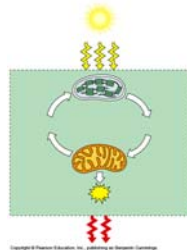


# Photosynthesis



## Introduction

- Van Helmont** a mid-seventeenth-century Belgian physician developed some early ideas about where plants get the materials they need to grow.

- His experiment was elegantly simple and disproved the then current idea that soil provided everything plants need.

- He concluded that water provided the substance of plant growth.

- In the early 1870s, **Priestly** showed that air ( $\text{O}_2$ ) could be restored by growing plants.

- Ingenhousz** soon demonstrated that air was restored only when plants were exposed to light.

- Not until well into the 1900s were the details of the process worked out.

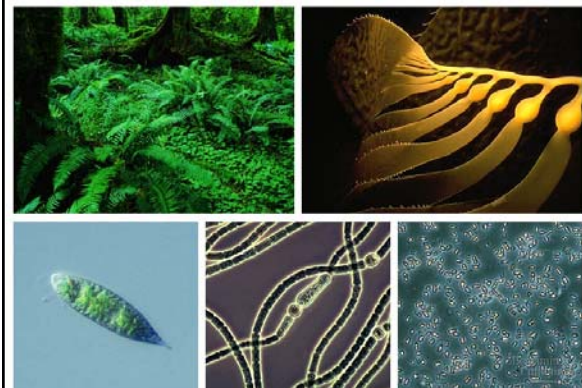
**NOTE:** ..... and are still being worked out.

## Autotrophs are the producers of the biosphere

- Autotroph* means “self-feeding,” and the term is applied to any organism that makes its own food without eating, decomposing, or absorbing other organisms or organic molecules.

- Autotrophs produce the biosphere’s food supply.

- Producers include plants, some bacteria, some archaea, and some protists. Producers that utilize light energy are referred to as *photosynthetic producers*.

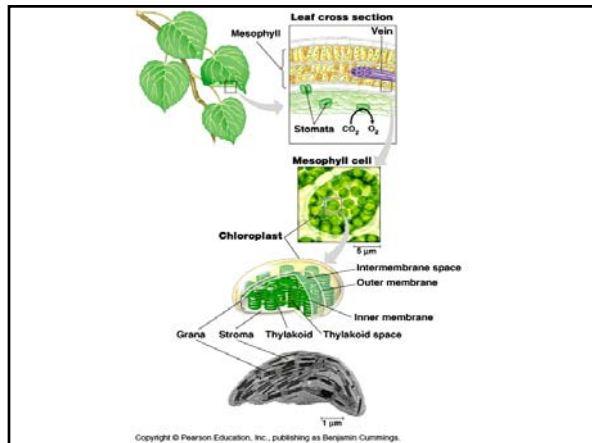


### Photosynthesis occurs in chloroplasts

- This is true for all photosynthetic organisms except prokaryotes, and is true for all green parts of plants.
- In most plants, the leaves and, specially, **mesophyll** cells are the dominant photosynthetic locations.
- Other structures in leaves provide entries and exits for the reactants and products of the process:  $\text{CO}_2$  and  $\text{O}_2$  diffuse through **stomata**;  $\text{H}_2\text{O}$  moves through veins from the roots.

- Within the **stroma** (fluid) of chloroplasts carbon dioxide is built into sugars.

- In chloroplasts, the green pigments that absorb light energy is **chlorophyll**, located within the **thylakoid** membranes (stacks of thylakoid are called **grana**) within the chloroplasts.

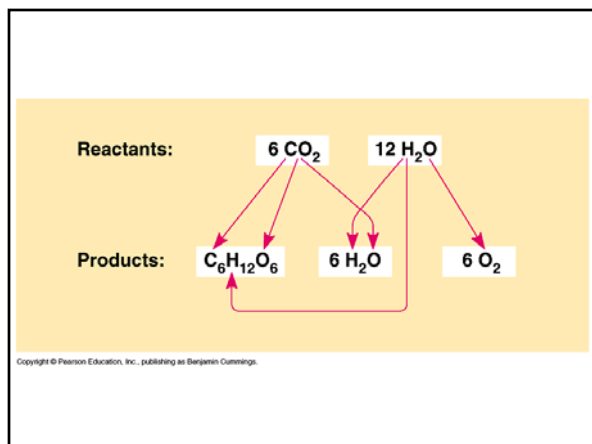


### Plants produce oxygen by splitting water

- Experiments in the 1950s tested the early hypothesis of Ingenhousz that the oxygen given off in photosynthesis came from the reactant  $\text{CO}_2$ .

### Two experiments used $^{18}\text{O}$ -labeled reactants as tracers.

- A plant given  $\text{C}^{18}\text{O}_2$  did not give off  $^{18}\text{O}_2$ .
- A plant given  $\text{H}_2^{18}\text{O}$  did give off  $^{18}\text{O}_2$ .
- Additional experiments have confirmed where other atoms in the products come from.



## Photosynthesis

- In many respects, the reverse of cellular respiration
- $\text{CO}_2 + \text{H}_2\text{O}$  are reactants
- Requires input of light energy
- Products are sugars +  $\text{O}_2$

**Photosynthesis is a redox process, as is cellular respiration**

- When  $\text{H}_2\text{O}$  molecules are split yielding  $\text{O}_2$ , the water molecules are oxidized giving up their electrons (an  $\text{H}^+$  ions).
- At the same time,  $\text{CO}_2$  molecules are reduced to glucose as electrons and  $\text{H}^+$  ions are added to them.
- \* In cell resp. glucose is oxidized and oxygen is reduced.

•In photosynthesis, the electrons travel "uphill" from the water to the glucose, adding the light energy captured by chlorophyll.

\* In cell resp, the electrons travel "downhill" from the glucose to the water, giving up their energy to ATP.

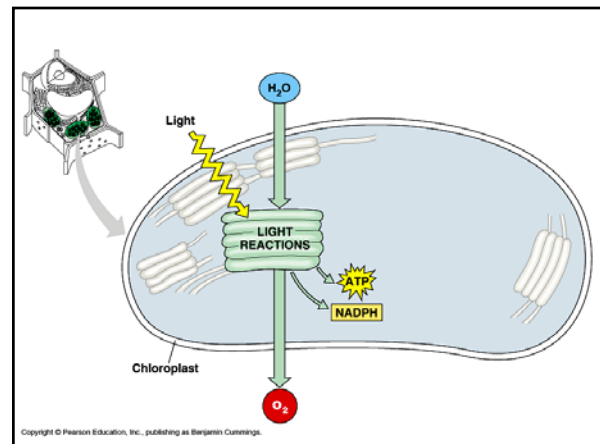
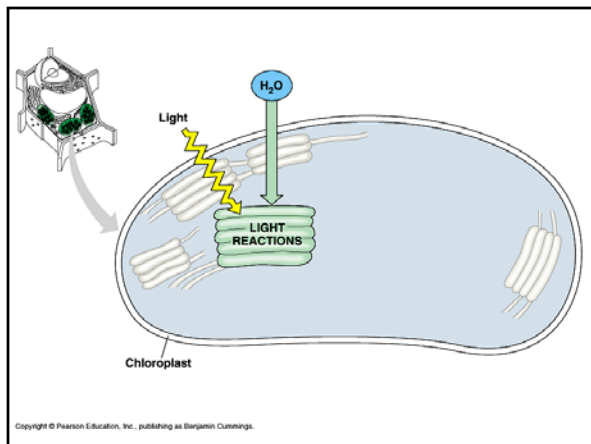
**Photosynthesis occurs in two stages linked by ATP and NADPH**

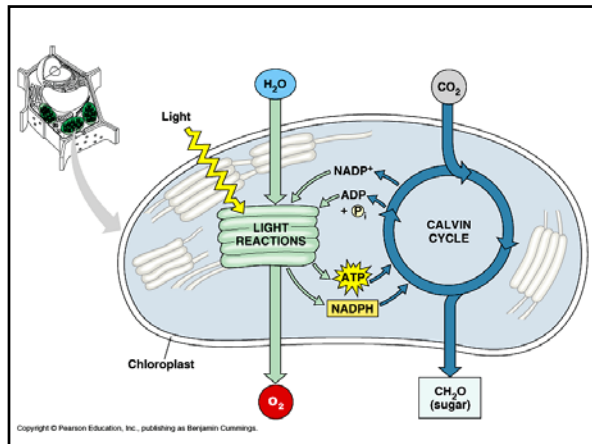
- (1) Light reactions:** Steps that convert light energy to chemical energy and produce  $\text{O}_2$  gas as a waste product.
- These rxns. occur in the thylakoid membranes and produce energy shuttles in the form of ATP and energized electron shuttles in the form of molecules of NADPH. Light is required for these steps.

**NOTE:**  $\text{O}_2$  is produced as a waste product.

**(2) Calvin cycle:** a cyclic series of steps that assemble glucose from  $\text{CO}_2$  molecules.

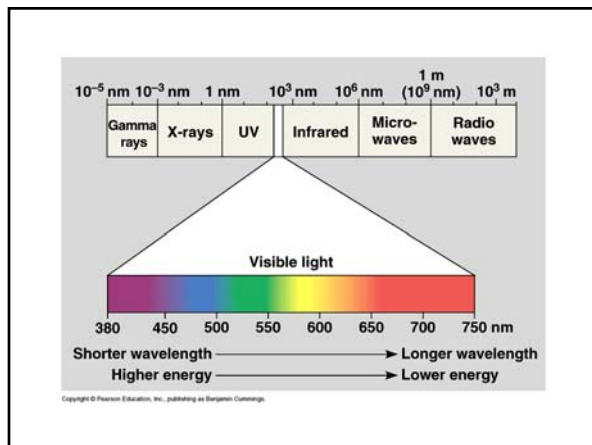
- These rxns. occur in the stroma (the fluid outside the thylakoids but inside the inner chloroplast membrane) and use the energy and electrons from ATP and NADPH in "carbon fixation." Light is not directly required, but because production of the shuttles requires light, the Calvin cycle steps usually run during daytime.





### Visible radiation drives light reactions

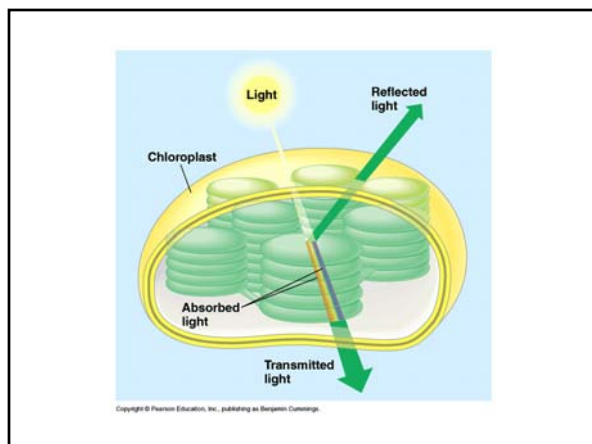
- Light is a type of energy called electromagnetic radiation, which travels in rhythmic waves.
- Only a small amount of electromagnetic radiation can be perceived by organisms. Humans perceive light of different wavelengths as different colors.



- A variety of pigments are involved in absorbing light of different wavelengths (in plants, chlorophyll *a*, chlorophyll *b*, and carotenoids).

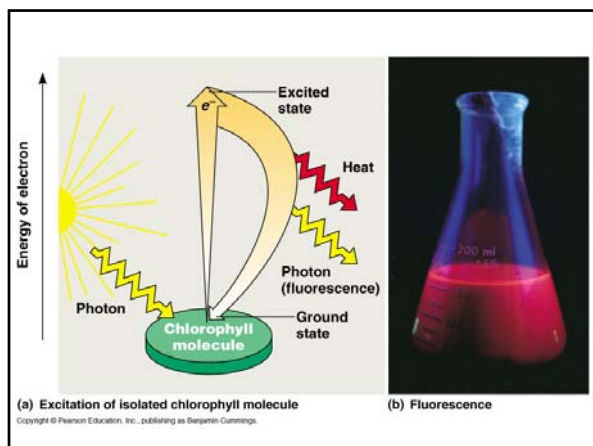
- In plants, only chlorophyll *a* participates directly in light rxns.. The other pigments function to broaden the range of energy absorbed and convey this additional trapped energy to chlorophyll *a*.

- While some carotenoids absorb light energy that will be used in photosynthesis, other carotenoids protect chlorophyll from damaging effects of excessive light energy.



### Photosystems capture solar power

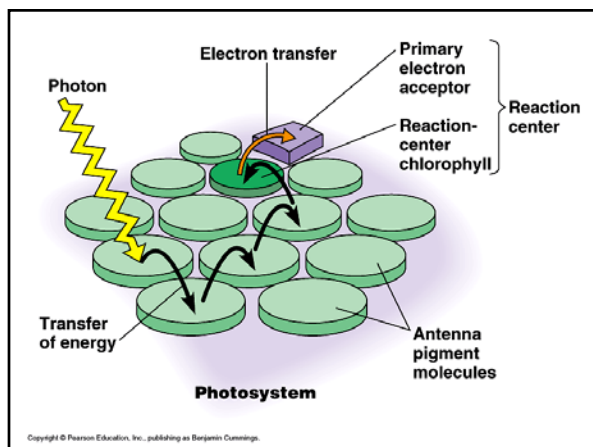
- In addition to behaving as waves, light also behaves as discrete packages of energy called photons.
- When a pigment absorbs a photon, the energy at one of the pigment's electrons is raised to an excited state.
- In some cases, if the pigment is isolated from its surrounding molecular environment, the excited electrons will lose energy, return to the normal level, and emit heat or light. For instance **chlorophyll *a*** fluoresces red.



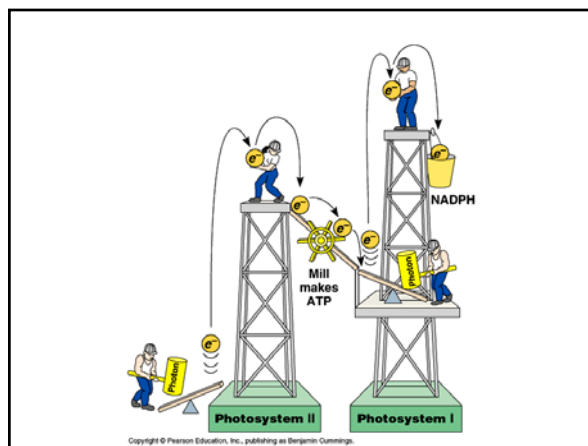
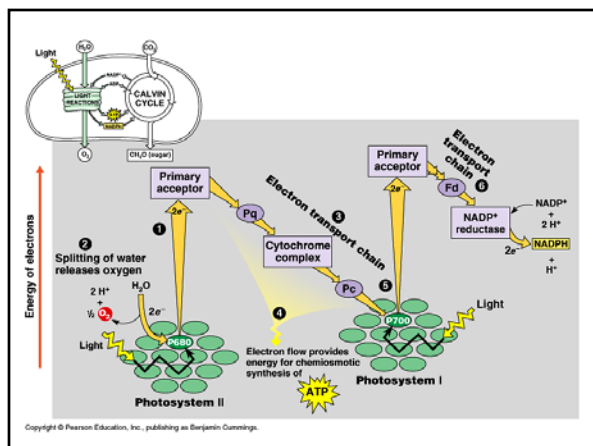
•In contrast, in intact chloroplasts, the excited electrons are passed (redox).

•Within the thylakoid membranes, many pigment molecules (200-300) are grouped with associate proteins into an antenna assembly, but only a single chlorophyll a molecule acts as the reaction center.

•Two photosystems (antenna assembly + reaction center + primary electron acceptor) have been identified, which differ in the wavelengths of peak light absorption: **photosystem I** (P700) and **photosystem II** (P680).



•The different grana are connected by thylakoid membranes called **stroma lamellae**. The stroma lamellae mainly bear PS I, the grana mainly PS II.



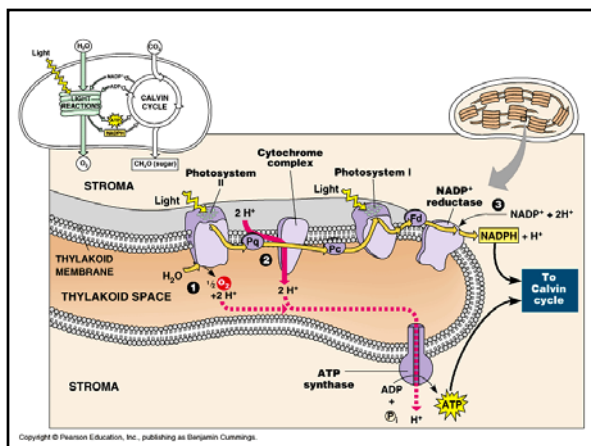
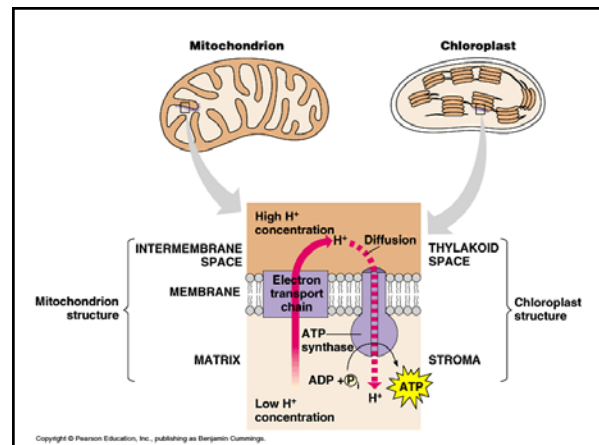
**In light reactions, electrons transport chains generate ATP, NADPH, and O<sub>2</sub>**

1. The kinetic energy of light is absorbed.
2. The absorbed energy excites electrons.
3. The excited electrons are passed along an electron transport chain in a series of redox reactions.
4. The energy released by these redox reactions is used to generate ATP, NADPH, and O<sub>2</sub>.

5. The production of NADPH requires 2 electrons. Photosystem I gets these electrons from Photosystem II. Photosystem II gets its electrons from the splitting of water, a process that also produces 2H<sup>+</sup> and ½ O<sub>2</sub>.

**Chemiosmosis powers ATP synthesis in the light reactions**

- The energy used from ETC is used to pump H<sup>+</sup> ions (formed when water was split) from the stroma across the thylakoid membrane to the interior of the thylakoids. This creates a concentration gradient across the thylakoid membrane.
- ATP synthase provides a port through which the H<sup>+</sup> ions can diffuse back into the stroma, releasing energy which is used to phosphorylate ADP to ATP.
- This process, by which light provides energy for chemiosmotic production of ATP, is known as photophosphorylation.



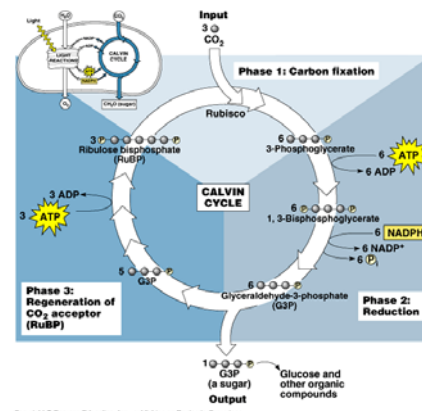
# The Calvin Cycle

### ATP and NADPH power sugar synthesis in the Calvin cycle

1. The net result of the steps of the Calvin cycle is the creation of phosphorylated, three-carbon molecules (G3P) from carbon dioxide and the energy and electrons provided by ATP and NADPH from light reactions.
2. Each  $\text{CO}_2$  molecule is added to a five-carbon intermediate (RuBP, for ribulose biphosphate) catalyzed by the enzyme RuBP carboxylase (rubisco).

3. A number of rearrangements of molecules occur in many steps, some involving the use of energy from ATP, some oxidizing the NADPH (the reactants in these being reduced at the same time).
4. The last step of the cycle is the rearrangement of the RuBP. The reactions involve considerable rearrangements of structure; all are proceeding at once, and since the steps ultimately regenerate one of the starting reactants, they can be regarded as occurring in a cycle.

5. It takes three molecules of  $\text{CO}_2$  entering the cycle for every G3P produced.
6. G3P can be used to make glucose or other organic compounds.
7. The Calvin cycle takes place in the chloroplast stroma.



### Photosynthesis uses light energy to make food molecules

- Sugar molecules a plant produces are the plant's own food supply, expended during cellular respiration.
- Plants use sugars as building blocks for other organic compounds, including cellulose.
- Plants, and other photosynthesizers, are the ultimate source of food for all organisms.

### C4 and CAM plants have special adaptations that save water

- Plants that use the Calvin cycle to fix carbon are known as C3 plants.
- When normal C3 plants try to conserve water by closing their leaf pores, oxygen is fixed to RuBP by rubisco rather than  $\text{CO}_2$ , since  $\text{CO}_2$  is not able to enter the plant. This is called **photorespiration**, and it yields no sugar molecules and produces no ATP.



• **C<sub>4</sub> plants** have special adaptations that conserve water and prevent photorespiration.

• These adaptations include producing four-carbon compounds with a special enzyme in separate cells during hot, dry weather when the stomata are closed and the CO<sub>2</sub> concentration is much lower than O<sub>2</sub> concentrations. In the other cells where the Calvin cycle is still operating, the four carbon compounds are broken down to release CO<sub>2</sub> to complete the cycle.

• C<sub>4</sub> metabolism is found in corn, sorghum, and sugarcane.

• **CAM plants** form CO<sub>2</sub> into four-carbon compounds with another enzyme at night, when temperatures are lower, humidity higher, and CO<sub>2</sub> more available.

• During the day, the four-carbon compounds are released to the Calvin cycle.

• CAM is found in several different types of succulent plants, such as cacti, pineapples, and jade plants.

