LESSON 1: PLANT CELLS

LEVEL ONE

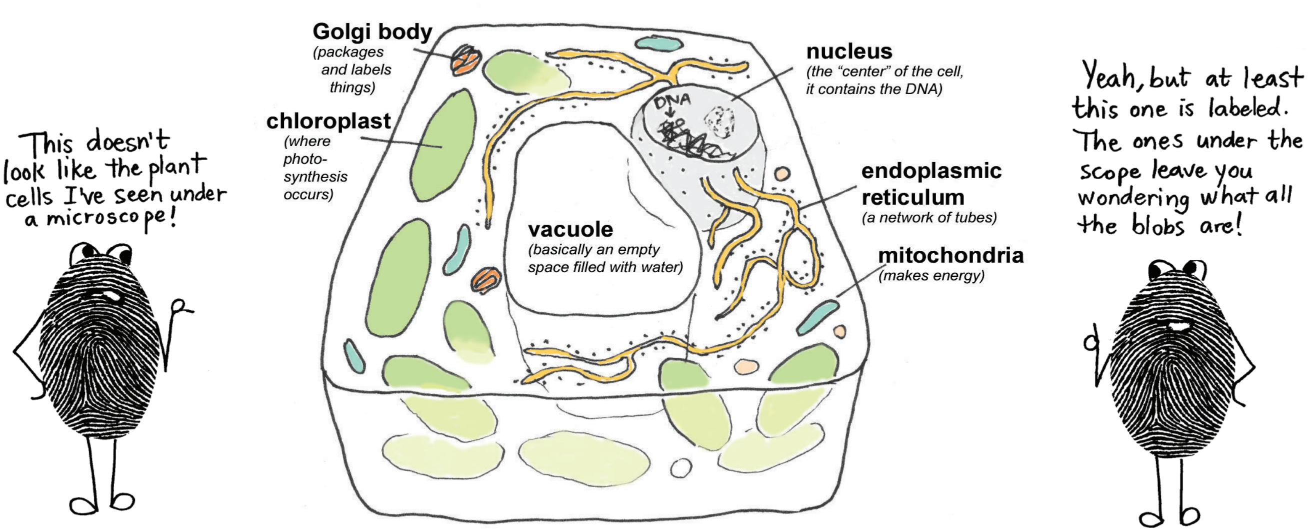
What is a plant? A quick answer might be "something that is green and has leaves." But are all plants green? There's a type of maple tree that has purplish-red leaves. Obviously it is a plant because it is a tree. So being green can't be a requirement for being a plant, though most plants are indeed green. What about leaves? Do all plants have leaves? Think about a cactus. Do those sharp needles count as leaves? Or what about the "stone plant"? It looks like a rock. (No kidding--it really does!) What makes a plant a plant?

The answer is... a plant is a plant because it can make its own food using a process called ***photosynthesis***. Plants can use the energy from sunlight to turn water and carbon dioxide into sugar. ("Photo" means "light," and "synthesis" means "make.") Wouldn't it be nice if you could make your own food from sunlight? No more going to the grocery store or planting a garden. You could just stand in the sunshine, take a deep breath, drink a glass of water, and make your own food. Sounds funny, but that's exactly what plants do. They take water from the ground, carbon dioxide from the air, and energy from light and turn them into food.

Photosynthesis is a very complicated chemical process. The exact details of how a plant takes apart the molecules of water and carbon dioxide and turns them into sugar is so complicated that you need a college degree in chemistry to really understand it. Since you probably don't want to learn about "photophosphorylation" and "chemiosmosis," we'll just stick to the basics of photosynthesis.

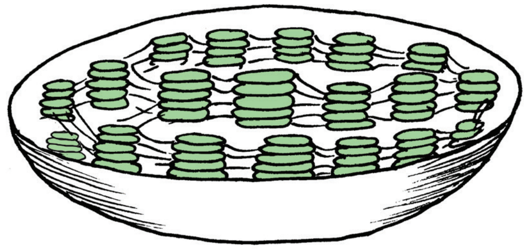
To understand the basics of photosynthesis we need to start by looking at a plant cell. A ***cell*** is the basic "building block" of a plant. A plant is made of individual cells in much the same way that a building is made of individual bricks.

Here is a simplified drawing of a typical plant cell.



Not all plant cells have exactly this shape. Some are very long and thin, some are flat, some are round, and some are curved. The shape of a plant cell depends on where it is in the plant. A root cell will look different from a leaf cell. However, all plant cells are at least somewhat similar to the one shown here. Most plant cells have organelles called ***chloroplasts***. (Some cells, such as root cells, are specialized for tasks not related to photosynthesis, so they don't have chloroplasts.) Real chloroplasts are green, just like the ones in our diagram. Other organelles have no color, but we added a bit of color to our organelles just to make the diagram look more interesting.

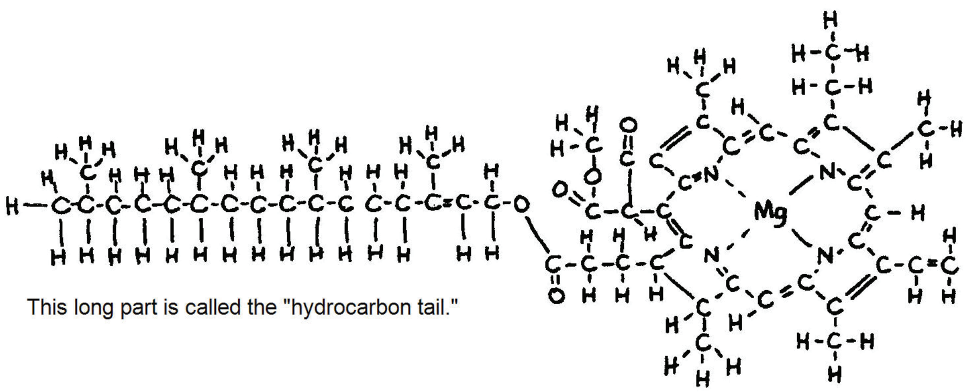
The things that look like stacks of pennies (or maybe pancakes) are called ***thylakoids***. Chlorophyll molecules are located on the surfaces of the thylakoids.



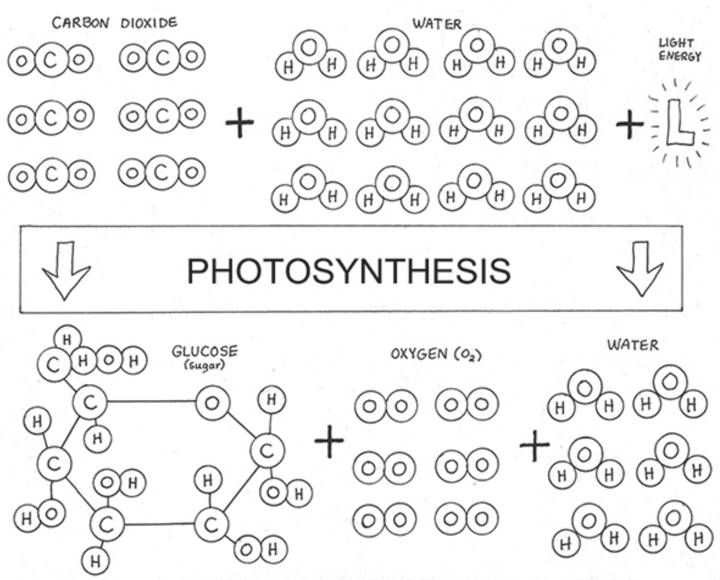
inside a chloroplast

It is inside the chloroplast that photosynthesis takes place. The chloroplast's job is to use the energy in the sunlight to make sugar. The chloroplasts contain a special chemical called ***chlorophyll***. This chemical happens to reflect green light, which is why most plants look green.

One molecule of chlorophyll is so small that you can't see it, even with a microscope. It's made of five different kinds of atoms (carbon, hydrogen, nitrogen, oxygen, and magnesium) linked together to make this shape:

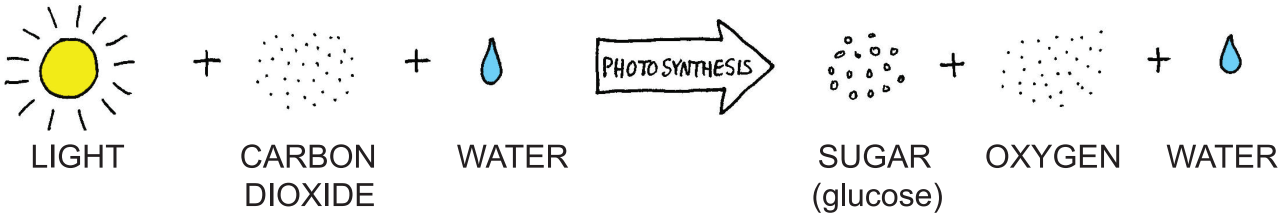


This molecule has the amazing ability to transform light energy into chemical energy. The light energy is used to tear apart molecules of water and carbon dioxide. The plant takes six carbon dioxides and twelve waters and turns them into one ***glucose*** (sugar) molecule plus six oxygens and six waters.



The water molecules on the bottom are ***not*** the same water molecules from the top. The plant tears apart the original water molecules and makes totally new ones!

Without drawing each individual molecule, the formula for photosynthesis looks like this:

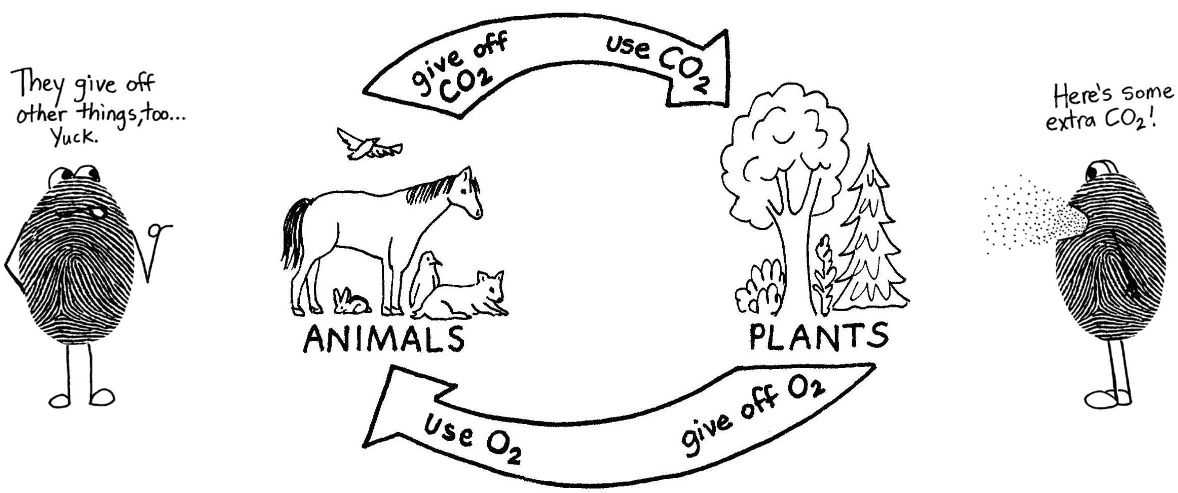


This says in pictures what we've already said in words: plants use sunlight, carbon dioxide and water to make sugar. In the process of making sugar, oxygen and water also are produced. Oxygen and water are called "by-products" of photosynthesis. (A by-product is something extra that is produced along with what you intended to make.)

Now let's do something interesting with this formula. Let's flip it around:

This "backwards" photosynthesis is called ***respiration***. Respiration is what all cells do (both plant and animal cells) to get energy from sugar. Plant cells use the sugar they make, plus oxygen and water from the environment, to make energy that keeps their cells alive and growing. Animals use the sugar they eat (made by plants), water they drink, and oxygen they breathe in, to make energy for their cells. Both plants and animals breathe out carbon dioxide and water vapor. (You can see this water vapor in your breath on a cold winter day—it looks like a cloud of steam.)

Both these processes—photosynthesis and respiration—go on at the same time in plants. (Animals do only respiration.) Photosynthesis and respiration complement each other nicely. The waste products of one process become the raw materials for the other. We could draw it like this:



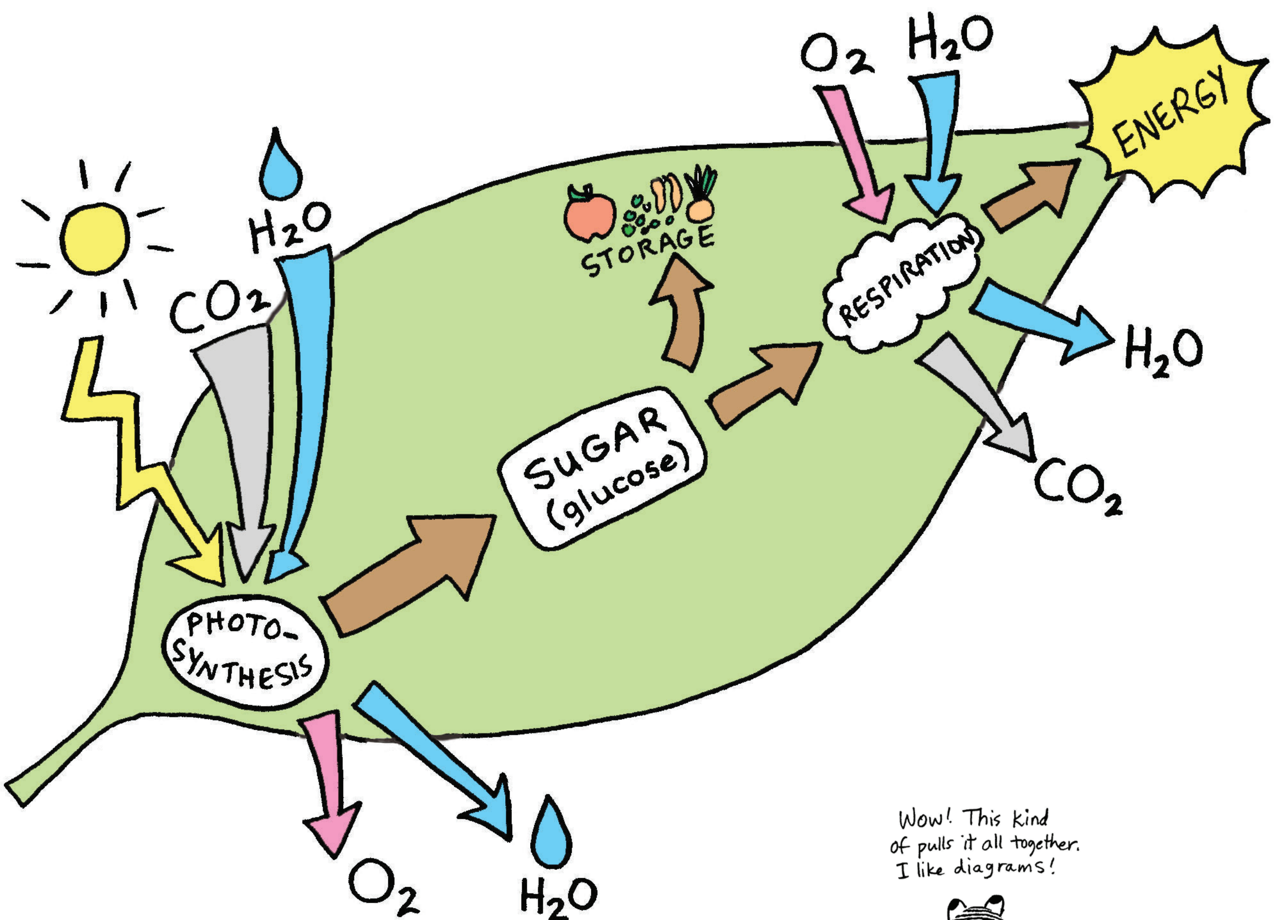
Animals depend on plants not only for putting oxygen back into the air, but also for supplying food. All animals are dependent upon plants whether they eat plants or not. Even carnivores such as lions depend on plants, because the prey that they eat (zebras, for instance) are usually plant eaters. Without grass for the zebra to eat, the lion would starve.

Could plants survive without animals? Perhaps some could. But what would happen if there were no bees or butterflies to pollinate flowers? What about plants that depend on seed-eating animals to spread their seeds? Plants do benefit from animals.

Let's wrap up this section with a brief review of what goes on in a leaf. See if you can follow along with this paragraph, putting your finger on the appropriate words or arrows in the diagram as you read. Stop when you come to a comma or period and make sure your finger is in the right place before you continue.

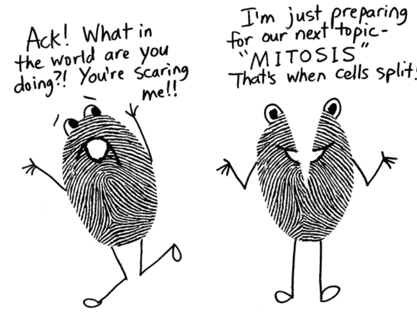
The plant uses light, carbon dioxide, and water in a process called photosynthesis. This process results in the production of oxygen, water, and glucose (sugar). Some of the glucose is used by the plant as its own food. (This "eating" process inside a plant cell is called "respiration.") For respiration, the plant needs some of its sugar, plus oxygen and water. It produces energy, plus carbon dioxide and water.

Plants usually make more glucose than they need. The leftover glucose is packaged into starches or fats and is stored in the roots, seeds and fruits.



And now for something completely different...

HOW CELLS DIVIDE

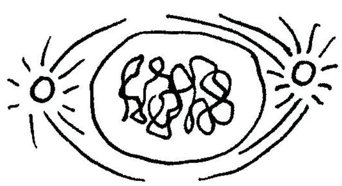


As a plant grows, it must increase the number of cells it has. To make more cells, plants use a process called ***mitosis***. Mitosis is both very simple and very complex. It is simple because it just means that a cell splits in half, making two cells. That's it. The word mitosis just means splitting in half. However, in order to do this, the cell must go through some very complicated procedures.

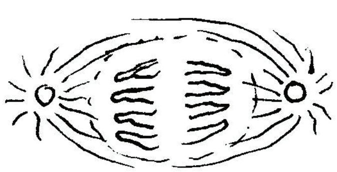
First, the nucleus must prepare. If there are to be two cells, each new cell must have a complete copy of the DNA instructions. Also, each new cell will need a full set of organelles. Let's say a cell needs 10 chloroplasts to survive. That means that before it is ready to split in half, the "parent" cell needs to have 20 chloroplasts, 10 for each new "daughter" cell. (Sorry, there are no "son" cells, only "daughter" cells!) Each new cell will also need mitochondria, Golgi bodies, ribosomes and all the other organelles. So a cell has to keep busy making new organelles all the time.

When the cell has enough organelles to make two cells, the division process starts. Scientists have lots of complicated names for all these steps, but we're going to use ordinary words for our explanation. (If you want to know the complicated words, you can look them up on the Internet; just use the key word "mitosis.")

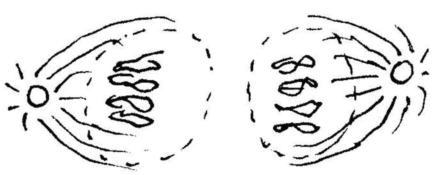
This is how the nucleus divides:



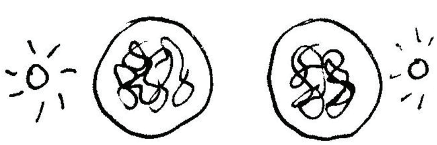
1) The DNA in the nucleus doubles, making two complete copies. Organelles called centrosomes go to the opposite sides of the nucleus and get ready to start pulling it apart.



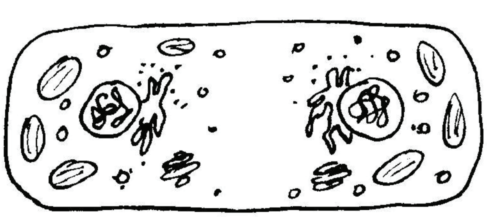
2) The two copies of the DNA separate. At this point they look pretty organized. Usually the DNA looks like a pile of yarn, but right now it's all lined up neat and tidy. The membrane around the nucleus start to disintegrate.



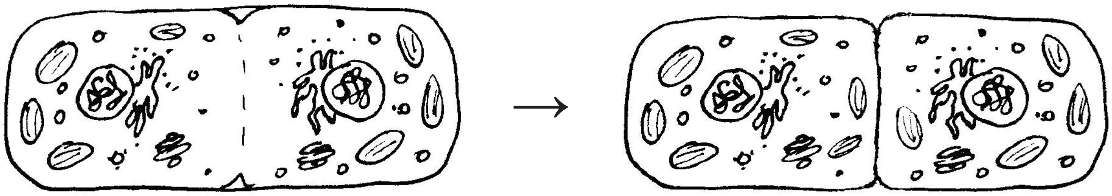
3) New membranes begin to form around the two new nuclei (nu-klee-i).



4) The membranes are complete. Now there are two separate, identical nuclei.



Now the whole cell prepares to split in half. Half of the organelles go to one side, and half go to the other. Each side has a nucleus. At this point the cell looks very long. In fact, this is sometimes called the "elongation phase" because the cell looks very long.



Now the cell builds a wall between the two sides. Usually the two cells stay stuck together, though, because that's the way a plant stays together. If the cells came apart, the plant would come apart. Then each cell starts all over again. As soon as mitosis is over, it's time to start making extra organelles again, to prepare for the next division. (And just think—this goes on billions of times each day, right in your own backyard!)

Wow--we made mitosis seem pretty easy to understand. Just be aware that if you go online and check out some Internet articles or videos about mitosis, you'll see words like "cytokinesis," "metaprophase," and "telophase." However, don't let these fancy words scare you off. For example, in cytokinesis, "cyto" means "cell," and "kinesis" means "movement." If you know what the Latin and Greek roots mean, the word becomes easy to understand.

ACTIVITY 1: LOOK AT SOME REAL CELLS

Use the key words "plant cell micrograph" in an Internet search engine (like Google) to see some actual photographs (micrographs) of real plant cells. The micrographs will be in black and white because the electron microscopes used to take the pictures don't use light to create their pictures--they use electrons. No light means no color.

ACTIVITY 2: SOME PLANT CELL VIDEOS

There are several short video clips related to plant cell mitosis posted on the Botany playlist at YouTube.com/TheBasementWorkshop.

ACTIVITY 3: WATCH CHLOROPLASTS "STREAMING"

Chloroplasts move around inside the cell in a very orderly way. They flow around in a circle, around the outside edge. They do this so that each chloroplast has an equal chance to absorb sunlight if the light is stronger on one side than another. You can see this in action by watching two videos posted on the Botany playlist (YouTube.com/TheBasementWorkshop).

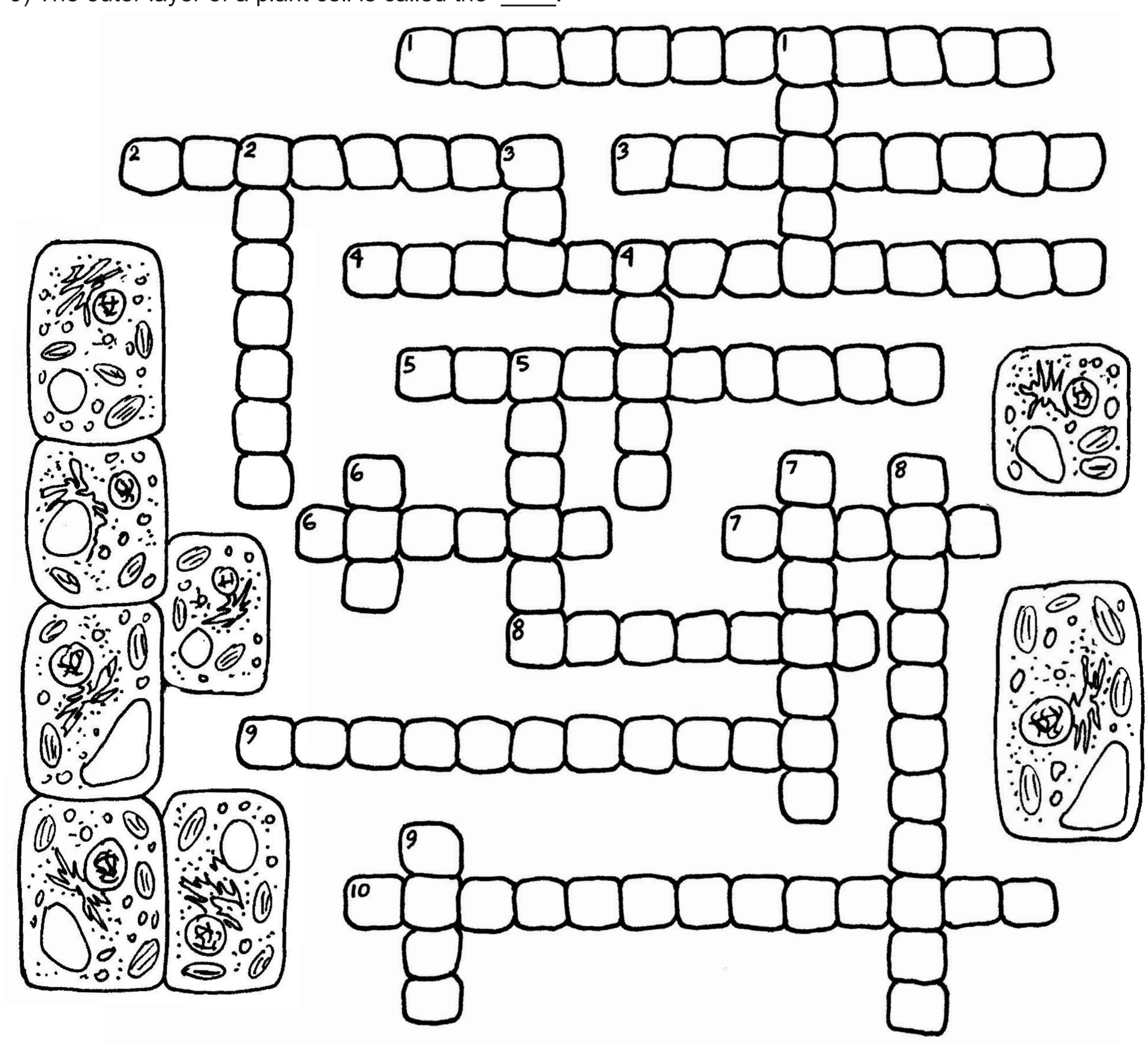
ACTIVITY 4: ONE MORE VIDEO: THE DISCOVERY THAT PLANTS DON'T EAT DIRT

Until recent centuries, people assumed that plants "ate" dirt. It seemed obvious. You put a seed into the ground and it grew into a large plant. It seemed likely that the plant absorbed nutrition from the soil through its roots. In 1643, a scientist named Jan Van Helmont decided to test if this was true. He carefully weighed a pot of dirt before he planted a seed. He let the seed grow into a large plant then dumped out the dirt and weighed it again. Surprise! The dirt weighed almost the same at the end of the experiment! You can watch a short video that shows Van Helmont and mentions a few other scientists who contributed to our knowledge of how plants work. This video is on the Botany playlist.

ACTIVTY 5: PHOTOSYNTHESIS/MITOSIS CROSSWORD PUZZLE

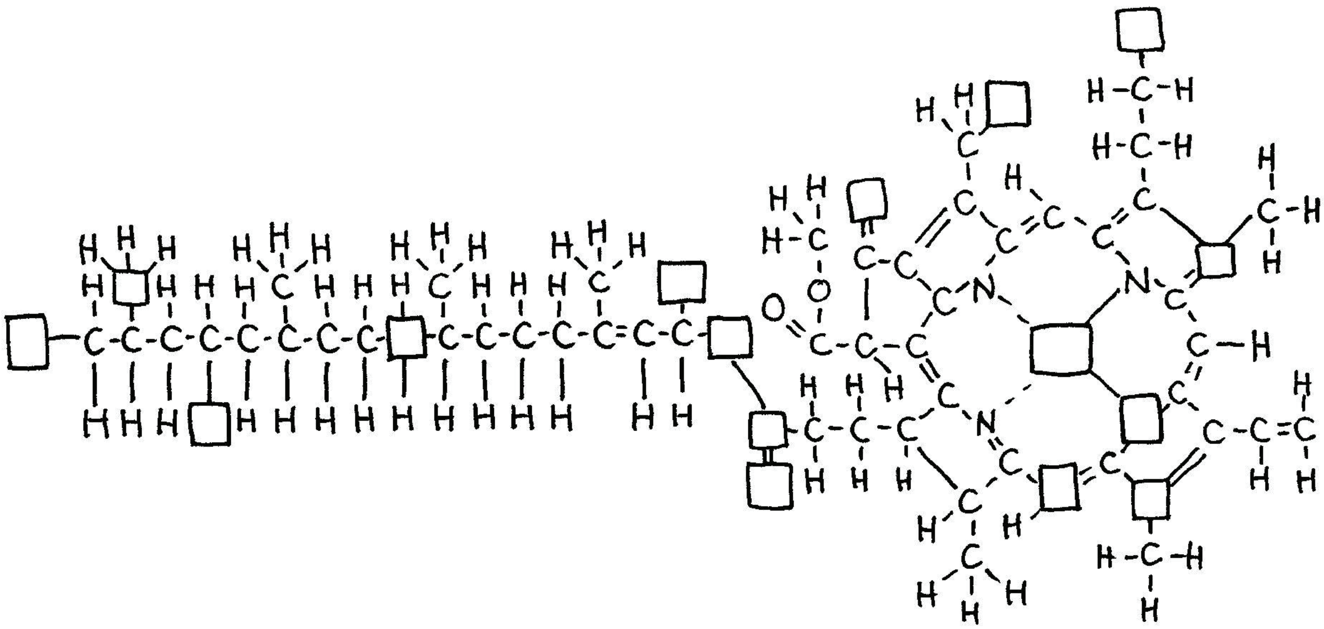
ACROSS
1) The organelles where photosynthesis takes place
2) The nucleus is surrounded by a thin ______________. (Hint: Read step 3 on page 5.)
3) The "parent" cell produces two "________________."
4) The process by which plants use light, carbon dioxide, and water to make glucose sugar
5) The phase in which a cell gets very long
6 The goal of respiration is to release _____.
7) Plants need this liquid for photosynthesis
8) The DNA of a plant cell is inside this organelle
9) The name of the chemical in the chloroplasts
10) Plants need this gas for photosynthesis.

DOWN
1) Plants use this source of energy for photosynthesis
2) When plant cells divide in half it is called __________.
3) Humans can't make their own sugar; we have to ___.
4) Glucose is a type of _____.
5) This is produced by plants during photosynthesis. It is also used by plants during respiration.
6) The instructions inside the nucleus are in the form of ___.
7) The empty "bubble" in a plant cell
8) The process used by both plants and animals to get energy from sugar and oxygen
9) The outer layer of a plant cell is called the ____.



<u>ACTIVITY 6</u>: FILL IN THE MISSING ATOMS IN CHLOROPHYLL

Use the chlorophyll atom in this chapter to help you fill in the missing atoms.



How many atoms of magnesium are in a chlorophyll molecule? _____
How many nitrogens? ______

<u>ACTIVITY 7</u>: LATIN WORD ROOTS

Many scientific words come from Latin or Greek. See if you can match the Latin or Greek word root on the left with its meaning on the right. To help you figure them out, think about the meanings of these words.

chloroplast	vacuum	photosynthesis	chlorophyll	nucleus	respiration	repeat

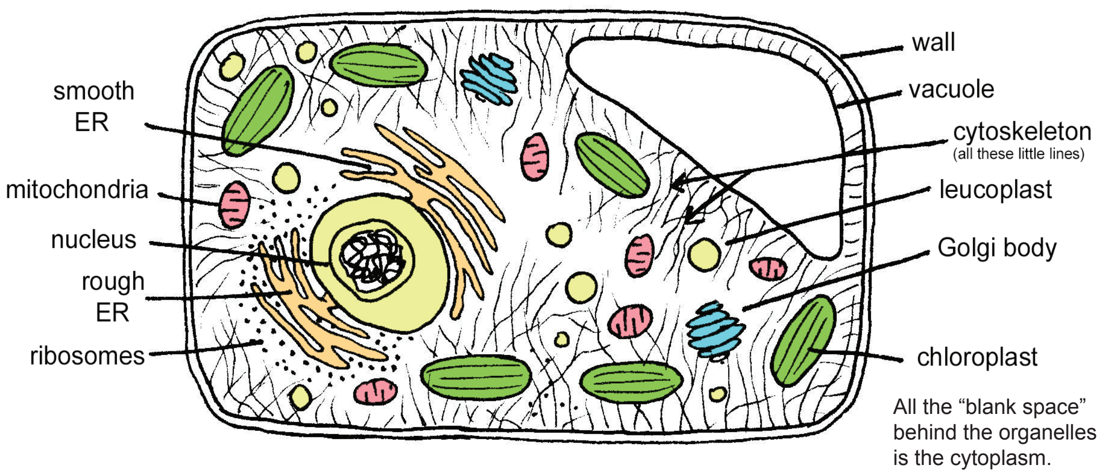
MATCH:

1) photo ____	A) empty
2) vacuus ____	B) to make
3) synth ____	C) again
4) chloro ____	D) light
5) nucula ____	E) breath
6) re ____	F) greenish-yellow
7) spiro ____	G) leaf
8) phyllo ____	H) little nut or kernel

(TIP: Do the ones you are sure of first, then use the process of elimination to try to figure out the ones you aren't so sure of.)

LEVEL TWO

A cell is sort of like a miniature factory. Real factories make products, store them in warehouses, and ship them out to customers. Cells make things like sugars, proteins and fats,and they store them and transport them. In this diagram, the plant cell looks flat. Remember that in real life plant cells are three-dimensional.



Here is what each little organelle does:

Vacuole: This is like a water-filled bubble in the middle of the cell. Water from outside the cell constantly “leaks” into the vacuole, keeping it full. This water pressure inside the cell keeps the cell firm and healthy. If a plant can’t get enough water to fill the vacuoles in its cells, the cells will shrink, causing the plant to wilt.

Cytoplasm: This is the jelly-like fluid inside the cell but outside the vacuole. It contains not only water, but proteins, fats, carbohydrates, and minerals. The cytoplasm circulates the chloroplasts around and around, making sure they all get an equal amount of light.

Chloroplasts: This is where photosynthesis occurs. Chloroplasts contain the chemical chlorophyll, which can use the energy in sunlight to turn carbon dioxide and water into sugar (making water and oxygen in the process).

Cytoskeleton**:** This is a network of fibers that does two jobs: it helps the cell to maintain its shape, and it serves as a system of “roads” on which various things can travel across the cell.

Nucleus**:** This is sort of the “center” of the cell. It contains the instructions for how the cell operates. The instructions are in the form of a very long protein molecule called ***DNA***. The DNA contains the “blueprints” for everything the cell makes.

Mitochondria: These are often called the “powerhouses” of the cell. Respiration takes place here. (Remember, respiration is how a cell gets energy out of glucose.) The mitochondria produce the energy the cell needs for its activities.

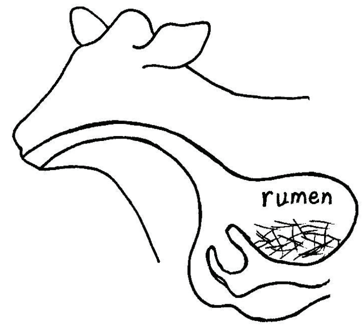
Leucoplasts: These are “storage tanks” for starches and lipids (fats). There are three different types of leucoplasts, the most common being the amyloplast. You will sometimes see the word “amyloplast” on a cell drawing instead of “leucoplast.” (“Amylo” means “starch.”)

Golgi bodies: These are often called the “post offices” of the cell. This is where proteins made by ribosomes are packaged and labeled for delivery to other areas of the cell, or to other cells.

Endoplasmic reticulum (ER): This seems to do several jobs. One type of ER manufactures protein molecules. Another type of ER makes lipids (fat) molecules. Both types of ER help the cell to maintain its shape by providing a bit of internal structure. ER also helps to transport things about the cell. Rough ER has ribosomes all around it; smooth ER does not.

Ribosomes: These little dots along the ER are a bit like the workers on an assembly line. They do the actual assembly of the plant’s proteins.

Now for some info about the cell wall. It's not really an organelle, but it's still important. The outside wall of a plant cell is very tough. It is made of something called ***cellulose***, which animals cannot digest. Only microorganisms (such as bacteria) can tear it apart. That is why animals that live on nothing but plants (herbivores) need lots of "good" microorganisms in their digestive systems to help them digest the plants. For example, a cow can live on nothing but grass because of the microorganisms living in the first of its four stomachs—the rumen. The microorganisms can tear apart the outer wall of the grass cells so that the proteins, fats and sugars inside of them spill out and are then available for the cow's body to use.



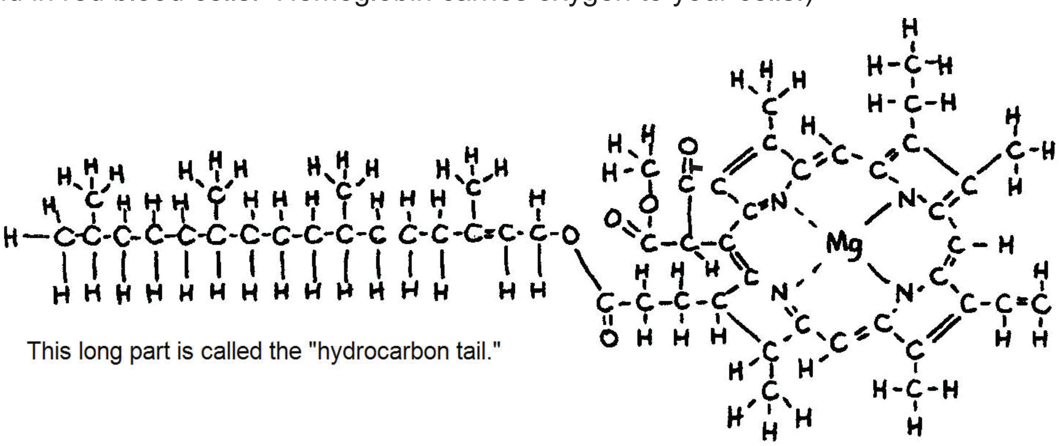
Plant cells spilling open

You don't have a rumen, so when you eat plant cells, most of them pass through your system undigested. This isn't bad for you, however. In fact, nutritionists call this plant material ***roughage*** or ***fiber***, and they recommend that you eat plenty of it. The plants in our diet help to keep our intestines healthy even though they provide only some nutrition. (Cooking can help to break down the cell walls, and very thorough chewing helps, too.)

Just inside the cell wall there is a ***cell membrane***. It is very thin and hard to see compared to the thick cell wall. Membranes are found in all types of cells, not just plant cells. They are fragile and come apart easily, but still have an important job. They control what comes into the cell, allowing nutrients and water to flow in but keeping harmful things out.

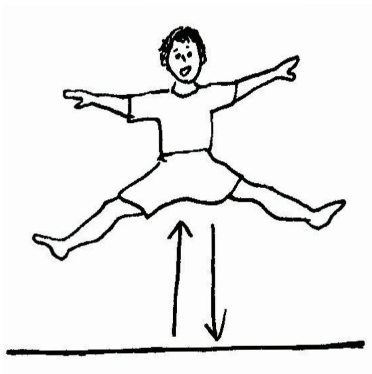
Let's discuss the process of photosynthesis again, this time taking a closer look at it. Just how does a chloroplast produce sugar?

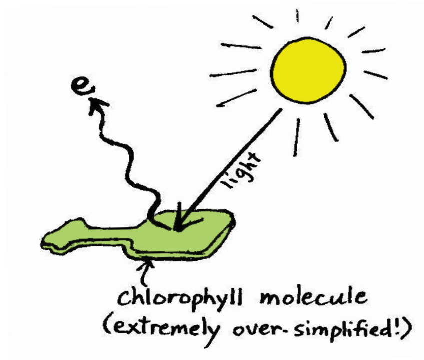
At the heart of photosynthesis is the chlorophyll molecule. (Interestingly enough, the ring of atoms around the magnesium atom can be found in other molecules, too. If you switch the magnesium atom for an iron atom, you get a "heme" molecule, an important part of the hemoglobin protein found in red blood cells. Hemoglobin carries oxygen to your cells.)



When a photon of light hits a chlorophyll molecule, it can super-charge an electron from one of these atoms, causing to become ***excited***. (It's hard to track down exactly which atom the electron belongs to.) The excited electron has so much energy that it is forced to leave the chlorophyll molecule and go elsewhere. A regular electron comes in and takes its place so the molecule doesn't fall apart.

When a person jumps up, gravity brings him back down again. An excited electron "jumps"

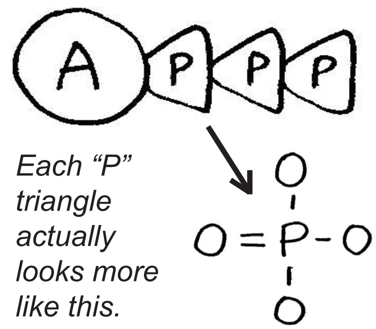




to a higher energy level, but it can't stay there any more than our jumper can stay in the air. The electron must come back down and return to its original energy level. On the way back down, though, the electron can pass its extra energy to other molecules, resulting in molecular "work" being done.

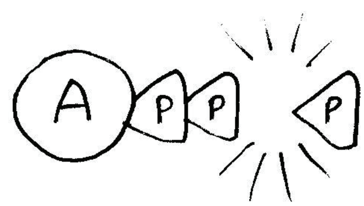
As it "falls," the high-energy electron passes through an assembly line made of tiny biological machines. The energy contained in the electron is used to power these machines. The goal of this assembly line is to re-charge the cell's biological batteries.

Floating around in the cell are millions of molecules called ATPs, which act like re-chargeable batteries. ATP is fairly simple, as far as biological molecules go. The A stands for ***adenine***, the same molecule found in the rungs of DNA. Then there is a little sugar called ***ribose***, which acts as a connector. The ribose holds on to three ***phosphates***. (A phosphate is nothing more than a phosphorus atom with a few oxygen atoms attached to it.) In this diagram, the ribose is not shown separately because when adenine and ribose are joined together they are called adenosine, which also starts with the letter A.



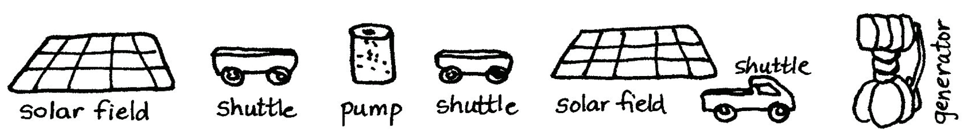
Each "P" triangle actually looks more like this.

The way this battery works is to pop off the phosphate on the end. When that third phosphate comes off, energy is released. You could think of it as a nano-sized pop gun. To re-load the gun, you simply stick the phosphate back on again. A cell has a few ways it can do this, but all of them require energy. Ultimately, the sun will provide this energy.



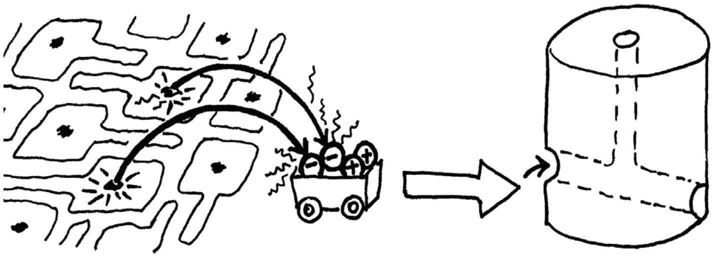
There are two stages in the photosynthesis process. One stage uses the energy of sunlight and the other uses the energy stored in biological batteries. Sometimes these stages are called the "Light Phase" and the "Dark Phase." The Light Phase needs light, but the Dark Phase doesn't need darkness. The new-and-improved names for these phases are "Light Dependent" and "Light Independent." We'll look at the Light Dependent phase first, since it provides energy for the Light Independent phase. (We'll meet the Independent phase on page 13, disguised as a sugar factory.)

Each phase has its own little assembly line. A quick overview of the Light Dependent assembly line looks like this. → We will look at each part separately and see how it works.



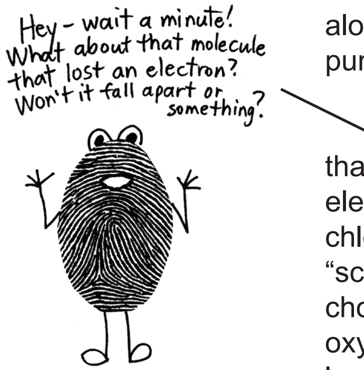
Have you ever seen fields full of solar panels? If not, go to Google, click "images," then type in "solar farms." You'll see huge, flat fields (usually in desert climates since they get a lot of sun) with hundreds of solar panels set up in neat lines. These solar panels collect energy from the sun and pass it along to a central collection area where the energy is then converted into electricity.

The plant cell's solar farms are embedded around the edges of the thylakoids (those pancake things in the chloroplasts). They are called ***photosystems***, instead of solar farms, and they have chlorophyll molecules instead of solar panels. Like solar farms, photosystems have a central collection point where the energy is harvested. These central points are called ***reaction centers***. Photons of light energy hit the chlorophyll molecule and energize them, causing them to vibrate. All the vibrations are passed along to the central chlorophyll molecule which then gets so energized

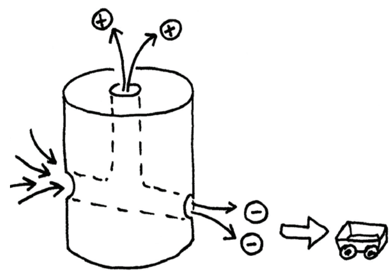


that an electron from its center goes flying off. While the electron is in this energized state, it can be used to do work. Quick! Get it to the pumping station! A little shuttle bus is waiting next to the photosystem, ready to pick up energized electrons and carry them over to the pumping station.

The shuttle bus has four seats and always picks up two electrons along with two protons. The protons also need to be transported to the pumping station, so the shuttle gives them both a ride. Off to the ion pump!



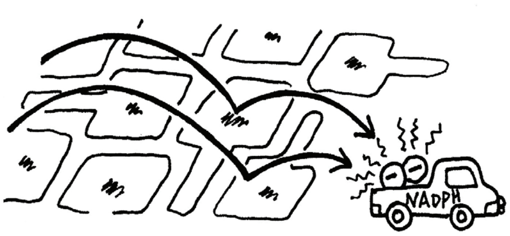
Good question! What is going to happen to the chlorophyll molecule that lost an electron? That electron was part of the molecule. Without the electron, the chlorophyll molecule will begin to collapse. Fortunately, the chloroplast has a way to deal with this emergency. It has little chemical "scissors" (made of atoms of manganese, calcium and chlorine) that can chop apart water molecules. Water is made of two hydrogen atoms and one oxygen atom. The chemical scissor cuts the bonds between the atoms. The lone oxygen atom goes off and finds another lone oxygen atom that has just been snipped, and the two form a bond and float off into the atmosphere together as a molecule of oxygen (O_2). The scissors then go to work on the hydrogen atoms. Since a hydrogen atom is nothing but one proton and one electron, only one snip is needed. The loose electron can go over and replace the missing electron in the chlorophyll molecule and the proton can go get on that shuttle bus.



Now we are ready to go back and discuss the shuttle bus that was heading to the pumping station. Let's see what happens next.

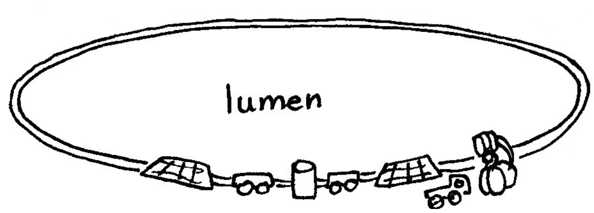
At the station, the electrons and protons are stuffed into the pump. The electrons provide a surge of energy to propel the protons up and out the top of the pump. When the electrons come out the other side they have given off a lot of their energy and are tired. They need to be re-charged to be of any further use. They get picked up by another shuttle bus. (We'll come back to the protons in just a minute.)

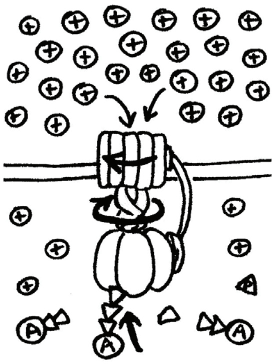
This next shuttle takes the tired electrons to another photosystem. The electrons get charged up again and then they are put into a fancy shuttle called NADPH. This letter group isn't very pronounceable. The closest word might be NAPA, an auto parts dealer in North America that has a fleet of blue and white pick-up trucks with big yellow hats on their roofs. So we've drawn the NADPH shuttle as a pick-up truck. The truck will take these energized electrons over to a sugar factory.



Now back to those protons that were pushed out the top of the pump. We need to zoom out for a second and look at where this assembly line is located. It lies right in the middle of the thylakoid membrane. The tops of all the little machines are on the inside (***lumen***) of the thylakoid, and the bottoms are outside of the thylakoid, in the fluid-filled space of the chloroplast (the ***stroma***).

The protons collect in the lumen of the thylakoid. The pumps keep pumping them in. Soon there are so many that they are looking for a way to escape. There is more "personal space" available out in the stroma, so that is where they want to go. This is where the generator comes in.





The correct name for the generator is ***ATP synthase***. “Synth” means “to make.” This machine doesn’t make ATP from scratch, though. It just pops the third phosphate back on. (ATP that is missing the third phosphate is called ADP, with the D being an abbreviation for “di,” meaning “two.”)

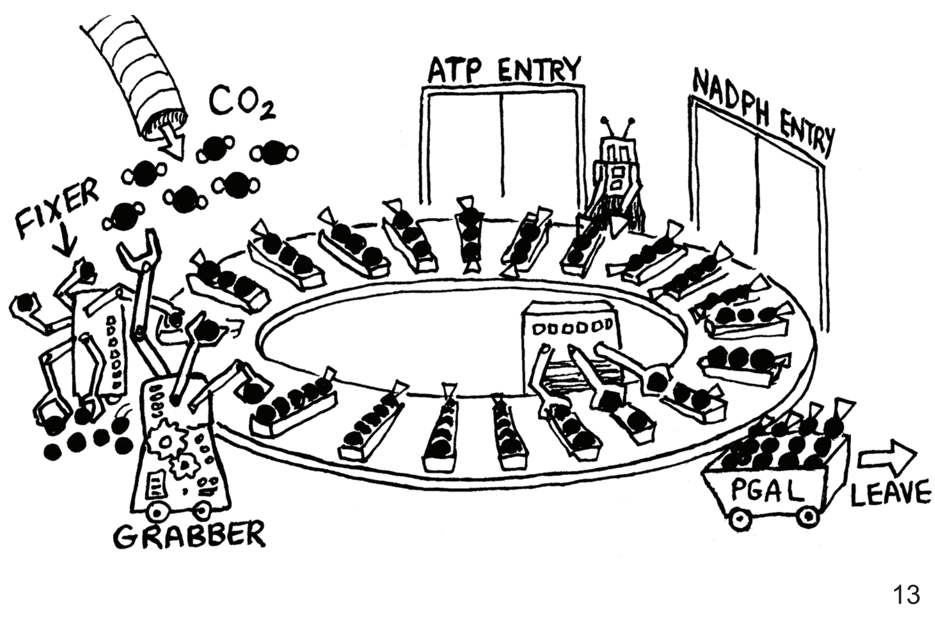
The protons upstairs in the lumen would like to get down where it is not so crowded and the only escape route is through this machine. The protons don’t mind going through it, and on the way down their positive charge is used to turn the rotor of the machine. The bottom part of the rotor has spaces that were designed for ADP to be held in place while a phosphate is snapped back on. So all the ADPs in the area are re-charged back into ATPs.

This first part of photosynthesis has as its only goal the recharging of ATPs and the filling of NADPH shuttle buses with high-energy electrons. The next part of the process is the formation of sugar molecules. This process does not need light because it is powered by these little bio-batteries. (But since the batteries need light to be re-charged, even this Light Independent process is still ultimately dependent on light.)

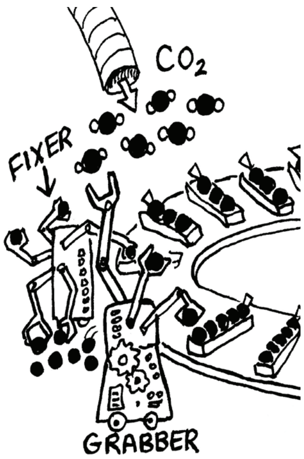
Let’s imagine our little NADPH shuttle buses and ATP molecules pulling into the parking lot of a sugar factory. (We were tempted to call it a candy factory, since candy is made from sugar, but then you would have been disappointed when the man who came out to greet you was not Willy Wonka.) The sign above the door says, “Welcome to the Calvin Cycle.” The manager comes to the door to greet us and introduces himself as Professor Melvin Calvin. (Okay, he’s not as cool as Willy Wonka, but he did receive a Nobel Prize in 1961, so try to be impressed.) When asked if he invented or built this factory that bears his name, he humbly admits that he simply discovered it. It was already built and in operation when he arrived. He just figured out how it worked. However, his friends were so impressed with his discoveries that they decided to name the factory after him.

Professor Calvin invites us inside to watch the factory in operation. The assembly line is a large circle. Fastened to the conveyor belt are compartments with black balls inside them. We learn that these black balls are carbon atoms. The Professor laughs as he comments how strange it is that sugar is made of carbon atoms — the same kind of carbon atoms that are found in the gasoline we put into our cars. He thinks of this factory as a fuel factory more than a sugar factory.

There is an air hose hanging from the ceiling in one place. The professor explains that the hose brings in a constant supply of air from the outside. The air contains something very necessary for this sugar-making process: carbon dioxide molecules. The compartments right below the air hose contain 5 carbon atoms. We notice that one of the carbons in each 5-carbon chain has a phosphate attached to it. Apparently,



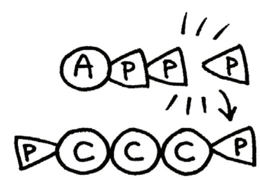
phosphates show up others places, too, not just on ATP. Professor Calvin says that phosphates are very common in the world of biological chemistry.

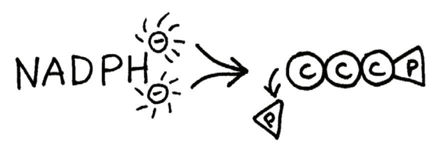


As we watch, a little robotic machine reaches up and grabs a carbon dioxide molecule. It snips off the two oxygens and then tries to stuff the carbon into a compartment that already has five carbons in it.

"This is what I can't understand," says the Professor. "The compartments can only hold five carbons, but the robot is programmed to try to add a sixth carbon. It never works. As soon as the circle begins to rotate, the six carbons fall out of the compartment! Luckily, the next robot down the line picks them all up and then puts sets of three carbons into compartments. I've thought about fixing that first robot so it doesn't keep trying to overload the compartments, but even without repairs, the assembly line manages to crank out an amazing number of sugar units, so I decided not to mess with it. Since the second robot fixes the first one's mistake, I call this part of the operation 'carbon fixing.'"

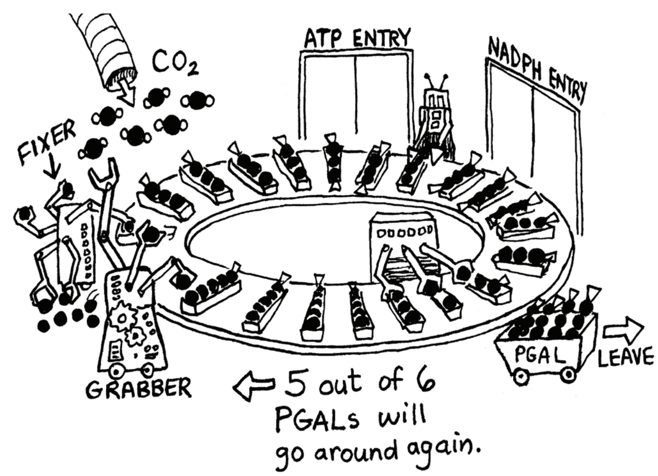
The 3-carbon arrangement works out very well, and as we watch the circular conveyor rotate, the carbons stay in groups of three for the rest of the ride. After the carbons leave the "fixer" robot, one carbon in each group of three has a phosphate attached to it. Professor Calvin then warns us that the next two steps won't make a lot of sense to us. At the next station, some ATPs are waiting and ready. They pop off their third phosphate and give it to a 3-carbon group. Now the group has two phosphates—one at each end. At the next station, we see some NADPH trucks ready to unload their passengers of high-energy electrons. Oddly enough, after being given a high-energy electron, the carbon groups then lose the phosphate they just gained! What was the point of receiving a phosphate if you are just going to get rid of it right away? The Professor tells us that there is more to this process than meets the eye. The end result of this cycle is that the 3-carbon groups are energized and ready to become part of a 6-carbon sugar molecule. These ready-to-go, 3-carbon molecules are called PGALs. (You can say "pea-gals" if you want to. That makes it easier to remember, too.)





This is the end of the cycle, but we notice that some of these 3-carbon groups stay on the belt, ready to go around the loop again. We are confused.

"It's simple math," says the Professor. "This process always begins with 5-carbon groups. The lowest number of 3-carbon groups that can be turned into 5-carbon groups without any left over is five groups. 5 x 3 = 3 x 5. Five of these PGALs must be recycled around again, to form three more 5-carbon units. One out of every six PGALs is taken off the conveyor belt. Seems very inefficient to me, but I've decided not to tamper with the system."

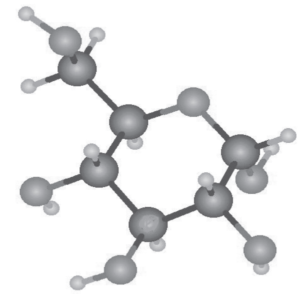


We ask if the factory runs 24 hours a day or whether it shuts down at night.

"We can only operate if we have an adequate supply of ATPs and NADPH electrons. They come from the solar farm down the street. On sunny days there's plenty of energy. At night the solar farm can't operate. After the sun goes down, we eventually run out of ATPs and NADPH electrons and have to shut down. We do have some emergency back-up systems, though. If it gets really hot and dry and our plant has to close its air vents (to prevent water loss) we can store some of the incoming carbon dioxide by mixing it with chemical preservatives. But we'd much rather have a steady supply of carbon dioxide coming in through our air hose."

We have one last question for the Professor. We wonder what happens to those PGALs that leave the conveyor belt.

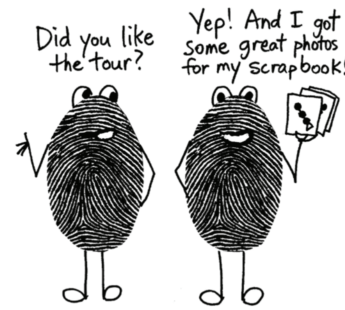
"Those are like half-sugars. This factory doesn't have to worry about final assembly. The PGALs get dumped out into the stroma where floating robots pick them up. The robots are programmed to take two PGALs and put them together to form a 6-carbon molecule called ***glucose***. Glucose is a type of sugar. I guess calling this a sugar factory is a tiny bit inaccurate, since we don't do the final assembly. But all the hard work gets done here. The final assembly is such a 'snap' that this hard-working factory gets credit for the sugar-building process."



GLUCCOSE: $C_6H_{12}O_6$

We thank the professor for the tour. What a strange but fascinating place! As we are leaving, he adds one last comment.

"I forgot to warn you — not everyone calls our products PGALs. If you hear someone talking about G3Ps, don't get confused. They're talking about PGALs."



We promise to remember his warning and not get upset about molecules having more than one name. We know someone who gets called "Robert" by his parents, "Bob" by his classmates, and "Blinky" by his best friend. (We're too polite to ask the best friend where the nickname "Blinky" came from.)

ONE FINAL NOTE: We have greatly simplified the Calvin Cycle. We've focused on just the carbon atoms, since they form the "backbone" of the glucose molecule. Glucose also has oxygen and hydrogen atoms attached to it. In the picture above, the darkest atoms are the carbons, the tiny ones are the hydrogens and the medium gray ones are the oxygens. The carbons almost form a ring, but not quite. One oxygen completes the ring, with one carbon stuck off to the side.

<u>ACTIVITY 1</u>: WATCH ANIMATIONS OF ATP SYNTHASE

Go to YouTube.com/TheBasementWorkshop and click on the Botany playlist. You will find some awesome computer animations showing the ATP synthase machine in action. There are also a few other photosynthesis-related videos. (Watch any other videos listed for this chapter that you have not already watched.)

<u>ACTIVITY 2</u>: MATCHING

Match the cell part on the left with its function on the right.

1) nucleus __	A) makes energy
2) endoplasmic reticulum ___	B) does packaging and shipping
3) Golgi bodies ___	C) jelly-like fluid
4) leucoplasts ___	D) an empty area
5) chloroplasts ___	E) network of fibers
6) vacuole ___	F) stores starches and fats
7) mitochondria ___	G) uses light, water and CO_2 to make sugar
8) ribosomes ___	H) assembles proteins
9) cytoplasm ___	I) assembles, transports, gives shape
10) cytoskeleton ___	J) contains DNA instructions

ACTIVITY 3: MORE MATCHING

Can you match the cell part with the factory part or factory worker that it is most similar to?

1) nucleus ___
2) Golgi bodies ___
3) vacuole ___
4) mitochondria ___
5) ribosomes ___
6) leucoplasts ___
7) endoplasmic reticulum ___
8) cytoskeleton ___

A) workers on the assembly line
B) foreman (boss)
C) empty courtyard in middle of factory
D) storage tanks
E) sidewalks, roads
F) shipping department
G) generator supplying electricity
H) assembly line

ACTIVITY 4: ANSWER THESE QUESTIONS

1) In your own words, what does the chlorophyll molecule do? ______________________________
____

2) What two molecules provide energy for the Calvin Cycle? _________________________

3) What biological "machine" puts the third phosphate back onto ADP? _______________

4) What cellular process is the "opposite" of photosynthesis? _________________

5) What type of energy is used to excite the electron in the center of the chlorophyll? __________

6) We know that plants need CO_2. In what phase of photosynthesis is it used? _________________

7) Carbon fixation is when a plant takes _________________ molecules from the air and uses the ____________ atoms to make sugar molecules.

8) After ATP has its third phosphate popped off, it is no longer called ATP. It is now called ______.

9) Where does final assembly of glucose occur? (the formation of a 6-carbon sugar from two 3-carbon PGALs) __________________

10) Out of every 6 PGALs made, how many have to ride around again? ____

11) What scientist received a Nobel Prize for his research on photosynthesis? __________________

12) How many carbons are in a glucose molecule? ______

13) Where is the Light Dependent Phase assembly line located?
a) stroma of chloroplasts b) thylakoid lumen c) thylakoid membrane d) cytoplasm of cell

14) Where does the Calvin Cycle occur?
a) the stroma of the chloroplasts b) the lumen of the thylakoids c) the thylakoid membrane

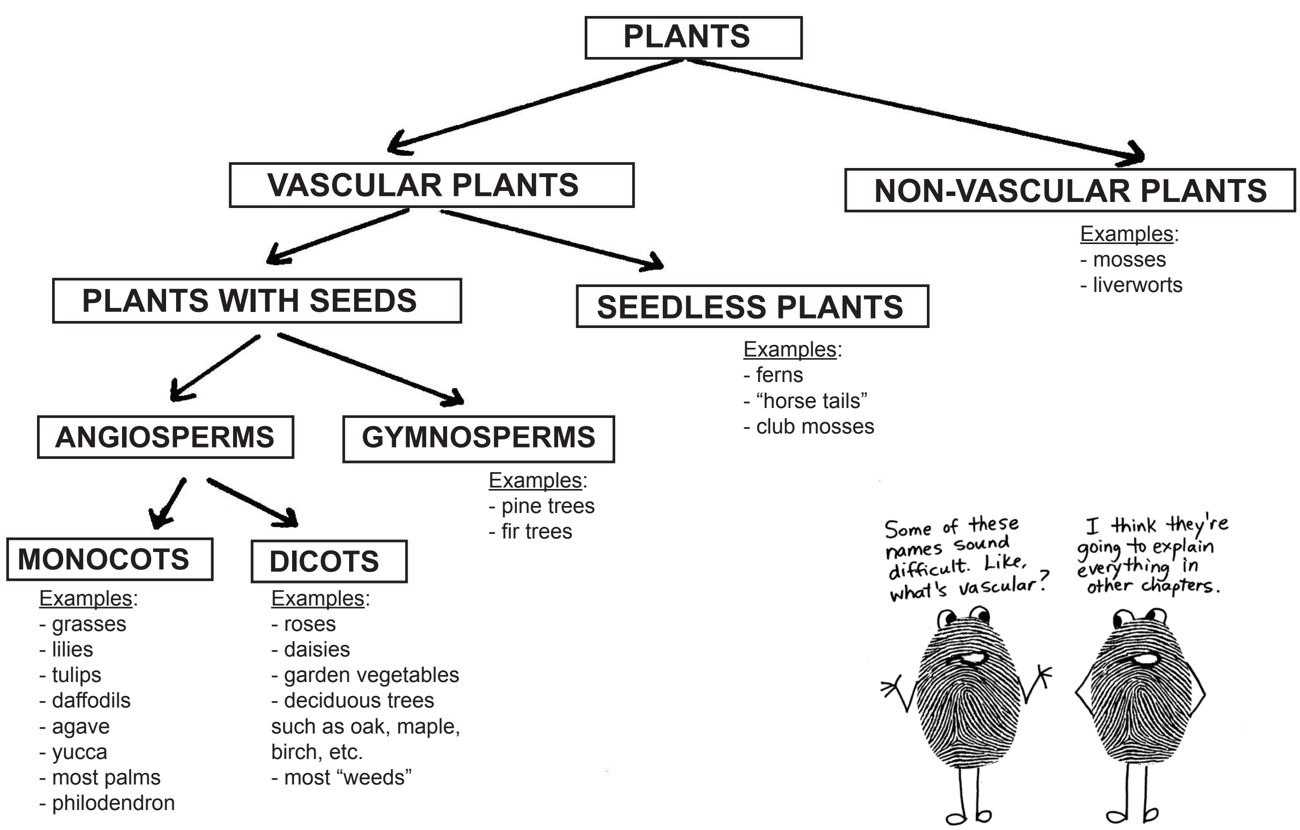
15) What type of particle goes down through the ATP synthase "generator" machine? ___________

LESSON 2: PLANT CLASSIFICATION

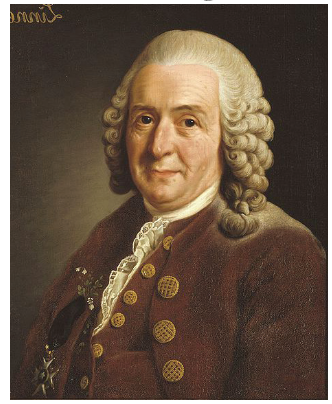
LEVEL ONE

Now you have it firmly in your mind that a plant is an organism that uses the process of photosynthesis. However, there's one more little technicality about qualifying as a plant. You have to have more than one cell. That may sound obvious, but did you know that there are lots of one-celled organisms that use photosynthesis? For example, some kinds of bacteria use photosynthesis. There are also some types of one-celled protozoa that use photosynthesis, such as the euglena and the volvox. So to be a plant, you can't be a bacteria or a protozoa. You must be made of many cells.

The plant "kingdom" is huge. There are millions of different types of plants. Scientists who study plants (***botanists***) like to sort them into categories (classify them). Without a way to put plants into categories, botanists would feel like their field of science was incredibly disorganized. They'd feel the way you'd feel if you woke up one morning to discover that someone had gathered up all the items in your house, then randomly distributed them into storage areas. If you opened a dresser drawer you'd find a random assortment of objects—a flashlight, a spoon, a marble, a couple of toys, a pencil, a book, a battery, a plate, a toothbrush and maybe a sock. Open a closet and you'd find a tennis racket, a stack of books, a pair of jeans, a radio, a flower pot, a guitar, a toy car, a stuffed animal... you get the idea. Now if you wanted to get dressed and needed a shirt and a pair of pants, where would you look for them? How long would it take to find a particular toy or book? Way too long! That's why we organize our houses, putting all the similar objects together. If you want a frying pan, you know to go to the kitchen. If you want to play tennis, you know your racket will be in the garage with the sports gear. Botanists feel the same way about organizing plants into categories. (Okay, so they're science geeks.) Here is the way botanists organize the plant kingdom.

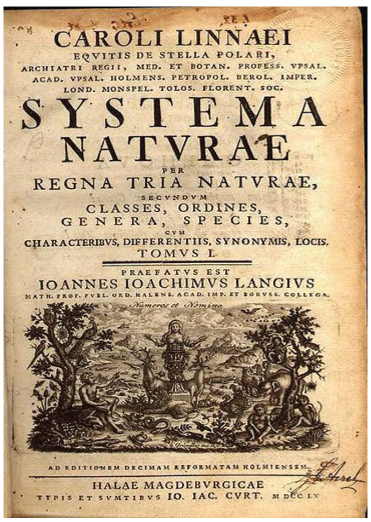


You can look back at this chart whenever you get confused by terms like "vascular" or "gymnosperm."

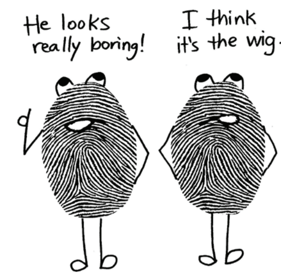


One of the first scientists to tackle the problem of classification was a man named Carl Linnaeus. Carl grew up in Sweden in the early 1700s and had loved plants since he was a small child. When he was learning to talk he wanted to know all the names of the plants in his father's garden. Carl's father loved plants, too. In fact, he changed the family's last name from Ingermarrson, which means "farmer's son," to Linnaeus, in honor of a large linden tree which grew near their house. When Carl was seventeen, he left home to begin his university studies. Back in those days, university students often had people called "patrons" who gave them money while they were in school. Carl was very good at getting patrons who were interested in supporting his studies. Unfortunately, however, as soon as he found a better patron he dropped the previous one. He made many friends and many enemies this way. Both the friends and the enemies will come back into the story later on.

Even with patrons, Carl never had a lot of money and was always worrying about how to make ends meet. His fretting about money came out in a humorous way one day when he said this: "My hair stands on end and lice bite at its roots when I look at the prices in this catalog!"


CAROLI LINNAEI
EQVITIS DE STELLA POLARI,
ARCHIATRI REGII, MED. ET BOTAN. PROFESS. VPSAL. ACAD. VPSAL. HOLMENS. PETROPOL. BEROL. IMPER. LOND. MONSPEL. TOLOS. FLORENT. SOC.
SYSTEMA NATVRAE
PER
REGNA TRIA NATVRAE,
SECVNDVM
CLASSES, ORDINES, GENERA, SPECIES,
CVM
CHARACTERIBVS, DIFFERENTIIS, SYNONYMIS, LOCIS.
TOMVS I.
PRAEFATVS EST
IOANNES IOACHIMVS LANGIVS
AD EDITIONEM DECIMAM REFORMATAM HOLMIENSEM.
HALAE MAGDEBVRGICAE
TYPIS ET SVMTIBVS IO. IAC. CVRT. MDCCLX

The title page from a 1760 edition of Carl's book *Systema Naturae*.



Carl was a very good scientist, though. He made many discoveries about the life cycles of plants, especially the importance of flowers. Until then, no one knew that flowers have male and female parts. Even before he had graduated from the university, Carl was being asked to give lectures on plants. Before he was 30 years old, he had published several books on plants.

Back in Carl's time, botanists and naturalists were expected to go on long journeys to collect specimens for their studies. Carl went to Lapland (Finland) and hated every bit of the trip. He complained about bad weather, bad food, bad travel conditions and (worst of all)... bugs! He hated bugs. During this trip someone told Carl about a very interesting place in Lapland that he really should see. Carl agreed it would be a fantastic addition to his itinerary (list of places he went). The only problem was that this area was 300 miles inland, which meant several more weeks of bad weather, bad food, bad travel conditions, and bugs. So Carl just imagined what it would have been like to go there and wrote about it in his journal, faking the details!

At some point in his studies, Carl realized that botanists needed a system of naming plants, a system that would be recognized all over the world. Carl noticed that some plants had very simple, common names like "white oak," and other plants were known by complicated Latin names such as (just try to say this in one breath) *physakis amno ramosissime ramis angulosis glabris foliss dentoserratis*. Carl suggested that each plant should have a two-word Latin name, just like people have first and last names. Latin was best for this because it was already used by scientists all over the world, and because it was a "dead" language (no one actually spoke it as their real language) so it wouldn't change over time. This method of naming plants (and animals) would be called ***binomial nomenclature***, which is a fancy way of saying "the two-name naming system" (bi=two, nom=name, nomen=name, clature=call).

Carl would think up a name for a group of plants (what we now call the ***genus***), then make up a name for each specific member of that group (what we now call ***species***). For example, the group of trees we know as oaks have the genus name *Quercus (kwer-kus)*. The white oak is *Quercus alba*, the gray oak is *Quercus grisea,* and the leather oak is *Quercus durata*. The group of plants we call the honeysuckles are the *Lonicera (lon-i-sare-uh)*. The yellow honeysuckle is the *Lonicera implexa* and the sweet honeysuckle is the *Lonicera japonica*. (Notice that the names are written in italics and only the genus is capitalized.)

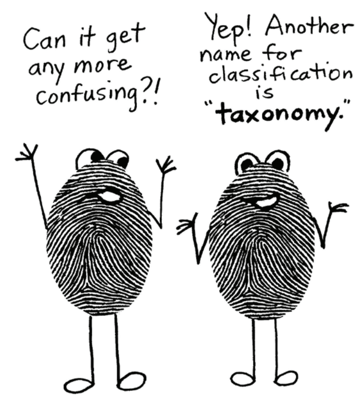
Now those friends and enemies come back into the story. Carl had to come up with a lot of new plant names, and often he would use the names of people he knew. Someone once said that you could make a list of Carl's friends and enemies by looking at a list of plants he had named. Plants that were attractive or useful bore the names of people Carl admired. Plants that were prickly or ugly were used as a way to get just a tiny bit of revenge on folks he hadn't gotten along with. For instance, Carl named a species of unpleasant weeds *Siegesbeckia,* after Johann Siegesbeck, the director of a Russian botanical garden who had given Carl a hard time about his books—he thought Carl had talked too much about the "love life" of flowers. The "black-eyed Susan" (a flower with a dark center and yellow petals) was named after a real person named Susan, a woman Carl admired. The sheep laurel, with its beautiful bunches of red or purple flowers, was named *Kalmia augustifolia*, after Peter Kalm, one of Carl's botanical students. The *Lonicera* (honeysuckle) was named after Adam Lonicer, a German doctor of the 1500s who studied plants and used herbal medicines.

Eventually, Carl's naming system was adopted by all scientists everywhere in the world. It became more and more complex as more people started adding their ideas to it. Today, there are seven basic levels in the naming system: ***kingdom, phylum, class, order, family, genus, species***. However, often extra subdivisions and sub-categories are added. And, as we warned you, not all scientists use the same divisions. For example, here are two ways to list the full classification of the white oak. You could use either one and be correct:

Kingdom: Plants (or "Plantae")
Division: Angiosperms
Sub-division: Dicots
Sub-division: Rosids
Order: Fagales
Family: Fagaceae
Genus: *Quercus*
Species: *alba*

Kingdom: Plants
Subkingdom: Tracheobionta (vascular plants)
Superdivision: Spermatophyta (seed plants)
Division: Magnoliophyta (flowering plants)
Class: Magnoliopsida (dicots)
Order: Fagales
Family: Fagaceae
Genus: *Quercus*
Species: *alba*

As if these difficult words weren't enough, other reference sites add the categories "Euphyllophyta" and "Fabids" to these lists! As we said, there isn't a single "correct" way to classify plants. You'll get a slightly different list from each book or website you consult. However, it is still a good idea to know the basic seven categories: kingdom, phylum, class, order, family, genus, species. These words come up often in many branches of science and it's good to be familiar with them.



<u>ACTIVITY 1</u>: LEARN THE CLASSIFICATION SONG

The sound track for this song can be accessed by going to **www.ellenjmchenry.com** and then clicking on the MUSIC tab.

Kingdom, phylum, *(clap, clap)*, **class, order,** *(clap, clap),* **family,** *(clap, clap)*, **genus, species,** *(clap, clap).*
Kingdom, phylum, *(clap, clap)*, **class, order,** *(clap, clap),* **family,** *(clap, clap)*, **genus, species,** *(clap, clap).*
Kingdom, phylum, class, order, family, genus, species!
Kingdom, phylum, class, order, family, genus, species!
REPEAT

ACTIVITY 2: PLANTS NAMED AFTER PEOPLE

Some plants were named after people — either the scientist who discovered the plant, or a friend or family member of the scientist. See if you can guess the last name of the person for whom these oak were named. (We'll only do a few of these because they're pretty much no-brainers!)

1) *Quercus muehlenbergii* ____________________
2) *Quercus engelmannii* ____________________
3) *Quercus michauxii* ______________________
4) *Quercus kelloggii* ___________________

ACTIVITY 3: USE YOUR "WORD DETECTIVE" SKILLS

See if you can match the scientific names with the common names. All you need to do is use "word detective" skills. Think of words you know that look or sound like the scientific names. Start with the matches that are easiest.

1) *Daucus carota* _____
2) *Solanum tuberosum* _____
3) *Pinus cembra* _____
4) *Acer saccharum* _____
5) *Juglans nigra* _____
6) *Citrus sinensis* _____
7) *Sophara japonica* _____
8) *Primula vulgaris* _____
9) *Papaver orientale* _____
10) *Paulownia imperialis* _____

A) Oriental poppy
B) Cembrian pine
C) Carrot
D) Empress tree
E) Primrose
F) Orange
G) Potato
H) Sugar maple
I) Black walnut
J) Pagoda tree

ACTIVITY 4: HAVE SOME FUN WITH SCIENTIFIC LATIN

What? Fun with Latin?! Sure, why not?
Use some made-up Latin words to classify yourself. Use this guide:

Kingdom: country
Phylum: state
Class: county
Order: city/town

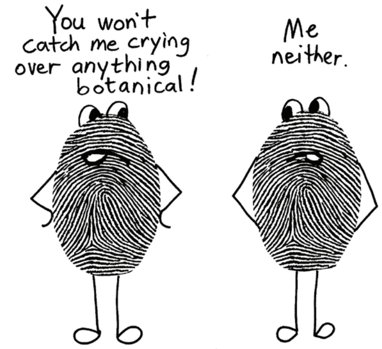
Family: neighborhood or street
Genus: last name
Species: first name

Use some classic Latin endings such as *-us -um -ae -ica -ii -ius*
Example: *Americanus Pennsylvanicus Alleghenus Pittsburghae Avalonica Smithus Jamesii*
(We know him as Jim Smith from Pittsburgh, PA.)

Your (silly) Latin scientific name: ____
____

Now make up one for someone else: ____
____

LEVEL TWO



Not everyone immediately adopted Linnaeus' new naming system. Some botanists resisted change, even if it was for the better. That's just how some people are. A botanist named Johann Dillenius accused Linnaeus of "throwing all botany into confusion." However, when Dillenius went to see Linnaeus and let Linnaeus explain the advantages of this new system, Dillenius realized how ingenious this system was. In fact, he got so emotional over it that he almost cried (or so the story goes). One by one, botanists came to see how superior this new system was and eventually they all began using it.

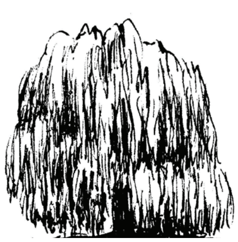
The work of Carl Linnaeus was only the beginning. Since Carl's time, many organized minds have added to the classification system. As far as we know, all *known* plants and animals on Earth have been named and classified. (However, there are some disagreements among scientists about certain species or sub-species because they don't fit perfectly into this system.) As soon as any new plant or animal is discovered, it is compared to all similar organisms so it can be put into a kingdom, phylum, class, order, family and genus. Then the discoverer gets to choose a species name for it. All these words must be in Latin and must have correct endings, such as "ius," "ium," "ae," or "ii." (The ending "ii" means "of." So *jamesii* would mean "of James.")

Kingdom is the most general category. There are basically five kingdoms: plants, animals, fungi, monerans (bacteria), and protists (single-celled protozoa). Sometimes scientists like to get all fancy with the names of the kingdoms and use Latin endings, making the animal kingdom *Animalia* and the plant kingdom *Plantae*. Within each kingdom are large groups called ***phyla*** (one phylum, two phyla). Now just to make everyone's life difficult, botanists decided that they'd rather called the phyla ***divisions***. So don't be confused when you see the word "division." Just think "phyla." (That way the classification song will still make sense for the plant kingdom.)

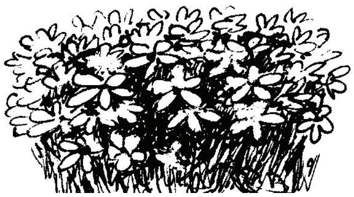
The major plant divisions include ***bryophytes*** (mosses and some algae), ***pteridophytes*** (ferns) (and that initial "p" is silent), ***coniferophytes*** (conifers), and ***anthophytes*** (flowering plants). Now, you may want to know why we showed you that chart on page 17 if it doesn't match up with these divisions. Well... that chart is still valid because science books still use those categories when talking about the plant kingdom. The world of science terminology is sometimes confusing because it has evolved over hundreds of years. And to make things worse, scientists sometimes disagree about terminology or categories. The chart on page 17 is still very helpful, even though it doesn't give Latin names of divisions. It gives you a good overall sense of how botanists think about the plant kingdom.

The classes, orders, and families of plants are the least well-known terms among non-botanists. (You can always look them up on the Internet.) You can probably guess that certain types of plants are grouped together, such as grasses, cacti, squashes, or garden flowers. Hobby gardeners probably know more genus and species names (such as *Quercus alba* for the white oak) than they do classes, orders or families.

Every scientific name, no matter how boring it sounds, has a story behind how it got its name. Some of these stories are short and not too interesting. Others have quite a bit of history behind them. Here are some of the more interesting stories:

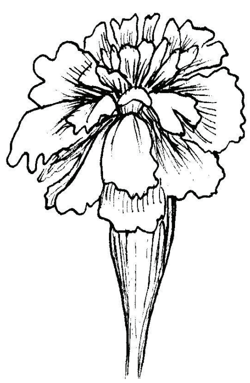


The weeping willow is *Salix babylonica*. All willows are *Salix*, but the weeping willow is *babylonica* as a reference to Psalm 137 in the Bible, where it says, "By the waters of Babylon we sat down and wept. We hung our harps on the willow trees there." The Israelites were taken captive by the Babylonians in 582 B.C. and forced to live out the rest of their lives in Babylon, far from their homeland.

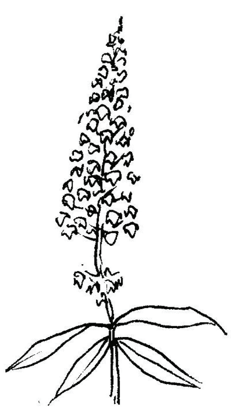


The *Phlox drummondii* was named after Thomas Drummond, a Scottish botanist who came to America in 1831 to study and collect plants. Poor Thomas had a really bad time in America. He tried to survive a northwest winter alone in the wilderness and almost didn't make it. He was attacked by grizzly bears and then almost starved to death, spending weeks chewing on nothing but an old deerskin. Later, he survived a cholera epidemic, lost the use of his arms for two months, and had boils (sores) all over his body that were so severe he couldn't lie down. He went south to Texas and almost starved to death again while stranded on Galveston Island. He finally died during a voyage to Cuba. Whenever he found a new plant, he would send specimens back home to botanists he knew in Britain. The last plant Thomas sent over before he died was a species of white phlox, and his friends decided it should be named in his honor. (The world "phlox" is Greek for "flame," named for its fiery red color.)

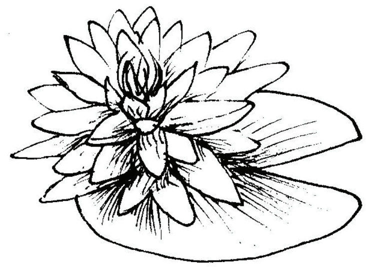
The nasturtium (*na-stur-shum*) comes from the Latin word "nasus" meaning "nose," and "tortus" meaning "twisted." When you smell a nasturtium you wrinkle (twist) your nose because of the strong smell. The scientific name for nasturtium is *Tropaeolum*, from the Greek word "tropaion" meaning "trophy." The leaves of the nasturtium reminded Linnaeus of Greek shields. In ancient Greece, the soldiers would hang the shields and helmets of the defeated enemies on tree trunks. When Linnaeus saw a nasturtium vine growing up the side of a tree, the leaves and flowers reminded him of ancient Greek shields and helmets hung on trees.



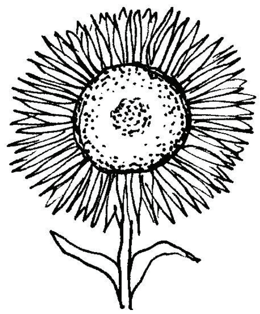
The marigold comes from the phrase "Mary's gold" and was the official flower of the Virgin Mary in medieval times. Church altars were decorated with marigolds almost year-round. Now for the ironic twist--we go from the heavenly to the earthly. The scientific name for the marigold is *Tagetes patula*, and Linnaeus is to blame for this one. Tages was the grandson of the Roman god, Jupiter. Tages was a god of the underworld who came up out of the dirt in a field one day and taught humans the fine art of fortune-telling by examining the intestines of animals. No kidding. The Romans and Greeks would kill an animal and look at its guts before making major decisions. Was this Linneaus' idea of a joke? Or maybe he thought marigolds smelled as bad as animal intestines? No one knows. (*Patula* just means "spreading." Marigolds do spread out quickly and grow to be quite large.)



The scientific name for the butterfly bush is *Buddleia davidii*, named after Rev. Adam Buddle of Essex, England, and Père (Father) Armand David, a French Jesuit missionary to China. Rev. Buddle was just a nice amateur botanist whom Linneaus apparently liked (and who was an expert on mosses, not bushes), but Père David was another one of those crazy, adventuresome botanists who braved countless hardships in order to collect plants. David recorded in his diary that "although it was inconvenient," he was so afraid of the local wolves that he kept his donkey with him in his tent at night. He also said it took great courage to eat the local food. David was lucky, however, and lived long enough to return to France. Some of his Jesuit friends were not so lucky—they were tortured and killed by the natives. Père David managed to send thousands of Chinese plants back to Europe, many of which are common sights now in both Europe and North America.



This spectacular water lily is *Victoria amazonica*, although the name has been changed several times. When it was first brought to England from the Amazon, a flower was presented to Queen Victoria and she was told the flower would be named *Victoria regina* ("Victoria the queen") in her honor. But, oops — a bit later they found out that someone had already discovered it and named it ten years earlier. Now what do you tell the queen? Then they did even more research and discovered that the two plants were not identical, so they could still keep the name of the queen, but by then they thought they really should make some reference to the place the flower came from — the Amazon. However, at that time anything associated with the Amazon was considered to be uncivilized, so putting the queen's name next to the word "amazon" would have been unseemly. So the solution they came up with was to go ahead and change the name of the plant to *Victoria amazonica* but just keep the true name a secret until after the queen died.



The sunflower's botanical name is *Helianthus*, from the Greek words "helios," meaning "sun," and "anthos" meaning "flower." There's a reason for this name: these flowers turn so that they are always facing the sun! The Greek myth associated with this plant is that of Clytie, the mortal who was in love with the Titan god Helios, who had been raised to the sky and turned into the sun. Helios never even noticed poor Clytie. (But don't feel too bad for her; when she found out that Helios loved her sister, she buried her sister alive!) The sunflower is native to America, not Europe, so the ancient Greeks never saw this plant. How this myth became attached to this flower is a mystery.

<u>ACTIVITY 1</u>: MATCH THE PLANT NAME WITH ITS ORIGIN

1) Clematis ____

2) Impatiens ____

3) Chrysanthemum ____

4) Foxglove ____

5) Geranium ____

6) Daisy ____

7) Candytuft ____

8) Gladiolus ____

9) Columbine ___

10) Forsythia ____

A) The seeds of this plant pop out as if they are in a hurry.

B) The leaves of this plant look like a Roman gladiator's sword.

C) The name of this flower comes from the Greek word "geranos," meaning "crane" (the bird) because its seed pod looks like the beak of a crane.

D) This plant produces long, thin flowers that resemble fingers.

E) Named after William Forsyth, a rascal of a botanist who sold the British government a secret plant medicine which turned out to be nothing but cow dung, lime, sand, soapsuds and urine.

F) Centuries ago, this plant was said to be the "day's eye" because its flowers opened in the morning and closed at night.

G) If held upside down, this flower looks a bit like a ring of doves. The Latin word for dove is "columba."

H) This name is from the Greek word "klema" meaning "twig."

I) This name comes from two Greek words: "chrysos" meaning "gold," and "anthos" meaning "flower."

J) This name comes from the place of the plant's origin: Candia (the island of Crete)

<u>ACTIVITY 2</u>: WATCH A VERY NICE BUT VERY SHORT BIOGRAPHY OF LINNAEUS

There's a very nice 4-minute summary of the life and work of Linnaeus posted on the Botany playlist at www.YouTube.com/TheBasementWorkshop.

<u>ACTIVITY 3</u>: PLANTS WITH PLACE NAMES

Some plants are named after places where they grow, or the place where they were first discovered. See if you can identify the place name in each of these plant names.

1) A flower named *Callistephus chinensis:* __________________
2) A flower named *Arum italicum:* ________________
3) A wildflower named *Tradescantia virginiana:* _____________________
4) A tree named *Azadirachta indica*: __________________
5) A decorative flowering plant named *Dianella tasmanica*: __________________
6) A grass named *Raddia brasiliensis*: ________________

<u>ACTIVITY 4</u>: "ALL IN THE FAMILY"

Have you ever heard someone talk about plants or animals being "related" to each other? You might have heard something like, "Spiders are related to crabs." What does this mean?

The more classification categories two organisms share, the more they are considered to be "related." For example, look at the classification (taxonomy) of these three plants. Their taxonomy is listed starting with the kingdom and going all the way down to genus and species.

POTATO: Plants, Angiosperms, Dicots, Asterids, Solanes, Solanaceae, *Solanum, tuberosum*
TOMATO: Plants, Angiosperms, Dicots, Asterids, Solanes, Solanaceae, *Solanum, lycopersicum*
SWEET POTATO: Plants, Angiosperms, Dicots, Asterids, Solanes, Convolvulaceae, *Ipomoea, batatas*

Which is more related to a potato — a tomato or a sweet potato? If you look at a potato and a sweet potato they seem very related. But if you look at their classification (taxonomy) you will see that the lists for the potato and the tomato are almost identical except for the species. The sweet potato list is different right after "Solanes." The sweet potato isn't even in the same family with the potato, but the tomato is!

Here are some members of the (very large) Prunus family:

CHERRY: Plants, Angiosperms, Dicots, Rosids, Rosales, Rosaceae, *Prunus, serotina*
PLUM: Plants, Angiosperms, Dicots, Rosids, Rosales, Rosaceae, *Prunus, domestica*
PEACH: Plants, Angiosperms, Dicots, Rosids, Rosales, Rosaceae, *Prunus, persica*
APRICOT: Plants, Angiosperms, Dicots, Rosids, Rosales, Rosaceae, *Prunus, armeniaca*

The members of this family all share a common trait when it comes to forming seeds. Can you think of what it might be? (Hint: Compare their seeds with those of apples, pears or bananas.)

If you have Internet access, try to find the answers to these questions. (Wikipedia is very helpful.)

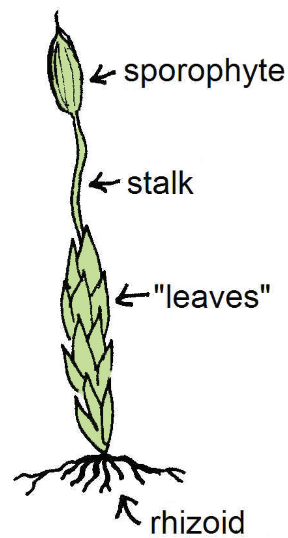
1) Which is more "related" to a zucchini--an acorn squash or a cucumber? _________________
2) Which is more "related" to a carrot--a tomato or a yam? ________________
3) Which is more "related" to an oak tree--a maple tree or a chestnut tree? _________________

LESSON 3: NON-VASCULAR PLANTS

LEVEL ONE

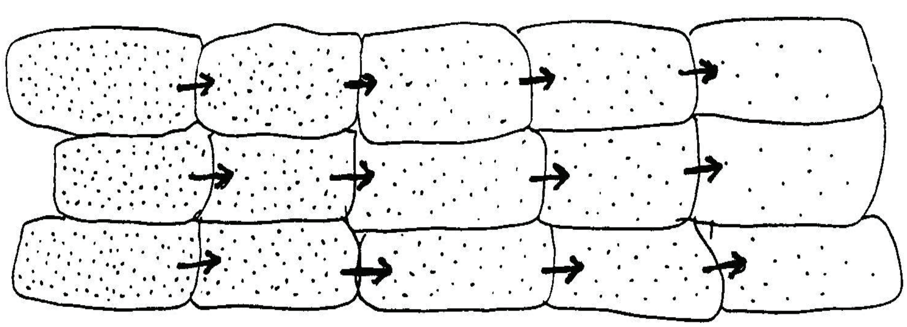
Now let's tackle one of those categories on page 17: the ***non-vascular*** plants. These plants *don't* have whatever "vascular" is. The word vascular comes from the Latin word "vascularis," meaning a vessel or duct that has some kind of fluid flowing through it. So vascular plants have vessels running through them and non-vascular plants don't.

Non-vascular plants are basically ***mosses*** and make up the division called ***bryophytes*** *(bry-o-fites)*. The word bryophyte comes from two Greek words: "bryon," meaning "moss," and "phyton" meaning "plant." (A related type of plant, the **liverwort**, is usually put into this category also. If you want to know more about liverworts, read level 2.) This lesson is on moss, that soft green stuff you find growing around the roots of trees or between bricks on your shady patio. Mosses are a bit strange and deserve their own category because they don't have seeds and they don't have proper roots or stems or leaves. (But they are still plants because they use photosynthesis.) If we want to talk about the parts of a moss plant, we can't really talk about their leaves because technically they don't have leaves. But they do have green things that look like leaves and these green things do carry on photosynthesis, so we'll just use the word "leaves" but with quote marks around it, indicating that we all know that mosses don't *really* have leaves. For roots, we'll say "rhizoids." The rhizoids' job is to anchor the moss to the ground. They don't take up water like the roots of vascular plants do. (We'll talk about that sporophyte on the next page. Sorry to leave you in suspense for a few minutes...)

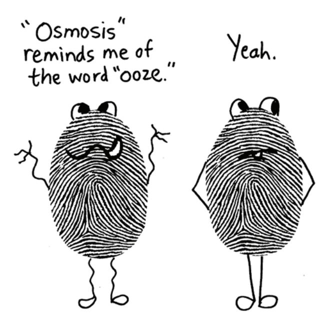


A vascular system is a system of "pipes" that allows plants to pump water to all parts of the plant, no matter how tall or wide the plant grows. Non-vascular plants don't have this system. The only way the parts of a non-vascular plant can get water is to absorb it right into their cells when it rains or when dew falls. For this reason, non-vascular plants must stay very small and must be in places where it stays damp. Where have you seen mosses growing? If they are in your lawn, they certainly aren't out where the sun shines a lot. They'll be in shady spots such as around the bases of large trees Some mosses can tolerate a bit of sun, but very few can survive all-day sun.

Cells that are not on the outside surface get their water by a process called ***osmosis***. This is a strange-sounding name for a simple idea. Osmosis is when a lot of something moves to a place where there is less of it. In a crowded building this might mean people moving from crowded rooms to empty rooms. Once all the rooms are equally filled, people will stop moving. In plants, osmosis means water molecules moving from cells that have lots of water to cells that have less water.



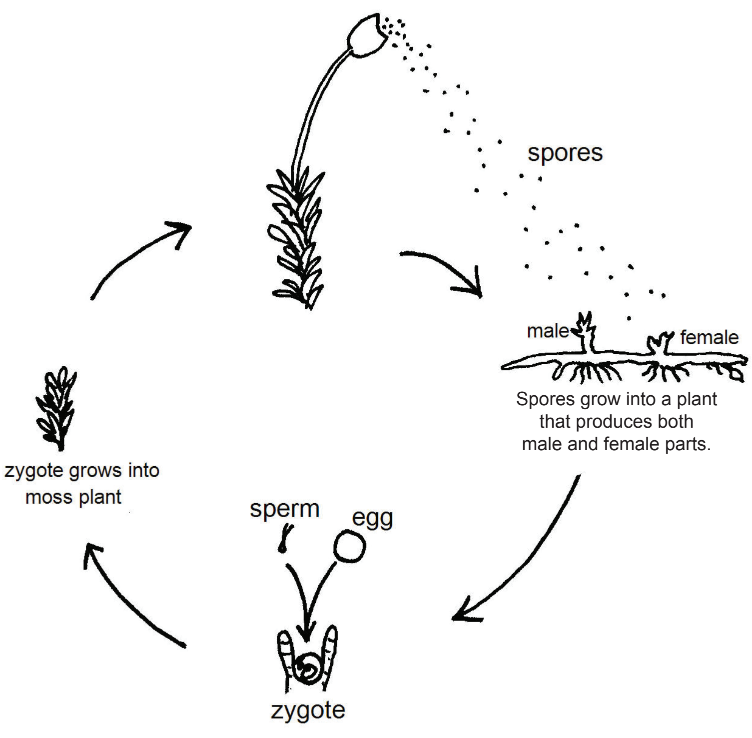
moist cells   less moist cell   dry cells



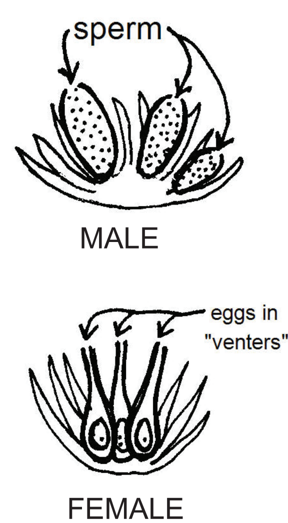
Mosses have a very strange life cycle. Like many forms of life, they produce male and female cells. However, they also produce spores like mushrooms do. They alternate back and forth between producing spores and producing male and female cells. This cycle is called ***alternation of generations***.

The moss plant (technically called the ***gametophyte*** *[gah-MEE-toe-fite]* stage) grows a stalk out the top, and at the top of that stalk a ***sporophyte*** appears. The sporophyte produces—spores, of course. The sporophyte bursts open and all the spores float down and land somewhere in the nearby vicinity. It's best for the moss if they land just a little bit away, but not too much. If they land too close, the bed of moss won't grow larger, but if they land too far away, it might be out in an area that isn't suitable for moss to grow (too sunny, for example). When the spores land, they grow into a green mat-like thing that then starts to produce little male and female parts. The male parts produce sperm and the female parts produce eggs, just like in animals. Then the egg and sperm must join together to form a ***zygote***. (The word "zygote" comes from the Greek word "zygotos," meaning "joined together.")

The egg can't move at all. It just sits there and waits for the sperm. The sperm can swim a very short distance, but they need water to swim in. When it rains, the sperm get picked up by the water droplets and splashed around, hopefully landing near enough to the eggs that they are only a short swim away. The sperm then swim down the venters and join with the eggs, creating a zygote that will be able to grow into a new moss plant. Then that new moss plant grows a sporophyte that produces spores. Then the spores grow into a plant that produces male and female cells, which form a zygote which grows into a moss plant, which produces a sporophyte...



Close-ups of male and female parts:



ACTIVITY: WATCH AN ANIMATION OF THE MOSS LIFE CYCLE

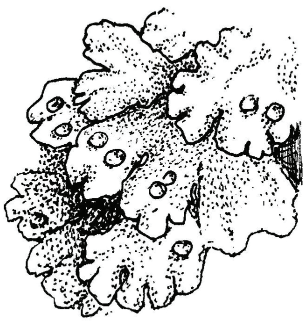
An animation of the information on this page is posted on the Botany playlist at www.YouTube.com/TheBasementWorkshop. There will be some new words we haven't learned here, but don't worry about it—just enjoy the show. The pictures are very helpful in understanding this cycle.

"Mosses" by Ernst Haeckel, 1904

"Liverworts" by Ernst Haeckel, 1904

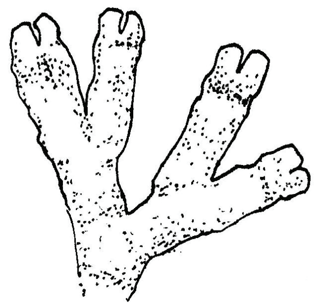
LEVEL TWO

Another main type of bryophyte is the ***liverwort***. The ending “-wort” comes from medieval times in Europe when it meant “healing herb.” (You’ll see the word “wort” in many plant names.) It was once thought that the liverwort was a healing herb that could help your liver. Perhaps medieval people saw some resemblance between the shape of the liverwort and the shape of a liver. Or maybe not. No one knows.

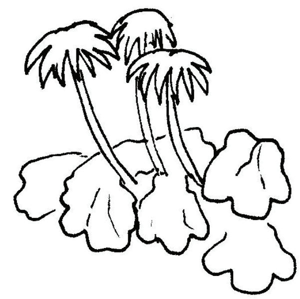


A “thallose” liverwort with gemma cups

A “leafy” liverwort



A weird-looking liverwort!



These umbrella things are male and female parts

Liverworts are found all over the world, even at the edges of deserts and arctic tundras, but they can’t survive in the heart of the deserts and tundras because there isn’t enough water. Like mosses, liverworts have non-vascular systems that depend on osmosis. They need to be close to the ground and be kept moist as much as possible. The liverworts that live in extreme climates must have special adaptations that allow them to be able to survive. (You’ll learn about adaptations in lesson 7.) These adaptations (perhaps extra-skinny “leaves” that keep moisture in, or sporophytes that can survive drought) are not present in most mosses.

Like the mosses, the liverworts have ***alternation of generations***. (It’s similar enough to mosses that it’s not worth drawing another diagram.) They produce sporophytes that then produce a ***protonema*** that looks like either a mass of stringy green fibers, or they make a tiny, flat green thing called a ***thallus***. (The word thallus comes from the Greek word “thallos” meaning “young shoot or twig.”) The thallus produces male and female parts that produce sperm and eggs that join together whenever there is enough rain to allow the sperm to swim. You can see in the drawing above (on the far right) that in some liverworts the male and female parts look like fancy umbrellas.

Liverworts also have a way of reproducing without the male and female cells. They can form a type of bud called a ***gemma*** (the “g” is soft, like in the word “gem”). A gemma can be a single cell or a group of cells that break off from the main plant and are then capable of growing into a whole new plant. These gemma are often found in gemma cups, little cup-like things on the tops of the liverwort “leaves.” You can see some gemma cups in the first drawing above (on the left). The little gemma cells sit in the cups and wait for it to rain. Then the raindrops splash the gemma out onto other surfaces, away from the “parent” plant, where the gemma can grow into an “adult” plant.

<u>ACTIVITY 1</u>: WATCH SOME SHORT VIDEOS OF LIVERWORTS (WOW—HOW EXCITING!)

There are some spectacular videos of liverworts and gemma cups on the Botany playlist at www.YouTube.com/TheBasementWorkshop.

ACTIVITY 2: REVIEW SOME OF THE WORDS WE JUST LEARNED

Answer these 10 questions. Then go down below to the STUPID PLANT JOKE and write the letters that correspond to each number. (Hey, it's better than having quiz or test, so don't complain!)

1) When a sperm fertilizes an egg, the result is a ___ ___ ___ ___ ___ ___
25 21 8

2) The process by which the cells in a moss plant receive water: ___ ___ ___ ___ ___ ___ ___
3 11

3) The part at the top of the stalk on a moss plant: ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
4 9 28 31

4) Mosses and liverworts are members of this group: ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
23 27 30

5) This flat, green thing produces male and female parts: ___ ___ ___ ___ ___ ___ ___
5 17

6) A regular moss plant, the type we are used to seeing, is technically called this stage:

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
18 29 19

7) This type of cell is NOT a reproductive cell, but nevertheless it can split off from a liverwort and

grow into a new liverwort: ___ ___ ___ ___ ___
16 1

8) The medieval word for "healing herb" is ___ ___ ___ ___
10 24

9) Mosses and liverworts do NOT have this system: ___ ___ ___ ___ ___ ___ ___ ___
7 22 15

10) The life cycle of mosses and liverworts is called ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
13 12 2

___ ___   ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___
26 14 6 20

A STUPID PLANT JOKE

What do you call it when a ___ ___ ___ ___ and a ___ ___ ___ ___ ___ ___ ___ ___ ___ have an
1 2 3 4   5 6 7 8 9 10 11 12 13

___ ___ ___ ___ ___ ___ ___ ___ ?   ___   ___ ___ ___ ___ - ___ ___ ___ ___ ___!
14 15 16 17 18 19 20 21   22   23 24 25 26   27 28 29 30 31

ACTIVITY 3: WATCH A 30-MINUTE DOCUMENTARY ON BRYOPHYTE SCIENTISTS

Some scientists spend their whole life studying mosses and liverworts. Meet some Belgian botanists who have cataloged hundreds of species of European bryophytes and listen to them explain why it is so important both to study them and to conserve (protect) them. The video is posted on the Botany playlist.

NOTE: Half of the film is in French, but there are subtitles written in English.