two three-carbon molecules called 3-phosphoglycerate
- 2) *Reduction*- a phosphate from ATP is added to 3-phosphoglycerate, which is then reduced by NADPH to **G3P** (glyceraldehyde 3-phosphate); for every three molecules of CO_2 consumed, 6 G3P sugar molecules are formed (BUT, 5 are recycled to regenerate RuBP and **only 1 G3P exits the cycle**)
- 3) *Regeneration of CO_2 acceptor (RuBP)*- the five molecules of G3P are rearranged to form RuBP at the expense of ATP

- it takes 9 molecules of ATP and 6 NADPH molecules to produce 1 G3P molecule, which is the starting material in making carbohydrates

Alternative mechanisms of carbon fixation have evolved in hot arid climates

Photorespiration- occurs when stomata close to reduce transpiration, which creates a limited supply of CO₂ and excess O₂ released during photosynthesis; rubisco's active site accepts O₂ and adds it to the Calvin cycle, which causes a two-carbon molecule to exit and be converted to CO₂ by mitochondria and peroxisomes; unlike respiration or photosynthesis, neither ATP or food is generated (also, decreases photosynthetic output by siphoning off fixed carbon from the Calvin cycle)

C₃ Plants- first organic product of carbon fixation is a three-carbon compound (due to CO₂ added to RuBP via rubisco); photorespiration occurs when stomata close in efforts to reduce transpiration; examples of C₃ plants in agriculture include: *rice, wheat, and soybeans*

C₄ Plants- first organic product of carbon fixation is a four-carbon compound; C₄ plants have two distinctive photosynthetic cells- **bundle-sheath cells** (surround veins of leaves) and **mesophyll cells** (between bundle-sheath and leaf surface); CO₂ is added to PEP to form the four-carbon product oxaloacetate via *PEP carboxylase* in the mesophyll cells, which has a much higher affinity for CO₂ than rubisco; this four-carbon sugar is then exported to the bundle-sheath cells via plasmodesmata, where the CO₂ is reassimilated by rubisco and the Calvin cycle (like C₃ plants); a high concentration of CO₂ is maintained in the bundle-sheath cells in order for rubisco to accept CO₂, as

opposed to O_2 (which in turn minimizes photorespiration!); examples of C_4 plants in agriculture include: *sugarcane*, *corn*, and *grass family*

CAM Plants- crassulacean acid metabolism, named after the Family Crassulaceae; stomata are closed during the day to conserve water and reopened at night to take in CO_2 ; the mesophyll cells convert CO_2 to organic acids at night and store them in their vacuoles until morning, when the acids will be reassimilated into CO_2 to supply the Calvin Cycle (along with NADPH and ATP supplied by light-dependent reactions); examples include *succulents*, many *cacti*, and *pineapples*