

Photosynthesis

Overview

The Process That Feeds the Biosphere

Introduction

- Life on Earth is solar powered.
- The _____ of plants use photosynthesis to capture light energy from the sun and convert it to chemical energy stored in sugars and other organic molecules.
Plants and other autotrophs are the producers of the biosphere.
- Photosynthesis nourishes almost all the living world directly or indirectly.
 - All organisms use organic compounds for energy and for carbon skeletons.
 - Organisms obtain organic compounds by one of two major modes:
_____ nutrition or _____ nutrition.
- _____ produce their organic molecules from CO₂ and other inorganic raw materials obtained from the environment.
 - Autotrophs are the ultimate sources of organic compounds for all heterotrophs.
 - Autotrophs are the *producers* of the biosphere.
- Autotrophs can be separated by the source of energy that drives their metabolism.
 - _____ use light as a source of energy to synthesize organic compounds.
 - Photosynthesis occurs in plants, algae, some other protists, and some prokaryotes.
 - _____ harvest energy from oxidizing inorganic substances, such as sulfur and ammonia.
 - Chemoautotrophy is unique to prokaryotes.
- _____ live on organic compounds produced by other organisms.
 - These organisms are the *consumers* of the biosphere.
 - The most obvious type of heterotrophs feeds on other organisms.
 - Animals feed this way.
 - Other heterotrophs decompose and feed on dead organisms or on organic litter, like feces and fallen leaves.
 - Most fungi and many prokaryotes get their nourishment this way.
 - Almost all heterotrophs are completely dependent on photoautotrophs for food and for oxygen, a by-product of photosynthesis.

Concept 10.1

Photosynthesis converts light energy to the chemical energy of food

Chloroplasts: The Sites of Photosynthesis in Plants

- All green parts of a plant have chloroplasts.
- However, the _____ are the major site of photosynthesis for most plants.
 - There are about half a million chloroplasts per square millimeter of leaf surface.
- The color of a leaf comes from _____, the green pigment in the chloroplasts.
 - Chlorophyll plays an important role in the absorption of light energy during photosynthesis.
- Chloroplasts are found mainly in _____ cells forming the tissues in the interior of the leaf.
- O₂ exits and CO₂ enters the leaf through microscopic pores called _____ in the leaf.
- Veins deliver water from the roots and carry off sugar from mesophyll cells to nonphotosynthetic areas of the plant.
- A typical mesophyll cell has 30–40 chloroplasts, each about 2–4 microns by 4–7 microns long.
- Each chloroplast has two membranes around a central aqueous space, the _____.
- In the stroma is an elaborate system of interconnected membranous sacs, the _____.

	<ul style="list-style-type: none"> ◦ The interior of the thylakoids forms another compartment, the <i>thylakoid space</i>. ◦ Thylakoids may be stacked into columns called _____. • Chlorophyll is located in the thylakoids. <ul style="list-style-type: none"> ◦ Photosynthetic prokaryotes lack chloroplasts. ◦ Their photosynthetic membranes arise from infolded regions of the _____ membranes, folded in a manner similar to the thylakoid membranes of chloroplasts.
<p>Tracking Atoms Through Photosynthesis: Scientific Inquiry</p>	<p><i>Evidence that chloroplasts split water molecules enabled researchers to track atoms through photosynthesis.</i></p> <ul style="list-style-type: none"> • Powered by light, the green parts of plants produce organic compounds and O₂ from CO₂ and H₂O. • The equation describing the process of photosynthesis is: <ul style="list-style-type: none"> ◦ $6\text{CO}_2 + 12\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$ ◦ C₆H₁₂O₆ is glucose. • Water appears on both sides of the equation because 12 molecules of water are consumed, and 6 molecules are newly formed during photosynthesis. • We can simplify the equation by showing only the net consumption of water: <ul style="list-style-type: none"> ◦ $6\text{CO}_2 + 6\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ • The overall chemical change during photosynthesis is the reverse of _____. • In its simplest possible form: $\text{CO}_2 + \text{H}_2\text{O} + \text{light energy} \rightarrow [\text{CH}_2\text{O}] + \text{O}_2$ <ul style="list-style-type: none"> ◦ [CH₂O] represents the general formula for a sugar.
<p>The Splitting of Water</p>	<ul style="list-style-type: none"> • One of the first clues to the mechanism of photosynthesis came from the discovery that the O₂ given off by plants comes from _____, not _____. ◦ Before the 1930s, the prevailing hypothesis was that photosynthesis split carbon dioxide and then added water to the carbon: <ul style="list-style-type: none"> ▪ Step 1: $\text{CO}_2 \rightarrow \text{C} + \text{O}_2$ ▪ Step 2: $\text{C} + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O}$ ◦ C. B. van Niel challenged this hypothesis. ◦ In the bacteria that he was studying, hydrogen sulfide (H₂S), not water, is used in photosynthesis. ◦ These bacteria produce yellow globules of sulfur as a waste, rather than oxygen. ◦ Van Niel proposed this chemical equation for photosynthesis in sulfur bacteria: <ul style="list-style-type: none"> ▪ $\text{CO}_2 + 2\text{H}_2\text{S} \rightarrow [\text{CH}_2\text{O}] + \text{H}_2\text{O} + 2\text{S}$ • He generalized this idea and applied it to plants, proposing this reaction for their photosynthesis: <ul style="list-style-type: none"> ◦ $\text{CO}_2 + 2\text{H}_2\text{O} \rightarrow [\text{CH}_2\text{O}] + \text{H}_2\text{O} + \text{O}_2$ • Thus, van Niel hypothesized that plants split water as a source of electrons from hydrogen atoms, releasing oxygen as a byproduct. • Other scientists confirmed van Niel's hypothesis twenty years later. <ul style="list-style-type: none"> ◦ They used _____, a heavy isotope, as a tracer. ◦ They could label either C¹⁸O₂ or H₂¹⁸O. ◦ They found that the _____ label only appeared in the oxygen produced in photosynthesis when water was the source of the tracer. • Hydrogen extracted from _____ is incorporated into sugar, and oxygen is released to the atmosphere (where it can be used in respiration).
<p>Photosynthesis as a Redox Process</p>	<ul style="list-style-type: none"> • Photosynthesis is a redox reaction. <ul style="list-style-type: none"> ◦ It reverses the direction of electron flow in respiration. • Water is split and electrons transferred with H⁺ from water to CO₂, reducing it to sugar. <ul style="list-style-type: none"> ◦ Because the electrons increase in potential energy as they move from water to sugar, the process requires energy. ◦ The energy boost is provided by light.

The Two Stages of Photosynthesis: A Preview

Here is a preview of the two stages of photosynthesis.

- Photosynthesis is two processes, each with multiple stages.
- The _____ **reactions** (*photo*) convert solar energy to chemical energy.
- The _____ **cycle** (*synthesis*) uses energy from the light reactions to incorporate CO₂ from the atmosphere into sugar.
- In the light reactions, light energy absorbed by chlorophyll in the thylakoids drives the transfer of electrons and hydrogen from water to _____ (nicotinamide adenine dinucleotide phosphate), forming NADPH.
 - NADPH, an electron acceptor, provides reducing power via energized electrons to the Calvin cycle.
 - Water is split in the process, and O₂ is released as a by-product.
- The light reaction also generates ATP using chemiosmosis, in a process called _____.
- Thus light energy is initially converted to chemical energy in the form of two compounds: _____ and _____.
- The Calvin cycle is named for Melvin Calvin who, with his colleagues, worked out many of its steps in the 1940s.
- The cycle begins with the incorporation of CO₂ into organic molecules, a process known as **carbon** _____.
- The fixed carbon is reduced with electrons provided by _____.
- ATP from the light reactions also powers parts of the Calvin cycle.
- Thus, it is the Calvin cycle that makes sugar, but only with the help of ATP and NADPH from the light reactions.
- The metabolic steps of the Calvin cycle are sometimes referred to as the light-_____ reactions, because none of the steps requires light *directly*.
- Nevertheless, the Calvin cycle in most plants occurs during daylight, because that is when the light reactions can provide the NADPH and ATP the Calvin cycle requires.
- While the light reactions occur at the _____, the Calvin cycle occurs in the _____.

Concept 10.2

The light reactions convert solar energy to the chemical energy of ATP and NADPH

Introduction

- The thylakoids convert light energy into the chemical energy of ATP and NADPH.

The Nature of Sunlight

- Light is a form of electromagnetic radiation.
- Like other forms of electromagnetic energy, light travels in rhythmic waves.
- The distance between crests of electromagnetic waves is called the _____.
 - Wavelengths of electromagnetic radiation range from less than a nanometer (gamma rays) to more than a kilometer (radio waves).
- The entire range of electromagnetic radiation is the **electromagnetic spectrum**.
- The most important segment for life is the band of **visible light**.
- While light travels as a wave, many of its properties are those of a discrete particle, the _____.
 - Photons are not tangible objects, but they do have fixed quantities of energy.
- The amount of energy packaged in a photon is _____ related to its wavelength.
 - Photons with _____ wavelengths pack _____ energy.
- While the sun radiates a full electromagnetic spectrum, the atmosphere selectively screens out most wavelengths, permitting only visible light to pass in significant quantities.
 - Visible light is the radiation that drives photosynthesis.

**Photosynthetic Pigments:
The Light Receptors**

- When light meets matter, it may be reflected, transmitted, or absorbed.
 - Different pigments absorb photons of different wavelengths, and the wavelengths that are absorbed disappear.
 - A leaf looks green because chlorophyll, the dominant pigment, absorbs _____ and _____ light, while transmitting and reflecting _____ light.
- A _____ measures the ability of a pigment to absorb various wavelengths of light.
 - It beams narrow wavelengths of light through a solution containing the pigment and measures the fraction of light transmitted at each wavelength.
 - An _____ plots a pigment's light absorption versus wavelength.
- The light reaction can perform work with those wavelengths of light that are absorbed.
- There are several pigments in the thylakoid that differ in their absorption spectra.
 - _____, the dominant pigment, absorbs best in the red and violet-blue wavelengths and least in the green.
 - Other pigments with different structures have different absorption spectra.
- Collectively, these pigments determine an overall _____ **spectrum** for photosynthesis.
 - An action spectrum measures changes in some measure of photosynthetic activity (for example, O₂ release) as the wavelength is varied.
- The action spectrum of photosynthesis was first demonstrated in 1883 in an elegant experiment performed by _____.
 - In this experiment, different segments of a filamentous alga were exposed to different wavelengths of light.
 - Areas receiving wavelengths favorable to photosynthesis produced excess _____.
 - Engelmann used the abundance of _____ bacteria that clustered along the alga at different segments as a measure of O₂ production.
- The action spectrum of photosynthesis does not match exactly the absorption spectrum of any one photosynthetic pigment, including chlorophyll *a*.
- Only chlorophyll *a* participates directly in the light reaction, but accessory photosynthetic pigments absorb light and transfer energy to chlorophyll *a*.
 - **Chlorophyll** _____, with a slightly different structure than chlorophyll *a*, has a slightly different absorption spectrum and funnels the energy from these wavelengths to chlorophyll *a*.
 - _____ can funnel the energy from other wavelengths to chlorophyll *a* and also participate in *photoprotection* against excessive light.
 - These compounds absorb and dissipate excessive light energy that would otherwise damage chlorophyll.
 - They also interact with oxygen to form reactive oxidative molecules that could damage the cell.

**Excitation of Chlorophyll
by Light**

- ***When a molecule absorbs a photon, one of that molecule's electrons is elevated to an orbital with more potential energy.***
 - The electron moves from its ground state to an excited state.
 - The only photons that a molecule can absorb are those whose energy _____ the energy difference between the ground state and excited state of this electron.
 - Because this energy difference varies among atoms and molecules, a particular compound absorbs only photons corresponding to specific wavelengths.
 - Thus, each pigment has a unique absorption spectrum.
- Excited electrons are unstable.
- Generally, they drop to their ground state in a _____ of a second, releasing heat energy.

	<ul style="list-style-type: none"> • Some pigments, including chlorophyll, can also release a photon of light in a process called _____. ◦ If a solution of chlorophyll isolated from chloroplasts is illuminated, it will fluoresce and give off heat.
<p>A Photosystem: A Reaction Center Associated with Light Harvesting Complexes</p>	<ul style="list-style-type: none"> • Chlorophyll excited by absorption of light energy produces very different results in an intact chloroplast than it does in isolation. • In the thylakoid membrane, chlorophyll is organized along with proteins and smaller organic molecules into _____. • A photosystem is composed of a _____ surrounded by a _____-_____ complex. • Each _____-_____ complex consists of pigment molecules (which may include chlorophyll <i>a</i>, chlorophyll <i>b</i>, and carotenoid molecules) bound to particular proteins. • Together, these light-harvesting complexes act like light-gathering “antenna complexes” for the reaction center. • When any antenna molecule absorbs a photon, it is transmitted from molecule to molecule until it reaches a particular chlorophyll <i>a</i> molecule, the _____ center. • At the _____ center is a primary _____, which accepts an excited electron from the reaction center chlorophyll <i>a</i>. <ul style="list-style-type: none"> ◦ The solar-powered transfer of an electron from a special chlorophyll <i>a</i> molecule to the primary electron acceptor is the first step of the light reactions. • Each photosystem—reaction-center chlorophyll and primary electron acceptor surrounded by an antenna complex—functions in the chloroplast as a light-harvesting unit. • There are two types of photosystems in the thylakoid membrane. <ul style="list-style-type: none"> ◦ Photosystem I (PS I) has a reaction center chlorophyll <i>a</i> that has an absorption peak at _____ nm. ◦ Photosystem II (PS II) has a reaction center chlorophyll <i>a</i> that has an absorption peak at _____ nm. ◦ The differences between these reaction centers (and absorption spectra) lie not in the chlorophyll molecules, but in the proteins associated with each reaction center. ◦ These two photosystems work together to use light energy to generate ATP and NADPH.
<p>Noncyclic Electron Flow</p>	<ul style="list-style-type: none"> • During the light reactions, there are two possible routes for electron flow: cyclic and noncyclic. • _____ electron flow, the predominant route, produces both _____ and _____. <ol style="list-style-type: none"> 1. Photosystem II absorbs a photon of light. One of the electrons of _____ is excited to a higher energy state. 2. This electron is captured by the primary electron acceptor, leaving the reaction center _____. 3. An enzyme extracts electrons from _____ and supplies them to the oxidized reaction center. This reaction splits water into two hydrogen ions and an oxygen atom that combines with another oxygen atom to form _____. 4. Photoexcited electrons pass along an electron transport chain before ending up at an oxidized photosystem I reaction center. 5. As these electrons “fall” to a lower energy level, their energy is harnessed to produce _____. 6. Meanwhile, light energy has excited an electron of PS I’s _____ reaction center. The photoexcited electron was captured by PS I’s primary electron acceptor, creating an electron “hole” in _____. This hole is filled by an electron that reaches the bottom of the electron transport chain from PS II. 7. Photoexcited electrons are passed from PS I’s primary electron acceptor down a

	<p>second electron transport chain through the protein _____ (Fd).</p> <p>8. The enzyme NADP⁺ _____ transfers electrons from Fd to NADP⁺. Two electrons are required for NADP⁺'s reduction to NADPH. NADPH will carry the reducing power of these high-energy electrons to the _____ cycle.</p> <ul style="list-style-type: none"> • The light reactions use the solar power of photons absorbed by both photosystem I and photosystem II to provide chemical energy in the form of ATP and reducing power in the form of the electrons carried by NADPH.
<p>Cyclic Electron Flow</p>	<ul style="list-style-type: none"> • Under certain conditions, photoexcited electrons from photosystem I, but not photosystem II, can take an alternative pathway, _____ electron flow. <ul style="list-style-type: none"> ◦ Excited electrons cycle from their reaction center to a primary acceptor, along an electron transport chain, and return to the oxidized _____ chlorophyll. ◦ As electrons flow along the electron transport chain, they generate ATP by _____. ◦ There is no production of NADPH and no release of oxygen. • What is the function of cyclic electron flow? • Noncyclic electron flow produces ATP and NADPH in roughly equal quantities. • However, the Calvin cycle consumes more ATP than NADPH. • Cyclic electron flow allows the chloroplast to generate enough surplus ATP to satisfy the higher demand for ATP in the Calvin cycle.
<p>A Comparison of Chemiosmosis in Chloroplasts and Mitochondria</p>	<ul style="list-style-type: none"> • Chloroplasts and mitochondria generate ATP by the same mechanism: _____ <ul style="list-style-type: none"> ◦ In both organelles, an electron transport chain pumps protons across a membrane as electrons are passed along a series of increasingly electronegative carriers. ◦ This transforms redox energy to a _____ - _____ force in the form of an _____ gradient across the membrane. ◦ ATP _____ molecules harness the proton-motive force to generate ATP as H⁺ diffuses back across the membrane. • Some of the electron carriers, including the cytochromes, are very similar in chloroplasts and mitochondria. • The ATP synthase complexes of the two organelles are also very similar. • There are differences between oxidative phosphorylation in mitochondria and photophosphorylation in chloroplasts. • Mitochondria transfer chemical energy from food molecules to ATP; chloroplasts transform light energy into the chemical energy of ATP. • The spatial organization of chemiosmosis also differs in the two organelles. • The inner membrane of the mitochondrion pumps protons from the mitochondrial matrix out to the _____ space. The thylakoid membrane of the chloroplast pumps protons from the stroma into the _____ space inside the thylakoid. • The thylakoid membrane makes ATP as the hydrogen ions diffuse down their concentration gradient from the _____ space back to the _____ through ATP _____ complexes, whose catalytic knobs are on the _____ side of the membrane. • The proton gradient, or pH gradient, across the thylakoid membrane is substantial. <ul style="list-style-type: none"> ◦ When chloroplasts are illuminated, the pH in the thylakoid space drops to about 5 and the pH in the stroma increases to about 8, a thousandfold different in H⁺ concentration. • The light-reaction “machinery” produces ATP and NADPH on the stroma side of the thylakoid. • Noncyclic electron flow pushes electrons from water, where they have low potential energy, to NADPH, where they have high potential energy. <ul style="list-style-type: none"> ◦ This process also produces ATP and oxygen as a by-product.

Concept 10.3

The Calvin cycle uses ATP and NADPH to convert CO₂ to sugar

Introduction	<ul style="list-style-type: none">• The Calvin cycle regenerates its starting material after molecules enter and leave the cycle.• The Calvin cycle is _____, using energy to build sugar from smaller molecules.• Carbon enters the cycle as CO₂ and leaves as sugar.• The cycle spends the energy of ATP and the reducing power of electrons carried by _____ to make sugar.• The actual sugar product of the Calvin cycle is not glucose, but a three-carbon sugar, _____ -3- _____ (G3P).• Each turn of the Calvin cycle fixes _____ carbon.• For the net synthesis of one G3P molecule, the cycle must take place _____ times, fixing three molecules of CO₂.• To make one glucose molecule requires six cycles and the fixation of six CO₂ molecules.• The Calvin cycle has three phases.
Phase 1: Carbon fixation	<ul style="list-style-type: none">• In the carbon fixation phase, each CO₂ molecule is attached to a five-carbon sugar, _____ (RuBP).<ul style="list-style-type: none">◦ This is catalyzed by RuBP carboxylase or _____.◦ Rubisco is the most abundant protein in chloroplasts and probably the most abundant protein on Earth.◦ The six-carbon intermediate is unstable and splits in half to form two molecules of 3-phosphoglycerate for each CO₂.
Phase 2: Reduction	<ul style="list-style-type: none">• During reduction, each 3-phosphoglycerate receives another phosphate group from _____ to form 1,3-bisphosphoglycerate.• A pair of electrons from NADPH reduces each 1,3-bisphosphoglycerate to G3P.<ul style="list-style-type: none">◦ The electrons reduce a carboxyl group to the aldehyde group of G3P, which stores more potential energy.• If our goal was the net production of one G3P, we would start with 3CO₂ (3C) and three RuBP (15C).• After fixation and reduction, we would have six molecules of G3P (18C).<ul style="list-style-type: none">◦ One of these six G3P (3C) is a net gain of carbohydrate.<ul style="list-style-type: none">▪ This molecule can exit the cycle and be used by the plant cell.
Phase 3: Regeneration	<ul style="list-style-type: none">• The other five G3P (15C) remain in the cycle to regenerate three RuBP. In a complex series of reactions, the carbon skeletons of five molecules of G3P are rearranged by the last steps of the Calvin cycle to regenerate three molecules of RuBP.• For the net synthesis of one G3P molecule, the Calvin cycle consumes _____ ATP and _____ NADPH.• The light reactions regenerate ATP and NADPH.• The G3P from the Calvin cycle is the starting material for metabolic pathways that synthesize other organic compounds, including glucose and other carbohydrates.

Concept 10.4

Alternative mechanisms of carbon fixation have evolved in hot, arid climates

Introduction	<ul style="list-style-type: none">• One of the major problems facing terrestrial plants is dehydration.• At times, solutions to this problem require tradeoffs with other metabolic processes, especially photosynthesis.• The stomata are not only the major route for gas exchange (CO₂ in and O₂ out), but also for the evaporative loss of water.• On hot, dry days, plants close their stomata to conserve water. This causes problems for photosynthesis.
Photorespiration: An Evolutionary Relic?	<ul style="list-style-type: none">• In most plants (_____ plants), initial fixation of CO₂ occurs via rubisco, forming a three-carbon compound, 3-phosphoglycerate.<ul style="list-style-type: none">◦ _____ plants include rice, wheat, and soybeans.

	<ul style="list-style-type: none"> • When their stomata partially close on a hot, dry day, CO₂ levels _____ as CO₂ is consumed in the Calvin cycle. • At the same time, O₂ levels rise as the light reaction converts light to chemical energy. • While rubisco normally accepts CO₂, when the O₂:CO₂ ratio increases (on a hot, dry day with closed stomata), rubisco can add O₂ to RuBP. • When rubisco adds O₂ to RuBP, RuBP splits into a three-carbon piece and a two-carbon piece in a process called _____. <ul style="list-style-type: none"> ◦ The two-carbon fragment is exported from the chloroplast and degraded to CO₂ by mitochondria and peroxisomes. ◦ Unlike normal respiration, this process produces no ATP. <ul style="list-style-type: none"> ▪ In fact, photorespiration _____ ATP. ◦ Unlike photosynthesis, photorespiration does not produce organic molecules. <ul style="list-style-type: none"> ▪ In fact, photorespiration <i>decreases</i> photosynthetic output by siphoning organic material from the Calvin cycle. • A hypothesis for the existence of photorespiration is that it is _____. • When rubisco first evolved, the atmosphere had far less _____ and more _____ than it does today. <ul style="list-style-type: none"> ◦ The inability of the active site of rubisco to exclude O₂ would have mattered little. • Today it does make a difference. <ul style="list-style-type: none"> ◦ Photorespiration can drain away as much as _____ of the carbon fixed by the Calvin cycle on a hot, dry day. • Certain plant species have evolved alternate modes of carbon fixation to minimize photorespiration.
<p>C₄ Plants</p>	<ul style="list-style-type: none"> • C₄ plants first fix CO₂ in a four-carbon compound. <ul style="list-style-type: none"> ◦ Several thousand plants, including sugarcane and corn, use this pathway. • A unique leaf anatomy is correlated with the mechanism of C₄ photosynthesis. • In C₄ plants, there are two distinct types of photosynthetic cells: _____ - _____ cells and _____ cells. <ul style="list-style-type: none"> ◦ Bundle-sheath cells are arranged into tightly packed sheaths around the veins of the leaf. ◦ Mesophyll cells are more loosely arranged cells located between the bundle sheath and the leaf surface. • The Calvin cycle is confined to the chloroplasts of the _____ cells. • However, the cycle is preceded by the incorporation of CO₂ into organic molecules in the mesophyll. • The key enzyme, _____, adds CO₂ to phosphoenolpyruvate (PEP) to form _____. <ul style="list-style-type: none"> ◦ PEP carboxylase has a very high affinity for CO₂ and can fix CO₂ efficiently when rubisco cannot (i.e., on hot, dry days when the stomata are closed). • The mesophyll cells pump these four-carbon compounds into bundle-sheath cells. <ul style="list-style-type: none"> ◦ The bundle-sheath cells strip a carbon from the four-carbon compound as CO₂, and return the three-carbon remainder to the mesophyll cells. ◦ The bundle-sheath cells then use rubisco to start the Calvin cycle with an abundant supply of CO₂. • In effect, the mesophyll cells pump CO₂ into the bundle-sheath cells, keeping CO₂ levels high enough for rubisco to accept CO₂ and not O₂. • C₄ photosynthesis minimizes photorespiration and enhances sugar production. • C₄ plants thrive in _____ regions with intense _____.
<p>CAM Plants</p>	<ul style="list-style-type: none"> • A second strategy to minimize photorespiration is found in succulent plants, cacti, pineapples, and several other plant families. <ul style="list-style-type: none"> ◦ These plants are known as CAM plants for _____ acid metabolism.

	<ul style="list-style-type: none"> ◦ They open their stomata during the _____ and close them during the _____. ▪ Temperatures are typically lower at night, and humidity is higher. ◦ During the night, these plants fix CO₂ into a variety of organic acids in mesophyll cells. ◦ During the day, the light reactions supply ATP and NADPH to the Calvin cycle, and CO₂ is released from the organic acids. • Both _____ and _____ plants add CO₂ into organic intermediates before it enters the Calvin cycle. <ul style="list-style-type: none"> ◦ In C₄ plants, carbon fixation and the Calvin cycle are spatially separated. ◦ In CAM plants, carbon fixation and the Calvin cycle are temporally separated. • Both eventually use the Calvin cycle to make sugar from carbon dioxide.
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A Review

The Importance of Photosynthesis

Introduction

Here is a review of the importance of photosynthesis.

- In photosynthesis, the energy that enters the chloroplasts as sunlight becomes stored as chemical energy in organic compounds.
- Sugar made in the chloroplasts supplies the entire plant with chemical energy and carbon skeletons to synthesize all the major organic molecules of cells.
 - About 50% of the organic material is consumed as fuel for cellular respiration in plant mitochondria.
 - Carbohydrate in the form of the disaccharide sucrose travels via the veins to nonphotosynthetic cells.
 - There, it provides fuel for respiration and the raw materials for anabolic pathways, including synthesis of proteins and lipids and formation of the extracellular polysaccharide cellulose.
 - Cellulose, the main ingredient of cell walls, is the most abundant organic molecule in the plant, and probably on the surface of the planet.
- Plants also store excess sugar by synthesis of starch.
 - Starch is stored in chloroplasts and in storage cells in roots, tubers, seeds, and fruits.
- Heterotrophs, including humans, may completely or partially consume plants for fuel and raw materials.
- On a global scale, photosynthesis is the most important process on Earth.
 - It is responsible for the presence of oxygen in our atmosphere.
 - Each year, photosynthesis synthesizes 160 billion metric tons of carbohydrate.