Intro to photosynthesis

Conversion of light energy to chemical energy. Reactions of photosynthesis, where they take place, and their ecological importance.

Introduction

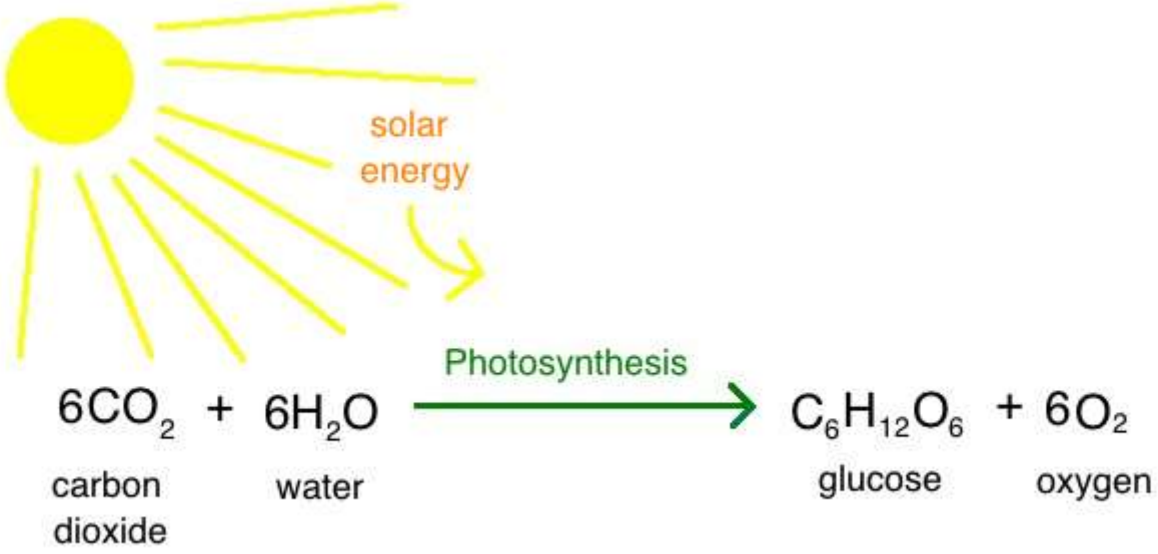
Have you hugged a tree lately? If not, you might want to give it some thought. You, along with the rest of the human population, owe your existence to plants and other organisms that capture light. In fact, most life on Earth is possible because the sun provides a continuous supply of energy to ecosystems.

All organisms, including humans, need energy to fuel the metabolic reactions of growth, development, and reproduction. But organisms can't use light energy directly for their metabolic needs. Instead, it must first be converted into chemical energy through the process of photosynthesis.

What is photosynthesis?

Photosynthesis is the process in which light energy is converted to chemical energy in the form of sugars. In a process driven by light energy, glucose molecules (or other sugars) are constructed from water and carbon dioxide, and oxygen is released as a by-product. The glucose molecules provide organisms with two crucial resources: energy and fixed—organic—carbon.

- **Energy.** The glucose molecules serve as fuel for cells: their chemical energy can be harvested through processes like cellular respiration and fermentation, which generate adenosine triphosphate—ATPa small, energy-carrying molecule—for the cell's immediate energy needs.
- **Fixed carbon.** Carbon from carbon dioxide—inorganic carbon—can be incorporated into organic molecules; this process is called **carbon fixation**, and the carbon in organic molecules is also known as **fixed carbon**. The carbon that's fixed and incorporated into sugars during photosynthesis can be used to build other types of organic molecules needed by cells.



In photosynthesis, solar energy is harvested and converted to chemical energy in the form of glucose using water and carbon dioxide. Oxygen is released as a by-product.

The ecological importance of photosynthesis

Photosynthetic organisms, including plants, algae, and some bacteria, play a key ecological role. They introduce chemical energy and fixed carbon into ecosystems by using light to synthesize sugars. Since these organisms produce their own food—that is, fix their own carbon—using light energy, they are called **photoautotrophs** (literally, self-feeders that use light).

Humans, and other organisms that can’t convert carbon dioxide to organic compounds themselves, are called **heterotrophs**, meaning different-feeders. Heterotrophs must get fixed carbon by eating other organisms or their by-products. Animals, fungi, and many prokaryotes and protists are heterotrophs.

Types of autotrophs. The signature characteristic of autotrophs is that they can fix their own carbon—convert inorganic to organic carbon—given a suitable energy source.

- **Photoautotrophs** use light energy to convert carbon dioxide into organic compounds. This process is called photosynthesis.
- **Chemoautotrophs** extract energy from inorganic compounds by oxidizing them and use this chemical energy, rather than light energy, to convert carbon dioxide into organic compounds. This process is called chemosynthesis.

Types of heterotrophs. Heterotrophs are unable to convert carbon dioxide to organic compounds themselves and must instead obtain fixed carbon from other organisms.

- **Photoheterotrophs** obtain energy from sunlight but must get fixed carbon in the form of organic compounds made by other organisms. Some types of prokaryotes are photoheterotrophs.
- **Chemoheterotrophs** obtain energy by oxidizing organic or inorganic compounds and, like all heterotrophs, get their fixed carbon from organic compounds made by other organisms. Animals, fungi, and many prokaryotes and protists are chemoheterotrophs.

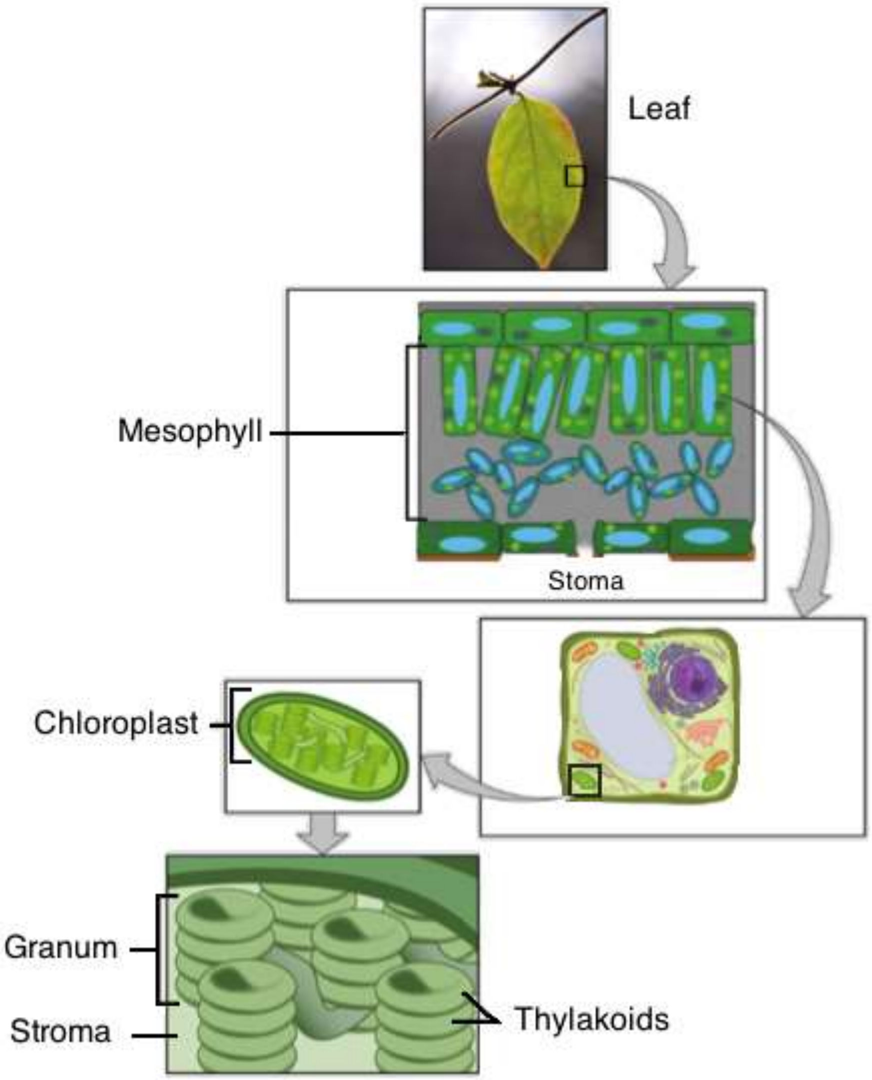
Besides introducing fixed carbon and energy into ecosystems, photosynthesis also affects the makeup of Earth’s atmosphere. Most photosynthetic organisms generate oxygen gas as a by-product, and the advent of photosynthesis—over 3333 billion years ago, in bacteria resembling modern cyanobacteria—forever changed life on Earth. These bacteria gradually released oxygen into Earth’s oxygen-poor atmosphere, and the increase in oxygen concentration is thought to have influenced the evolution of aerobic life forms—organisms that use oxygen for cellular respiration. If it hadn’t been for those ancient photo synthesizers, we, like many other species, wouldn't be here today!

Photosynthetic organisms also remove large quantities of carbon dioxide from the atmosphere and use the carbon atoms to build organic molecules. Without Earth’s abundance of plants and algae to continually suck up carbon dioxide, the gas would build up in the atmosphere. Although photosynthetic organisms remove some of the carbon dioxide produced by human activities, rising atmospheric levels are trapping heat and causing the climate to change. Many scientists believe that preserving forests and other expanses of vegetation is increasingly important to combat this rise in carbon dioxide levels.

Leaves are sites of photosynthesis

Plants are the most common autotrophs in terrestrial—land—ecosystems. All green plant tissues can photosynthesize, but in most plants, but the majority of photosynthesis usually takes place in the leaves. The cells in a middle layer of leaf tissue called the **mesophyll** are the primary site of photosynthesis.

Small pores called **stomata**—singular, stoma—are found on the surface of leaves in most plants, and they let carbon dioxide diffuse into the mesophyll layer and oxygen diffuse out.



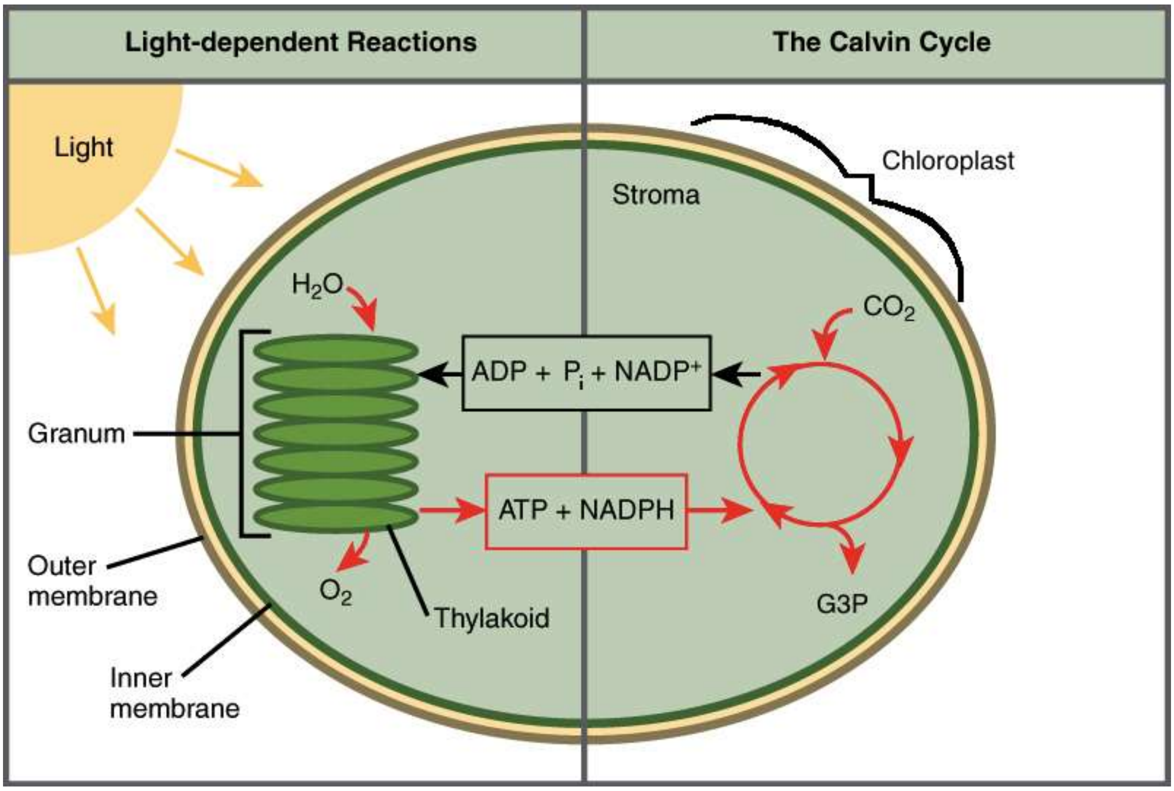
A diagram showing a leaf at increasing magnifications. Magnification 1: The entire leaf Magnification 2: Mesophyll tissue within the leaf Magnification 3: A single mesophyll cell Magnification 4: A chloroplast within the mesophyll cell Magnification 5: Stacks of thylakoids—grana—and the stroma within a chloroplast

Each mesophyll cell contains organelles called chloroplasts, which are specialized to carry out the reactions of photosynthesis. Within each chloroplast, disc-like structures called **thylakoids** are arranged in piles like stacks of pancakes that are known as **grana**—singular, granum. The membrane of each thylakoid contains green-coloured pigments called **chlorophylls** that absorb light. The fluid-filled space around the grana is called the **stroma**, and the space inside the thylakoid discs is known as the **thylakoid space**. Different chemical reactions occur in the different parts of the chloroplast.

The light-dependent reactions and the Calvin cycle

Photosynthesis in the leaves of plants involves many steps, but it can be divided into two stages: the light-dependent reactions and the Calvin cycle.

- The **light-dependent reactions** take place in the thylakoid membrane and require a continuous supply of light energy. Chlorophylls absorb this light energy, which is converted into chemical energy through the formation of two compounds, ATP—an energy storage molecule—and NADPH—a reduced (electron-bearing) electron carrier. In this process, water molecules are also converted to oxygen gas—the oxygen we breathe!
- The **Calvin cycle**, also called the **light-independent reactions**, takes place in the stroma and does not directly require light. Instead, the Calvin cycle uses ATP and NADPH from the light-dependent reactions to fix carbon dioxide and produce three-carbon sugars—glyceraldehyde-3-phosphate, or G3P, molecules—which join up to form glucose.



Schematic of the light-dependent reactions and Calvin cycle and how they're connected.
The light-dependent reactions take place in the thylakoid membrane. They require light, and their net effect is to convert water molecules into oxygen, while producing ATP molecules—from ADP and Pi—and NADPH molecules—via reduction of $NADP^+$.

ATP and NADPH are produced on the stroma side of the thylakoid membrane, where they can be used by the Calvin cycle.

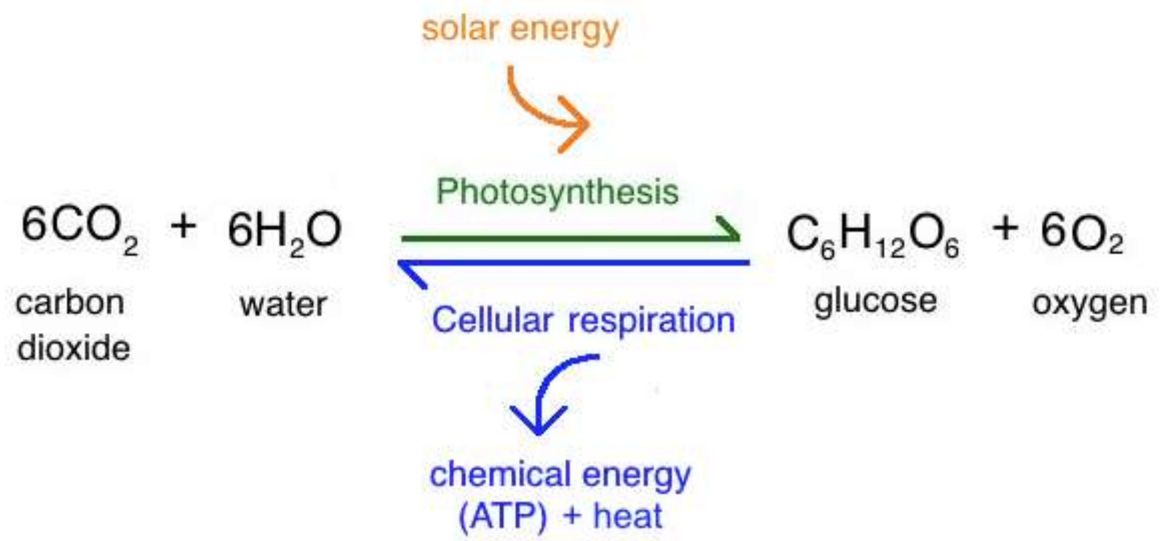
The Calvin cycle takes place in the stroma and uses the ATP and NADPH from the light-dependent reactions to fix carbon dioxide, producing three-carbon sugars—glyceraldehyde-3-phosphate, or G3P, molecules.

The Calvin cycle converts ATP to ADP and Pi, and it converts NADPH to $NADP^+$. The ADP, Pi, and $NADP^+$ can be reused as substrates in the light reactions.

Overall, the light-dependent reactions capture light energy and store it temporarily in the chemical forms of ATP and NADPH. There, ATP is broken down to release energy, and NADPH donates its electrons to convert carbon dioxide molecules into sugars. In the end, the energy that started out as light winds up trapped in the bonds of the sugars.

Photosynthesis vs. cellular respiration

At the level of the overall reactions, photosynthesis and cellular respiration are near-opposite processes. They differ only in the form of energy absorbed or released, as shown in the diagram below.



On a simplified level, photosynthesis and cellular respiration are opposite reactions of each other. In photosynthesis, solar energy is harvested as chemical energy in a process that converts water and carbon dioxide to glucose. Oxygen is released as a by-product. In cellular respiration, oxygen is used to break down glucose, releasing chemical energy and heat in the process. Carbon dioxide and water are products of this reaction.

At the level of individual steps, photosynthesis isn't just cellular respiration run in reverse. Instead, as we'll see the rest of this section, photosynthesis takes place in its own unique series of steps. However, there are some notable similarities between photosynthesis and cellular respiration.

For instance, photosynthesis and cellular respiration both involve a series of **redox** reactions (reactions involving electron transfers). In cellular respiration, electrons flow from glucose to oxygen, forming water and releasing energy. In photosynthesis, they go in the opposite direction, starting in water and winding up in glucose—an energy-requiring process powered by light. Like cellular respiration, photosynthesis also uses an electron transport chain to make a H^+ concentration gradient, which drives ATP synthesis by chemiosmosis.

If those things don't sound familiar, though, don't worry! You don't need to know cellular respiration to understand photosynthesis. Just keep reading and watching, and you'll learn all the ins and outs of this life-sustaining process.