Fascinating education®

Fascinating Education Script

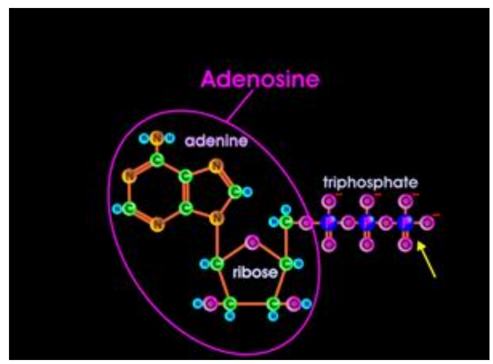
Fascinating Biology Lessons

Lesson 5: Take in Energy - Part 1

Slide 1: Introduction

Slide 2: ATP

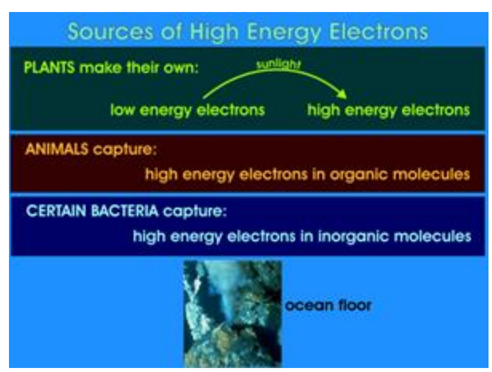
Cells need energy and the only source of energy available is high energy electrons. Cells use high energy electrons to make the high energy molecule ATP, adenosine triphosphate. Every cell needs ATP to run its machinery. ATP is the energy molecule of the cell.



ATP is made up of a molecule of adenine attached to the monosaccharide ribose. Together these two are known as adenosine. Attached to adenosine are three phosphate groups. This is ATP.

When the third phosphate is removed – when adenosine triphosphate is converted to adenosine diphosphate, energy is released to power the cell's chemical reactions.

Slide 3: Sources of energy



Where do cells find high energy electrons to make ATP?

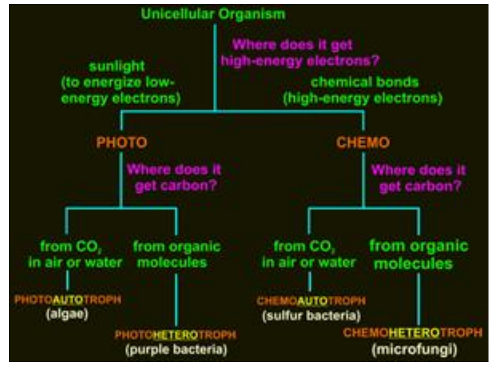
Plants use the electromagnetic energy of sunlight to make their own high energy electrons, by elevating low-energy electrons to high-energy electrons.

Animals capture high energy electrons already present in organic molecules. Organic molecules are molecules containing carbon that are made by plants and animals.

Certain bacteria capture high energy electrons from hydrogen sulfide spewing out of vents along the ocean floor.

Slide 4: Classification of organisms by energy intake

Biologists classify organisms according to how they get their high energy electrons and how they get their carbon to make organic molecules.



There are four basic categories of organisms: photoautotrophs, photoheterotrophs, chemoautotrophs, and chemoheterotrophs.

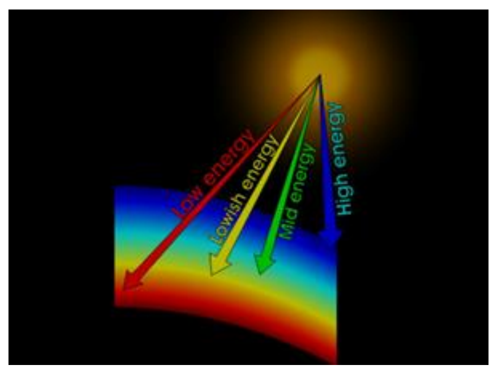
The first part of each label refers to how each organism gets its high energy electrons. For example "photo-" means it gets its energy by capturing the energy in sunlight. "Chemo-" means it gets its high energy electrons from a chemical bond.

The second part of the label refers to where the each organism gets carbon to make its proteins, carbohydrates, lipids, and nucleic acids. "Auto-" means it gets its carbon from carbon dioxide (CO_2) in the air or dissolved in water. "Hetero-" means it gets its carbon from organic molecules.

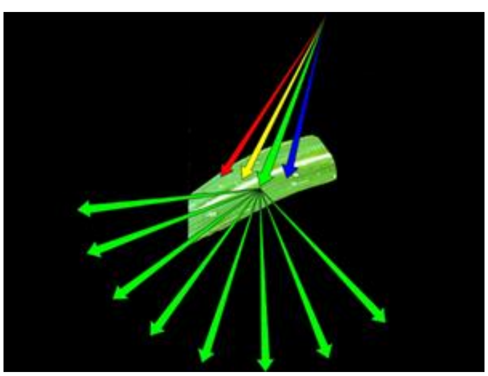
Thus, plants are multi-cellular photoautotrophs, which means they capture sunlight and use that energy to snag carbon atoms from carbon dioxide in the air to make glucose.

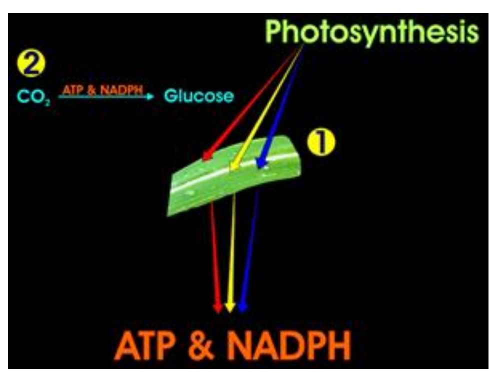
How do plants capture and transform the energy of sunlight into chemical energy?

Slide 5: Sunlight

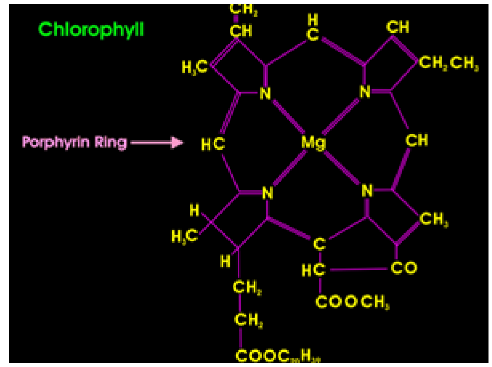


Sunlight, which appears white, is actually made up of red, yellow, green, and blue light. The reason plants are green is that green light is of little use to a plant and is reflected away. Red yellow, and blue light, however, are captured by chlorophyll and used to make two high energy molecules, ATP and NADPH. ATP and NADPH are used later to snag CO_2 from the air to make glucose.



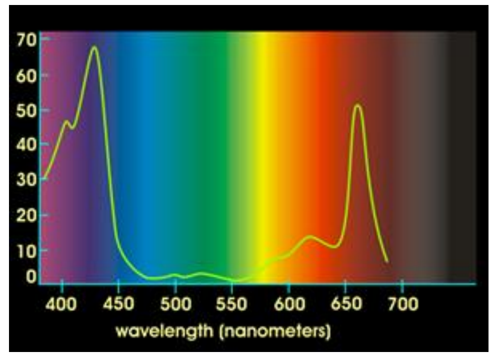


The process of capturing sunlight and using it to make glucose is called photosynthesis.



Chlorophyll is able to capture light because it has alternating single and double bonds in a ring, an arrangement that allows electrons to flow freely between atoms. This ring itself is a porphyrin ring containing an atom of magnesium in the middle.

When struck by the right photons of light, chlorophyll boosts one of its electrons to a higher, more energetic orbit.

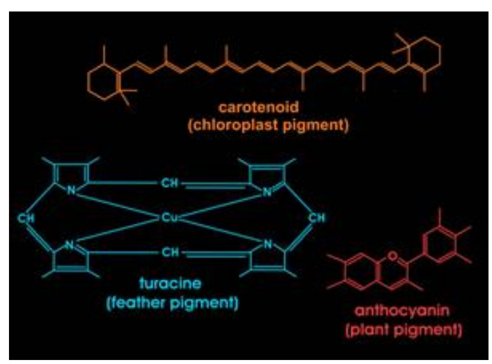


This absorption pattern for chlorophyll shows how little green or yellow light is absorbed by chlorophyll. If you could tinker with the structure of chlorophyll to allow it to use green or yellow light to energize electrons, plants could double their food production!

Slide 6: Carotenoids

Chlorophyll is not the only molecule that captures photons of light for photosynthesis, but these other pigments don't become visible until the fall when leaves turn orange, red, and yellow as chlorophyll production drops off. These other pigments are all varieties of carotenoids.

Carotenoids are particularly good at absorbing high-energy blue light, which is why they reflect away orange, red, and yellow light. In absorbing blue light, carotenoids help protect chlorophyll from damage by high energy blue light.



As you'd predict, every other bond in carotenoids is a double bond. The same goes for other pigments like turacine, a feather pigment, and anthocyanin. This strawberry is red because of the pigment anthocyanin.

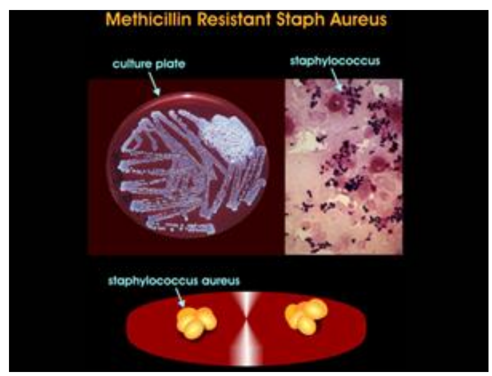
Carotenoids, as their name implies, give carrots their orange color. But you can get carrots with purple carotenoids, or other colors, too.

Purple carotenoids can even be found in corn, and green carotenoids in spinach.

This tomato is red because of a carotenoid called lycopene.

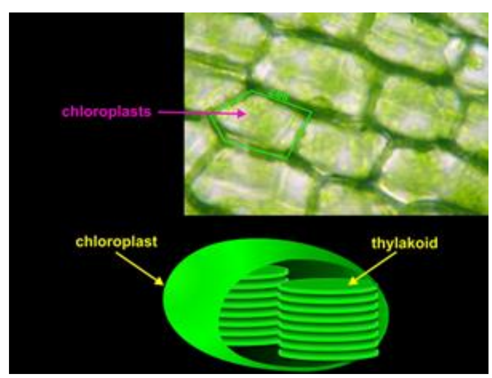
How about these flamingos? You'd bet on turacine because turacine is a feather pigment, but flamingos are pink because of carotenoids in the food they eat.

Here are staphylococcus bacteria resistant to methicillin, called MRSA: methicillin resistant staphylococcus aureus. "Aureus," which means gold, which is why the symbol for gold is Au, refers to its golden brown color.



The reason staphylococcus aureus is golden brown is that it is coated with carotenoids, which protect it from white blood cells. Antibiotics are now being developed to prevent staphylococcus from making carotenoids, which then makes them vulnerable to destruction by our white blood cells and antibodies.

Slide 7: Overview of photosynthesis

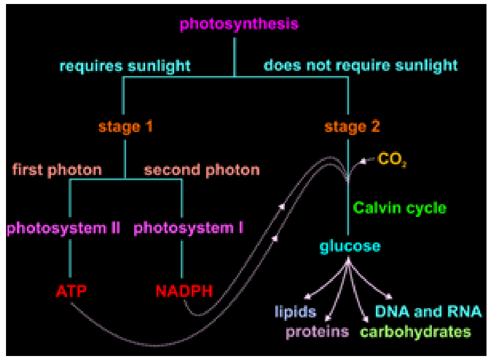


Photosynthesis takes place in plant cells within tiny structures called "chloroplasts," which contain stacks of hollow structures called "thylakoids."

Photosynthesis is divided into stage 1 and stage 2. Stage 1 requires sunlight; stage 2 does not. Stage 1 consists of two photosystems. In photosystem II, a photon of light is captured to make ATP.

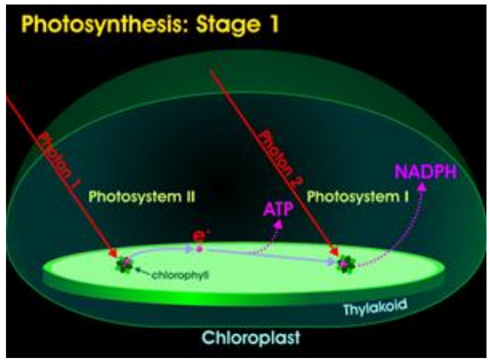
Then, in photosystem I, a second photon is captured to make the high energy molecule NADPH. The reason photosystem II precedes photosystem I is that photosystem I was discovered first, before photosystem II.

Stage 2 of photosynthesis uses the high energy molecules ATP and NADPH to capture carbon dioxide from the air and make glucose through a series of chemical reactions called the Calvin cycle. Since photons of light are not used in stage 2, stage 2 is also known as the dark reactions, but darkness is not necessary; the Calvin cycle also produces glucose during the day.



Plant cells are able to convert the glucose they make in the Calvin cycle into the lipids, proteins, carbohydrates, and DNA and RNA needed to run the cell.

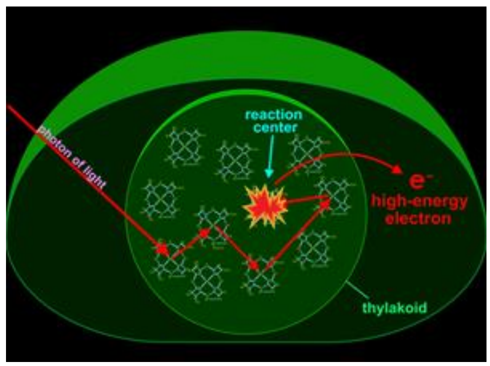
Slide 8: Stage I of photosynthesis – the light dependent reactions



Photosynthesis begins in stage 1 with the capture of a photon of light by molecules of chlorophyll embedded in thylakoid membranes. This first photon will be used by photosystem II to make ATP.

The second half of stage 1 begins with the capture of a second photon of light in photosystem I to make high energy NADPH.

Chlorophyll molecules are grouped around one central chlorophyll called the reaction center. When one of the chlorophylls captures a photon of light, the energy zigzags through the array of chlorophyll molecules until it reaches the reaction center. In the reaction center, the energy of the photon ejects one of chlorophyll's electrons with high energy.

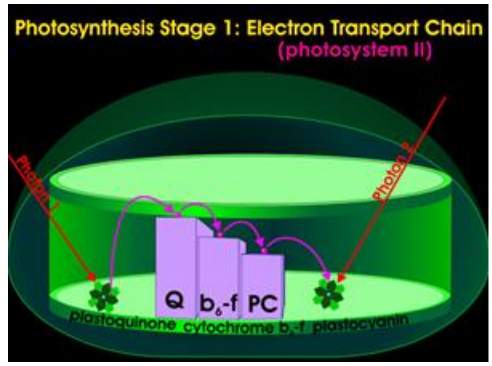


Slide 9: Photosystem II: extracting energy

The electron ejected from the reaction center attaches immediately to a protein, plastoquinone, or Q for short. From plastoquinone, the electron is passed to cytochrome b_6-f and then to plastocyanin, each step extracting energy from the electron.

These three protein complexes, plastoquinone, cytochrome b_6-f, and plastocyanin, constitute photosystem II.

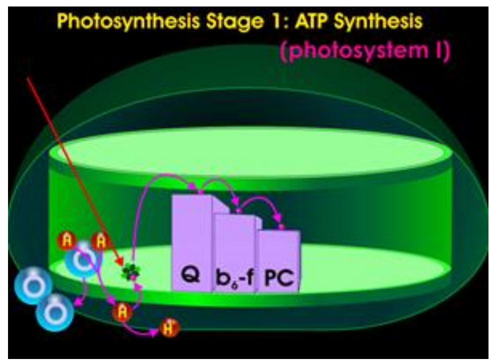
To replenish the electron's energy, plastocyanin passes the electron to another chlorophyll reaction center for another jolt of electromagnetic energy from a second photon of light.



The three protein complexes in photosystem II use the energy extracted from the excited electron to pump hydrogen ions into the interior of the thylakoid. Here's where the hydrogen ions come from.

Slide 10: Photosystem II: splitting water

When chlorophyll ejected its high-energy electron, it left a hole in the chlorophyll molecule for another electron to fill.

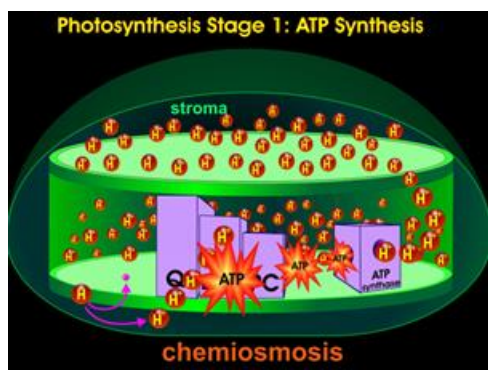


The replacement electron will come from molecules of water that are split by the water-splitting enzyme of photosynthesis into oxygen and hydrogen atoms.

The individual oxygen atoms immediately combine to form oxygen molecules that pass into the air, which means that the oxygen we breathe comes from water absorbed by plants.

Another enzyme, meanwhile, splits the individual hydrogen atoms into hydrogen ions and electrons. The electrons replenish chlorophyll's ejected electron, and the hydrogen ion is now available to be pumped into the interior of the thylakoid by the three protein complexes in photosystem II.

Slide 11: Photosystem II: making ATP



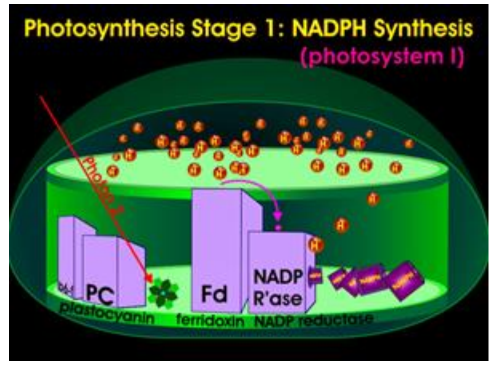
As hydrogen ions being pumped into the interior of the thylakoid accumulate, they eventually create an overwhelming chemical and electrical gradient.

The hydrogen ions start forcing their way out of the thylakoid into the chloroplast space, or stroma, through an enzyme called ATP synthase.

Each time a hydrogen ion passes through ATP synthase, a molecule of ATP is made. This process is called chemiosmosis.

Slide 12: Photosystem I: NADPH synthesis

Having given up a significant amount of energy to pump hydrogen ions into the interior of the thylakoids, the electron resting on plastocyanin is now ready to be reenergized by a second photon of light in photosystem I.

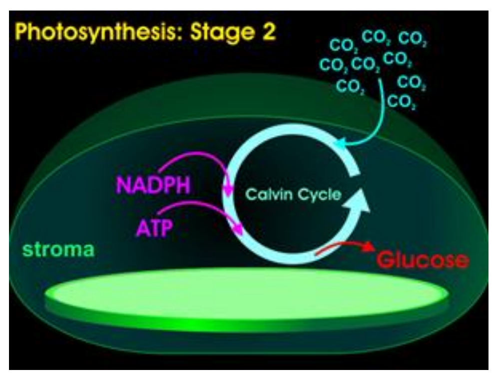


Plastocyanin passes the depleted electron to a chlorophyll reaction center. When a second photon of light strikes a chlorophyll molecule, its energy again zig-zags through the array of chlorophyll molecules to the reaction center where the photon's energy boosts the depleted electron to a much higher energy level.

The super high energy electron is then transferred to ferredoxin which then delivers the electron, along with a proton from the interior of the thylakoid, to NADP reductase.

Together, the excited electron and a hydrogen ion, this time from the stroma of the chloroplast, form a hydrogen atom and suddenly NADP becomes super-charged NADPH.

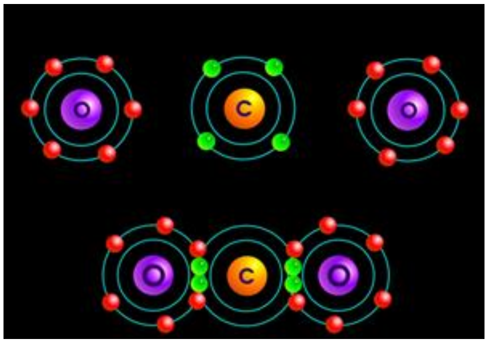
Slide 13: Stage 2 of photosynthesis – the dark reactions

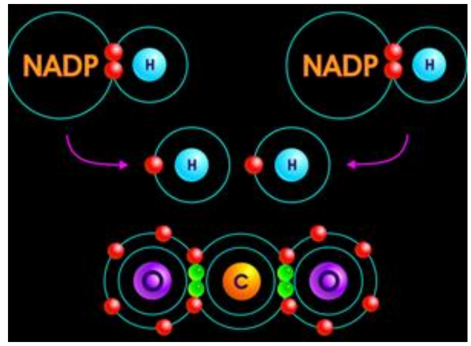


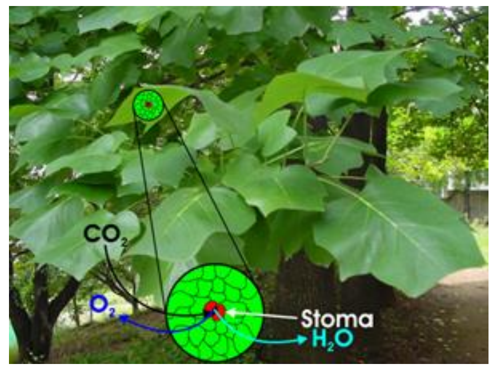
The ATP made during photosynthesis II and the super high-energy NADPH made during photosynthesis I provide the energy needed to run stage 2 of photosynthesis.

In this second stage, carbon dioxide from the air is split apart into carbon and oxygen atoms, which are inserted into a series of chemical reactions called the Calvin Cycle to make glucose. Because stage 2 of photosynthesis is powered by ATP and NADPH, no photons of light are needed, so stage 2 can take place day or night.

Carbon dioxide is a very difficult molecule to break apart, because both oxygen atoms are double-bonded to carbon. Fortunately, the hydrogen atom on NADPH has a great deal of energy, which makes NADPH the perfect reducing agent to break carbon dioxide's double bonds and allow the carbon and oxygen atoms to be moved into the Calvin cycle to be made into glucose.



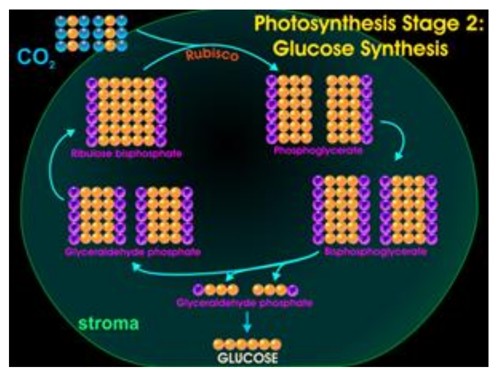




Carbon dioxide in the air enters leaves through the leaves' microscopic pores, called stomata, situated for the most part along the leaves' undersurface. Stoma means mouth in Latin, from which we get the word stomach.

The carbon dioxide molecules entering the stomata pass by oxygen and water molecules leaving the leaf to pass into the air.

Slide 14: The Calvin Cycle



Stage 2 of photosynthesis takes place outside the thylakoid but still inside the chloroplast, in the stroma of the chloroplast.

The first step in the Calvin cycle is the addition of 6 carbon dioxide molecules to 6 molecules of ribulose bisphosphate, each 5 carbons long, to form 12 molecules of phosphoglycerate, each 3 carbons long.

The reason ribulose bisphosphate isn't called biphosphate or diphosphate is that "bis" means two phosphate groups not connected to each other. "Bi" or "di" phosphate means the two phosphates are connected to each other.

The enzyme that attaches CO_2 to ribulose bisphosphate is rubisco. Given the number of plants on the earth, rubisco is probably the most abundant protein on earth.

What happens to the two oxygen atoms in CO_2? They are also incorporated into the Calvin cycle. This means that the only oxygen given off by plants comes from water molecules in stage 1, when water molecules were split into oxygen and hydrogen atoms.

Another phosphate is attached to each phosphoglycerate molecule to form twelve bisphosphoglycerate molecules.

Then a phosphate and an oxygen atom are removed from two of the bisphosphoglycerate molecules to make 2 molecules of glyceraldehyde phosphate.

These two glyceraldehyde phosphate molecules are then joined into a 6-carbon glucose molecule. This glucose molecule will be made into just about every molecule the plant needs. In other words, those CO_2 molecules in the air provide all the carbon atoms that make up the leaves, the wood, the bark, and the roots of a tree. The only thing the soil provides is water and minerals like calcium, magnesium, sodium, potassium, and so on.

The other five glyceraldehyde phosphate molecules are reconnected to bring us full circle to the six molecules of ribulose bisphosphate.

It shouldn't surprise you that animals simply reverse the Calvin cycle by eating glucose and breaking it down to phosphoglycerate, and beyond, in order to release glucose's high energy electrons to make ATP and NADPH.

Rubisco is the subject of intense research because it needs improvement. First of all, it's too slow. It only attaches about 3 CO_2 molecules a minute to 3 ribulose bisphosphate molecules.

Secondly, instead of attaching CO_2 to ribulose bisphosphate, rubisco might in some circumstances attach oxygen molecules to ribulose bisphosphate. That's going to run the Calvin cycle backward.

Scientists around the world are tinkering with the amino acid layout of rubisco to make it work faster, and attach only carbon dioxide to ribulose bisphosphate. Success with either one of these goals will greatly increase food production and reduce the amount of carbon dioxide in the air to help slow down global warming.

Slide 15: CAM plants

In really dry areas of the country, certain plants only allow their stomata to open at night in order to prevent excessive water loss during the day. Since most plants lose almost all their water through stomata, keeping stomata closed during the hot day can save a plant a lot of water in desert regions.

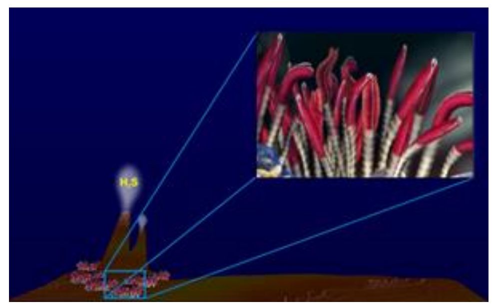
The problem is that with stomata closed during daylight, CO_2 can't get into the leaves during the day to be made into glucose. What these plants do instead, is absorb CO_2 at night and store the CO_2 temporarily overnight as malic acid, a 4-carbon, sour-tasting molecule used to flavor super-sour candy.

During the day, malic acid releases the CO_2 into the chloroplasts, where it is converted with the help of rubisco into glucose. Because this process was first studied in the family of plants called crassulaceae, plants that use malic acid to store CO_2 overnight are called CAM plants which stands for crassulacean acid metabolism.

Slide 16: Before photosynthesis

The purpose of photosynthesis is to convert the electromagnetic energy in light into chemical energy so the chloroplasts can make glucose. Before photosynthesis, before there were chloroplasts, before organisms could rely on the energy of the sun to make chemical energy, they had to oxidize inorganic molecules in the environment to obtain energy. Oxidation removes electrons, and in doing so, releases energy.

Descendants of those ancient bacteria continue to live today in areas of the world where there is no sunlight, where photosynthesis would be useless anyway. These primitive bacteria obtain their energy by oxidizing hydrogen sulfide seeping from the walls of caves.



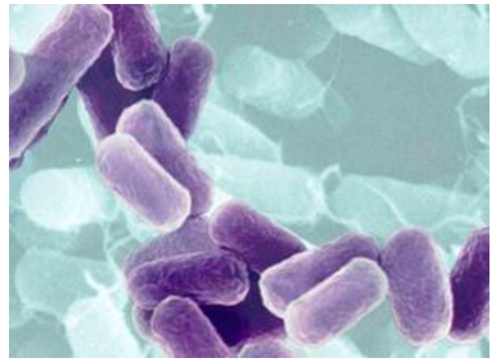
Other bacteria oxidize hydrogen sulfide bubbling up from vents along tectonic cracks in the ocean floor. The bacteria live inside these tube worms.

The tube worm is red because it contains, surprisingly, hemoglobin. Hemoglobin carries the hydrogen sulfide and oxygen to the bacteria. The bacteria then remove the hydrogen atoms from hydrogen sulfide and attach them to CO_2 molecules circulating in the water to make organic carbon molecules, mimicking what the Calvin cycle does. Despite the hostile environment and fragile energy source, tube worms can live up to 250 years.

Because the bacteria inside tube worms make their own food, they are autotrophs, and because they depend on chemical energy instead of the electromagnetic energy of sunlight, they're called chemoautotrophs, or chemotrophs for short.

Slide 17: Purple bacteria and cyanobacteria

The first chlorophyll, a blue chlorophyll, appeared around 3 and a half billion years ago. Armed with chlorophyll, bacteria could now generate plenty of energy, and remove many more hydrogen atoms from hydrogen sulfide to make a lot more glucose. Because these bacteria make food using the energy from sunlight, they are called photoautotrophs.



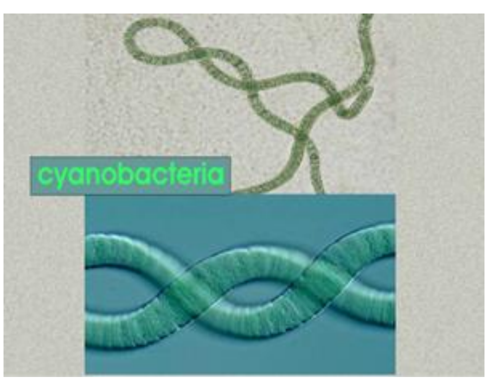
There are bacteria living today, called purple bacteria that still use that first chlorophyll to remove hydrogen atoms from hydrogen sulfide. These bacteria are confined to lakes and swamps that contain hydrogen sulfide.

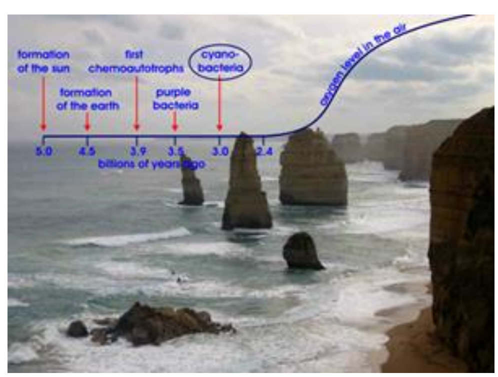
About a half a billion years after purple bacteria appeared in the world, another bacteria evolved a new twist on photosynthesis.

These bacteria, called cyanobacteria, figured out how to remove hydrogen atoms from H_2O (water) instead of H_2S (hydrogen sulfide).

Now, instead of sulfur, oxygen was discarded as a byproduct, and for another half a billion years, the oxygen being discarded into the air combined with all the calcium, silicon, iron, aluminum, magnesium, and other elements in rocks. Next time you're in the geology section of a museum, check out the chemical formulas of the rocks. You'll see all sorts of combinations of oxygen with every type of metal imaginable.

After a half a billion years of cyanobacteria saturating the rocks with oxygen, oxygen had no place to go but into the air. So about 2.4 billion years ago, the atmosphere began to fill up with oxygen, allowing plants and animals to more effectively oxidize the energy captured from sunlight.





Slide 18: What you know so far

1. Organisms can be classified by their source of energy and their source of carbon. Organisms that get their energy from sunlight are "photo," "chemo" if they get it from molecules. Organisms that get their carbon from the air or water are "auto," "hetero" if they get it from organic molecules. Plants and cyanobacteria are photoautotrophs because they use sunlight for energy and carbon in the air to make their organic molecules. Animals are chemoheterotrophs, because they eat organic molecules for energy and make their organic molecules from the carbon found in organic molecules.

2. Sunlight is captured primarily by ringed molecules in which every other bond is a double bond. Chlorophyll and carotenoids are two classes of such compounds.

Slide 19: What you know so far

3. Chlorophyll absorbs the red, yellow, and blue end of the spectrum, reflecting away green light. Carotenoids absorb blue light and reflect away the red and yellow end of the spectrum. Leaves turn red and yellow in the fall as chlorophyll products drops off. Carotenoids provide the pigments for many vegetables.

4. Photosynthesis is a two stage process, involving, in stage 1, the capture of light to make high-energy ATP and NADPH, and then, in stage 2, the capture of carbon dioxide from the air to make glucose, using the ATP and NADPH made in stage 1.

Slide 20: What you know so far

5. Stage 1 of photosynthesis requires two photons of light, the first one to energy an electron in chlorophyll to make ATP, and the second one to energize an electron in chlorophyll to make NADPH.

6. Photosynthesis takes place in thylakoids, hollow structures found inside chloroplasts inside plant cells. The mechanism of ATP production involves the splitting of water molecules into hydrogen and oxygen atoms, then the splitting of the hydrogen atoms into protons and electrons, and then the pumping of the protons into the interior of the thylakoids. Molecules of ATP are made each time one of the protons forces its way out of the interior of the thylakoid by passing through the enzyme, ATP synthase.

Slide 21: What you know so far

7. The protein complexes in the thylakoid membrane that extract the energy from the excited electron in order to pump the protons into the interior of the thylakoid are known as the "electron transport chain."

8. The enzyme that split water molecules into hydrogen and oxygen atoms is called the "water splitting enzyme of photosynthesis." The individual oxygen atoms combine with each other to form oxygen molecules and are released into the air.

9. Once the second photon of light has energized an electron in chlorophyll, and the energy in that electron has been extracted to make a molecule of high-energy NADPH, photosynthesis has completed its stage 1, the light-dependent reactions.

Slide 22: What you know so far

10. ATP and NADPH are used in the stage 2, the dark reactions, to remove carbon dioxide from the air and make glucose through a series of enzymatic steps known as the "Calvin cycle." The initial and most difficult step of catching a molecule of carbon dioxide in the air and incorporating into a ribulose bisphosphate is performed by the enzyme rubisco.

11. From the glucose made in the Calvin cycle, the cell is able to make all the proteins, carbohydrates, lipids, and nucleic acids it needs.

12. The first organisms to develop chlorophyll were cyanobacteria, still present today.