The Light-Dependent Reactions of Photosynthesis

MBB

Biochem H III Semester

Key Points

- Photosynthesis evolved as a way to store the energy in solar radiation as high-energy electrons in carbohydrate molecules.
- Plants, algae, and cyanobacteria, known as photoautotrophs, are the only organisms capable of performing photosynthesis.
- Heterotrophs, unable to produce their own food, rely on the carbohydrates produced by photosynthetic organisms for their energy needs.

Key Terms

- **photosynthesis**: the process by which plants and other photoautotrophs generate carbohydrates and oxygen from carbon dioxide, water, and light energy in chloroplasts
- **photoautotroph**: an organism that can synthesize its own food by using light as a source of energy
- **chemoautotroph**: a simple organism, such as a protozoan, that derives its energy from chemical processes rather than photosynthesis

The Importance of Photosynthesis

- The processes of all organisms—from bacteria to humans—require energy.
- To get this energy, many organisms access stored energy by eating food.
- Carnivores eat other animals and herbivores eat plants.
- But where does the stored energy in food originate?

- All of this energy can be traced back to the process of photosynthesis and light energy from the sun.
- Photosynthesis is essential to all life on earth. It is the only biological process that captures energy from outer space (sunlight) and converts it into chemical energy in the form of G3P.

- Glyceraldehyde 3-phosphate, which in turn can be made into sugars and other molecular compounds.
- Plants use these compounds in all of their metabolic processes; plants do not need to consume other organisms for food because they build all the molecules they need.
- Unlike plants, animals need to consume other organisms to consume the molecules they need for their metabolic processes.

The process of photosynthesis

- During photosynthesis, molecules in leaves capture sunlight and energize electrons, which are then stored in the covalent bonds of carbohydrate molecules.
- That energy within those covalent bonds will be released when they are broken during cell respiration.

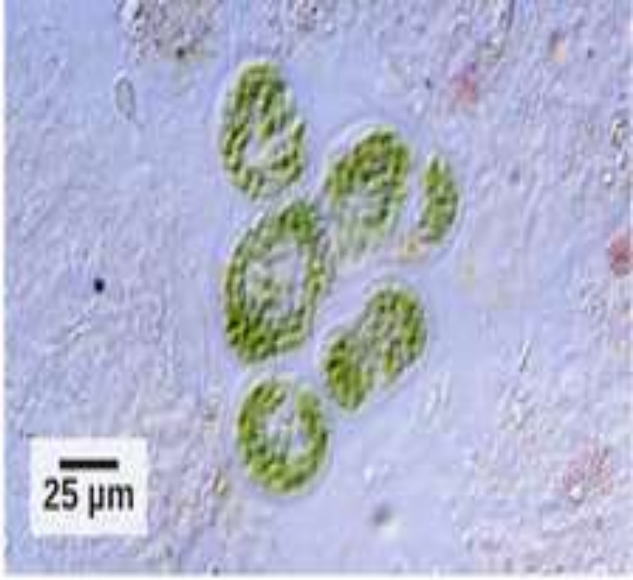
- How long lasting and stable are those covalent bonds? The energy extracted today by the burning of coal and petroleum products represents sunlight energy captured and stored by photosynthesis almost 200 million years ago.

- Plants, algae, and a group of bacteria called cyanobacteria are the only organisms capable of performing photosynthesis.
- Because they use light to manufacture their own food, they are called photoautotrophs (“self-feeders using light”).

- Other organisms, such as animals, fungi, and most other bacteria, are termed heterotrophs (“other feeders”) because they must rely on the sugars produced by photosynthetic organisms for their energy needs.
- A third very interesting group of bacteria synthesize sugars, not by using sunlight’s energy, but by extracting energy from inorganic chemical compounds; hence, they are referred to as chemoautotrophs.

(a)

(b)



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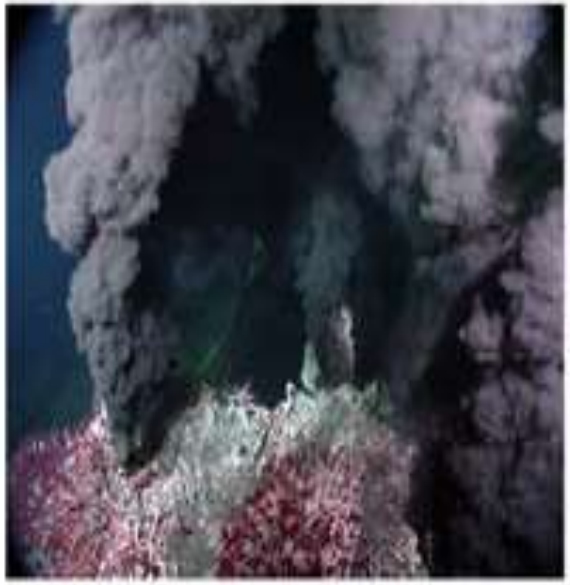

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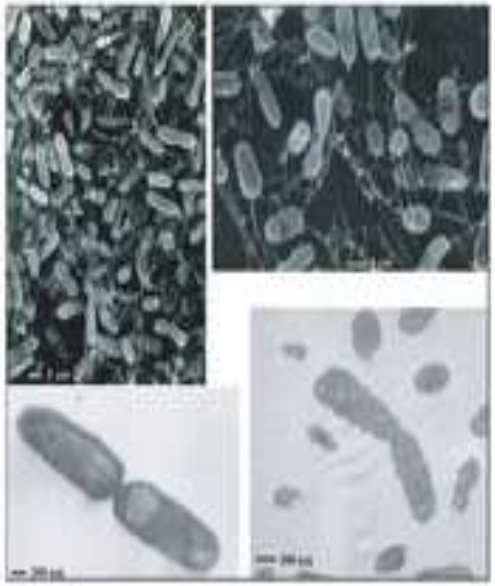


(e)

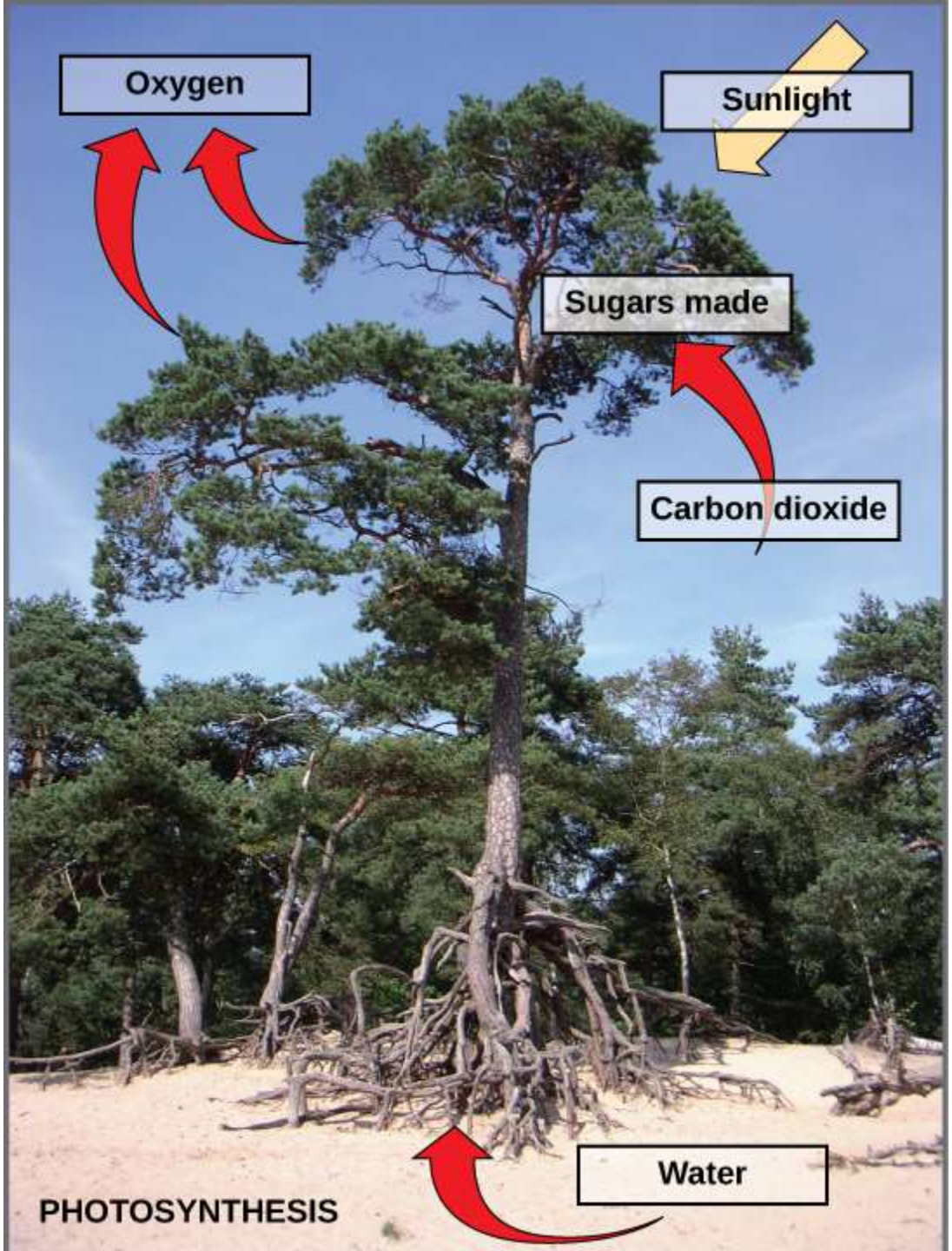
Photosynthetic and Chemosynthetic Organisms: Photoautotrophs, including (a) plants, (b) algae, and (c) cyanobacteria, synthesize their organic compounds via photosynthesis using sunlight as an energy source. Cyanobacteria and planktonic algae can grow over enormous areas in water, at times completely covering the surface.

In a (d) deep sea vent, chemoautotrophs, such as these (e) thermophilic bacteria, capture energy from inorganic compounds to produce organic compounds. The ecosystem surrounding the vents has a diverse array of animals, such as tubeworms, crustaceans, and octopi that derive energy from the bacteria.

Overview of photosynthesis

- Photosynthesis is a multi-step process that requires sunlight, carbon dioxide, and water as substrates.
- It produces oxygen and glyceraldehyde-3-phosphate (G3P or GA3P), simple carbohydrate molecules that are high in energy and can subsequently be converted into glucose, sucrose, or other sugar molecules.

- These sugar molecules contain covalent bonds that store energy.
- Organisms break down these molecules to release energy for use in cellular work.


Oxygen
Sunlight
Sugars made
Carbon dioxide
Water
PHOTOSYNTHESIS

Photosynthesis Equation

$6CO_2$	$6H_2O$	$C_6H_{12}O_6$	$6O_2$

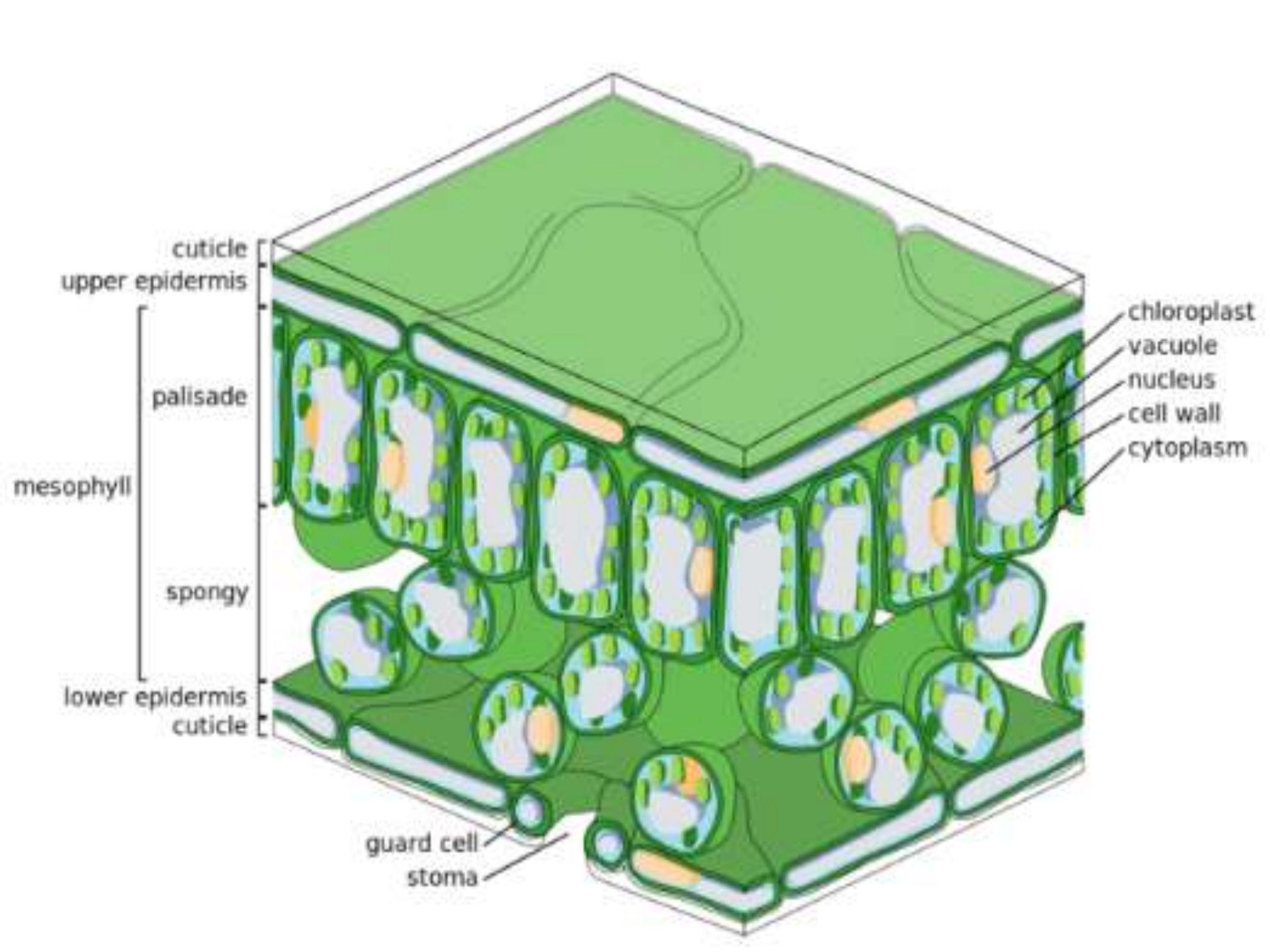
Photosynthesis and leaf

- In plants, photosynthesis generally takes place in leaves, which consist of several layers of cells.

- The process of photosynthesis occurs in a middle layer called the mesophyll.

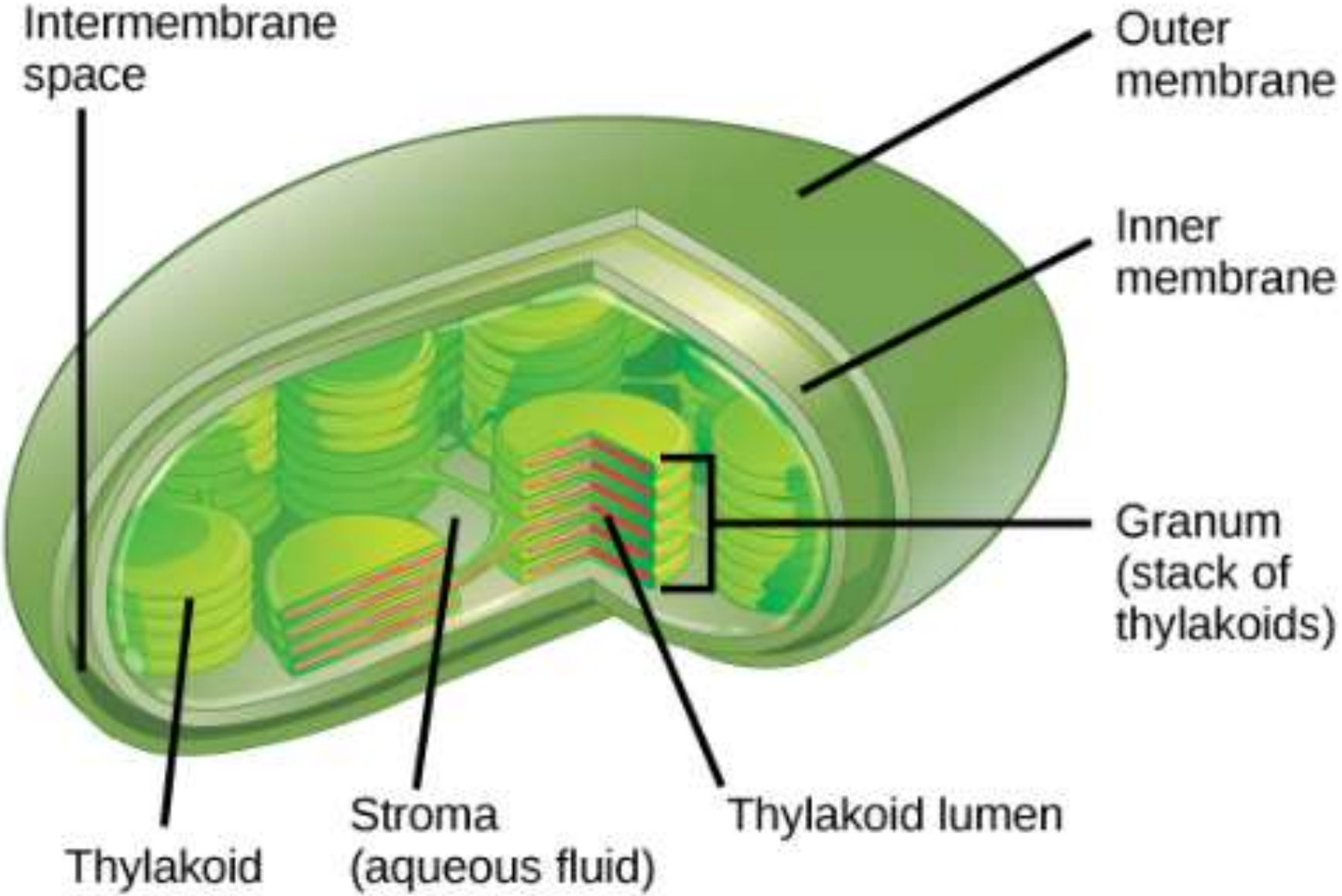
- The gas exchange of carbon dioxide and oxygen occurs through small, regulated openings called stomata (singular: stoma), which also play a role in the plant's regulation of water balance.
- The stomata are typically located on the underside of the leaf, which minimizes water loss.

- Each stoma is flanked by guard cells that regulate the opening and closing of the stomata by swelling or shrinking in response to osmotic changes.


cuticle
upper epidermis
palisade
mesophyll
spongy
lower epidermis
cuticle
guard cell
stoma
chloroplast
vacuole
nucleus
cell wall
cytoplasm

- In all autotrophic eukaryotes, photosynthesis takes place inside an organelle called a chloroplast.
- For plants, chloroplast-containing cells exist in the mesophyll.
- Chloroplasts have a double membrane envelope composed of an outer membrane and an inner membrane.
- Within the double membrane are stacked, disc-shaped structures called thylakoids.

- Embedded in the thylakoid membrane is chlorophyll, a pigment that absorbs certain portions of the visible spectrum and captures energy from sunlight.
- Chlorophyll gives plants their green color and is responsible for the initial interaction between light and plant material, as well as numerous proteins that make up the electron transport chain.
- The thylakoid membrane encloses an internal space called the thylakoid lumen.
- A stack of thylakoids is called a granum, and the liquid-filled space surrounding the granum is the stroma or “bed.”


Intermembrane space
Outer membrane
Inner membrane
Granum (stack of thylakoids)
Thylakoid
Stroma (aqueous fluid)
Thylakoid lumen

Light-dependent and light-independent reactions are two successive reactions that occur during photosynthesis.

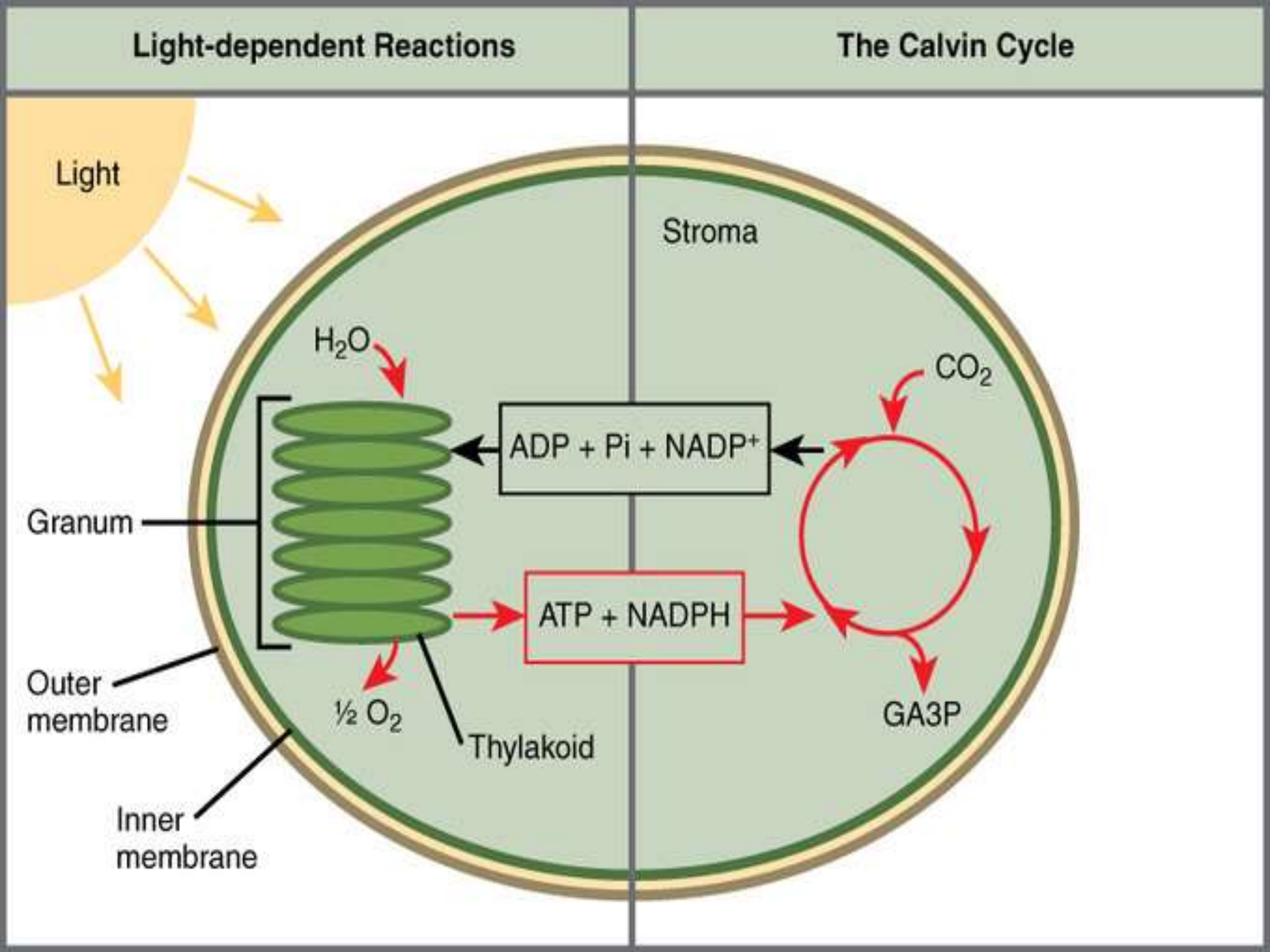
THE TWO PARTS OF PHOTOSYNTHESIS

Photosynthesis takes place in two sequential stages:

- **The light-dependent reactions**;
- **The light-independent reactions**, or Calvin Cycle.

Light-Dependent Reactions

- Just as the name implies, light-dependent reactions require sunlight.
- In the light-dependent reactions, energy from sunlight is absorbed by chlorophyll and converted into stored chemical energy, in the form of the electron carrier molecule NADPH (nicotinamide adenine dinucleotide phosphate) and the energy currency molecule ATP (adenosine triphosphate).
- The light-dependent reactions take place in the thylakoid membranes in the granum (stack of thylakoids), within the chloroplast.


Light-dependent Reactions
The Calvin Cycle
Light
Stroma
H_2O
CO_2
ADP + Pi + $NADP^+$
Granum
ATP + NADPH
Outer membrane
½ O_2
GA3P
Thylakoid
Inner membrane

The two stages of photosynthesis: Photosynthesis takes place in two stages: light-dependent reactions and the Calvin cycle (light-independent reactions).

Light-dependent reactions, which take place in the thylakoid membrane, use light energy to make ATP and NADPH.

The Calvin cycle, which takes place in the stroma, uses energy derived from these compounds to make GA3P from CO2.

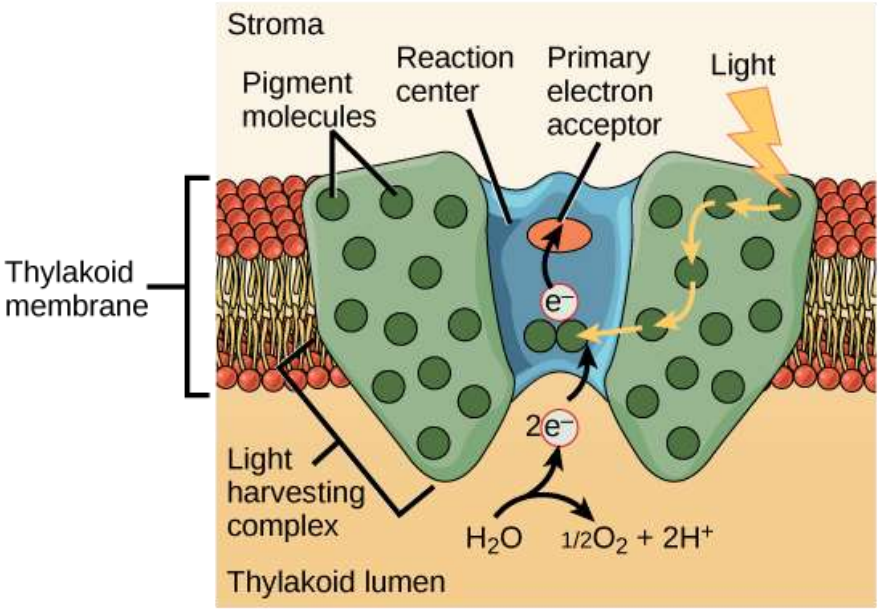
- The process that converts light energy into chemical energy takes place in a multi-protein complex called a photosystem.
- Two types of photosystems are embedded in the thylakoid membrane: photosystem II (PSII) and photosystem I (PSI).
- Each photosystem plays a key role in capturing the energy from sunlight by exciting electrons.
- These energized electrons are transported by “energy carrier” molecules, which power the light-independent reactions.

- Photosystems consist of a light-harvesting complex and a reaction center.
- Pigments in the light-harvesting complex pass light energy to two special chlorophyll *a* molecules in the reaction center. The light excites an electron from the chlorophyll *a* pair, which passes to the primary electron acceptor.

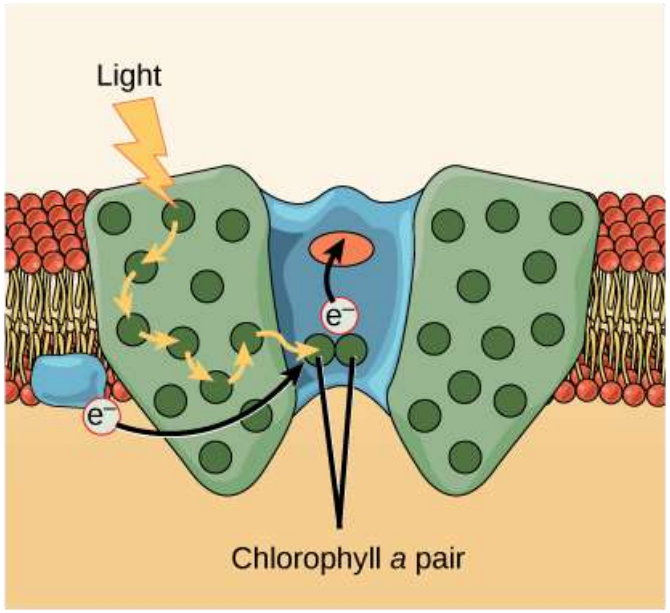
- The excited electron must then be replaced.
- In photosystem II, the electron comes from the splitting of water, which releases oxygen as a waste product.
- In photosystem I, the electron comes from the chloroplast electron transport chain.

- The two photosystems oxidize different sources of the low-energy electron supply, deliver their energized electrons to different places, and respond to different wavelengths of light.

(a) Photosystem II (P680)



(b) Photosystem I (P700)



Photosystems I & II: As explained above, the photosystems manipulate electrons with energy harvested from light.

Light-Independent Reactions

- In the light-independent reactions or Calvin cycle, the energized electrons from the light-dependent reactions provide the energy to form carbohydrates from carbon dioxide molecules.
- The light-independent reactions are sometimes called the Calvin cycle because of the cyclical nature of the process.

- Although the light-independent reactions do not use light as a reactant (and as a result can take place at day or night), they require the products of the light-dependent reactions to function.
- The light-independent molecules depend on the energy carrier molecules, ATP and NADPH, to drive the construction of new carbohydrate molecules.

- After the energy is transferred, the energy carrier molecules return to the light-dependent reactions to obtain more energized electrons.
- In addition, several enzymes of the light-independent reactions are activated by light.

- In light-dependent reactions, the energy from sunlight is absorbed by chlorophyll and converted into chemical energy in the form of electron carrier molecules like ATP and NADPH.
- Light energy is harnessed in Photosystems I and II, both of which are present in the thylakoid membranes of chloroplasts.
- In light-independent reactions (the Calvin cycle), carbohydrate molecules are assembled from carbon dioxide using the chemical energy harvested during the light-dependent reactions.