

LESSON 1: PLANT CELLS

LEVEL 1

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 Lego™ structure is made of individual bricks.

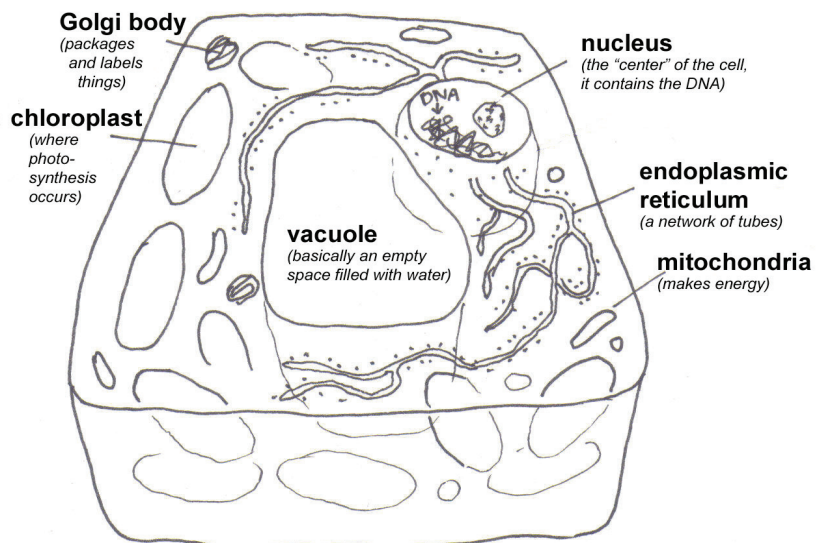
Here is a simplified drawing of a typical plant cell. (In reality they are much more complicated than this. But for now, this is enough.) Inside the cell are little parts called organelles.

Use a colored pencil to add a little color to this diagram. Color lightly!

Coloring suggestion:
green: chloroplasts
yellow: nucleus
red: endoplasmic reticulum
orange: mitochondria
purple: Golgi bodies

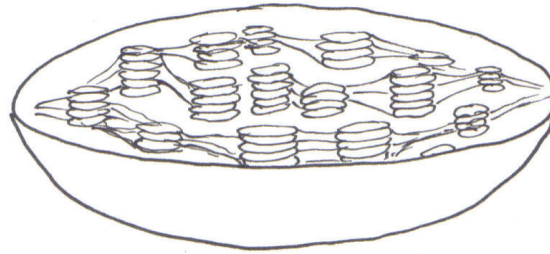


Organelles in real cells aren't colored (except for chloroplasts which are green). But colored diagrams look really nice - so go ahead and color away!



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 similar to the one shown here. Most importantly for our discussion of photosynthesis, all plant cells have organelles called **chloroplasts**.

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



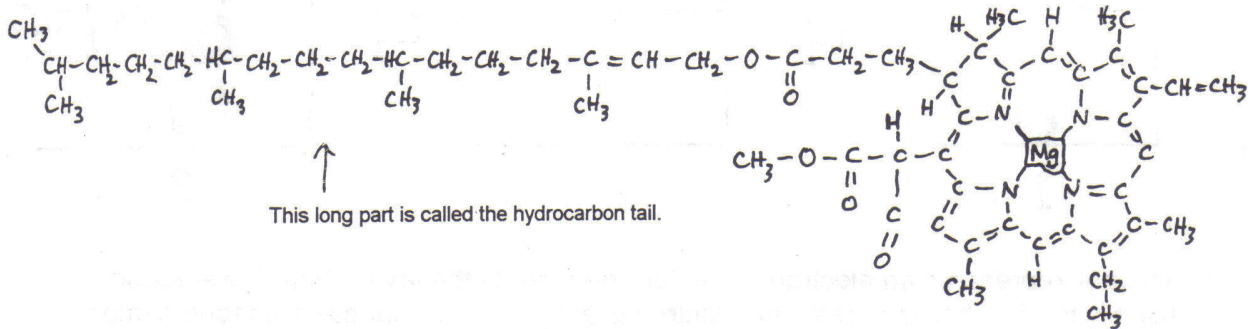
inside a chloroplast

Hmm... reminds me of a football filled with pennies.

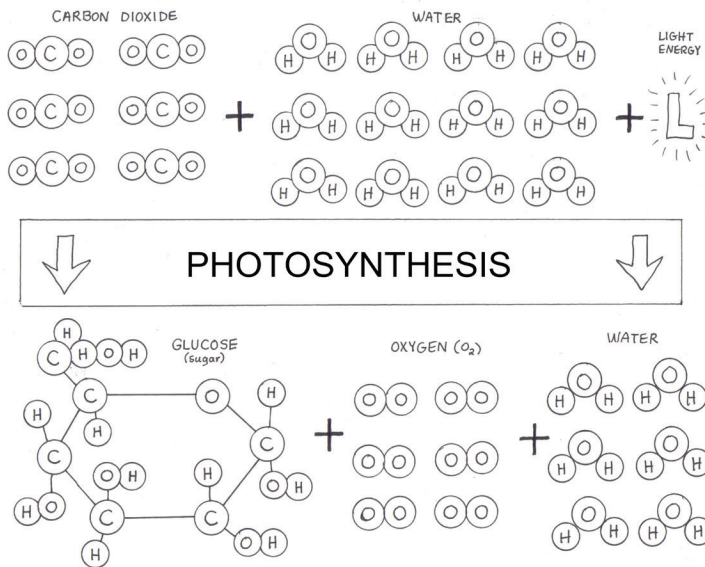


It is inside the chloroplast that photosynthesis takes place. The chloroplast's job is to use the energy in the sunlight to make sugar. The chloroplasts contain a special chemical called **chlorophyll**. This chemical happens to reflect green light, which is why most plants look green.

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.

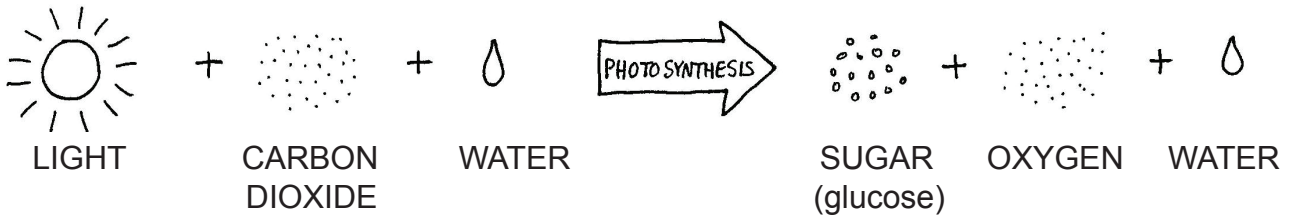


We've made this chart into a game! You'll love it!



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:



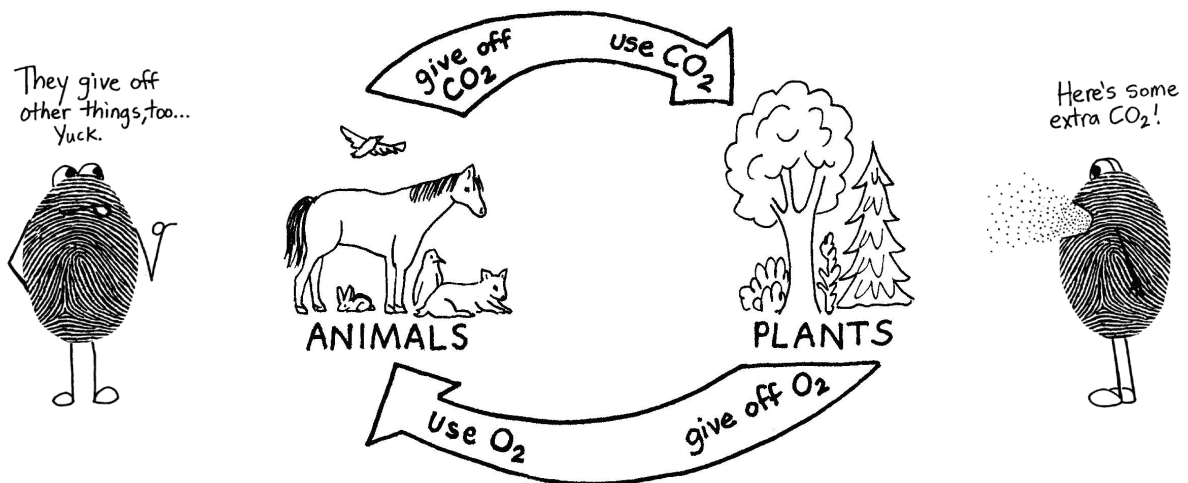
This says in pictures what we've already said in words: plants use sunlight, carbon dioxide and water to make sugar. In the process of making sugar, oxygen and water also are produced. Oxygen and water are called "by-products" of photosynthesis. (A by-product is something extra that is produced along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



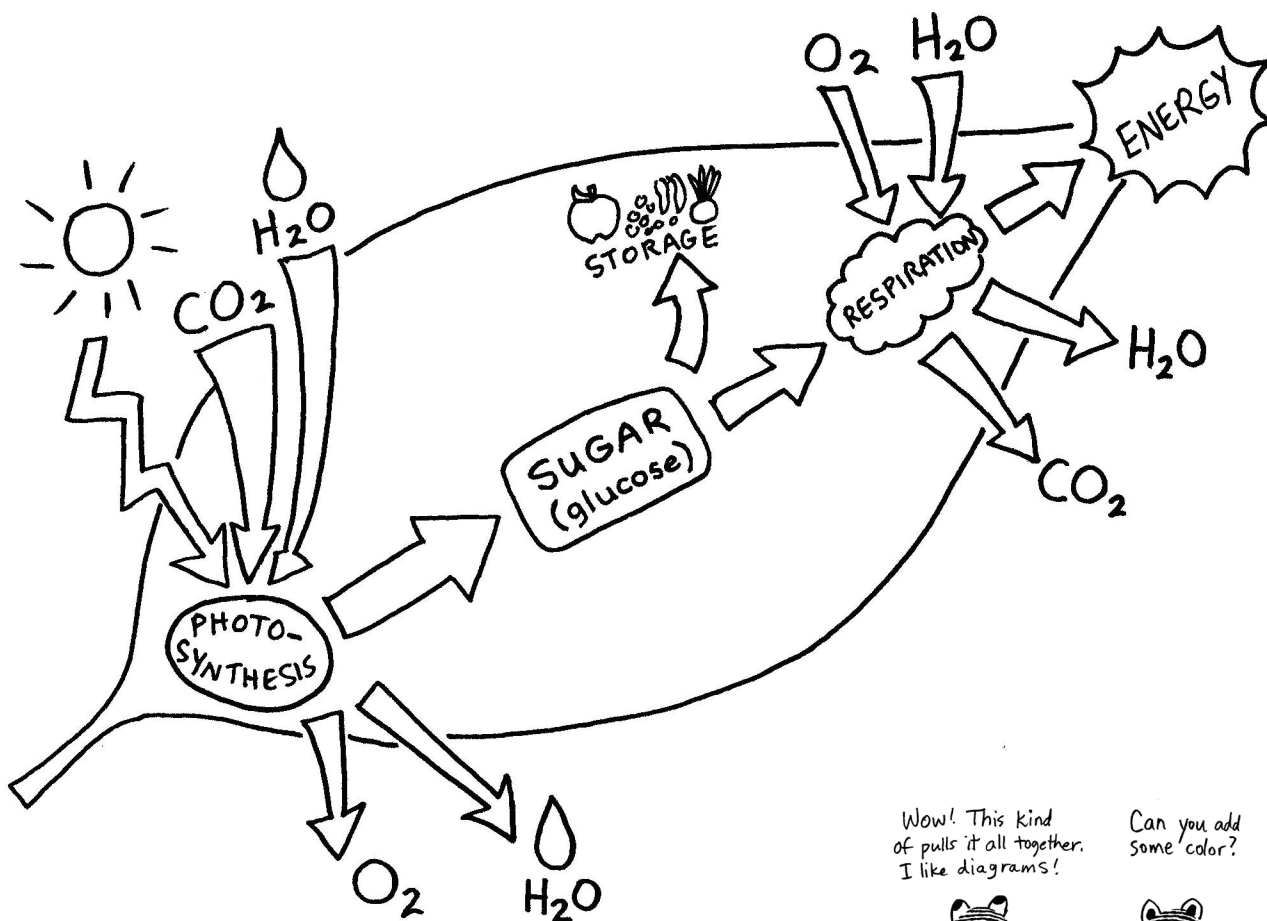
Animals depend on plants not only for putting oxygen back into the air, but also for supplying food. All animals are dependent upon plants whether they eat plants or not. Even carnivores such as lions depend on plants, because the prey that they eat (zebras, for instance) are usually plant eaters. Without 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. You may also want to color the diagram. Make sure you color lightly so that you can still see the words clearly.

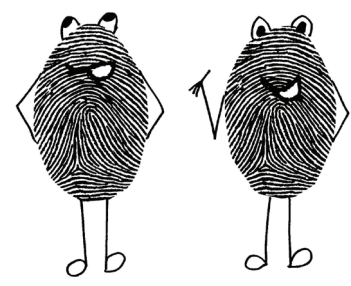
The plant uses light, carbon dioxide, and water in a process called photosynthesis. This process results in the production of oxygen, water, and glucose (sugar). Some of the glucose is used by the plant as its own food. (This "eating" process inside a plant cell is called "respiration.") For respiration,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



Wow! This kind of pulls it all together. I like diagrams!

Can you add some color?



And now for something completely different...

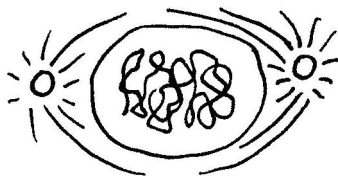
HOW CELLS DIVIDE

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.

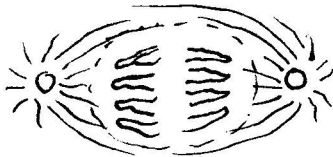
First, the nucleus must prepare. If there are to be two cells, each new cell must have a complete copy of the DNA instructions. Also, each new cell will need a full set of organelles. Let's say a cell needs 10 chloroplasts to survive. That means that before it is ready to split in half, the "parent" 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.")

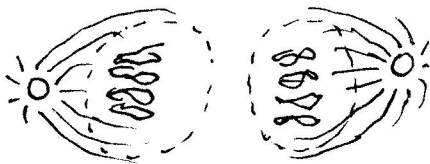
This is how the nucleus divides:



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.



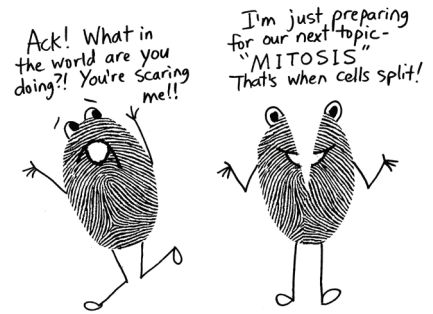
3) New membranes begin to form around the two new nuclei (*nu-klee-i*).

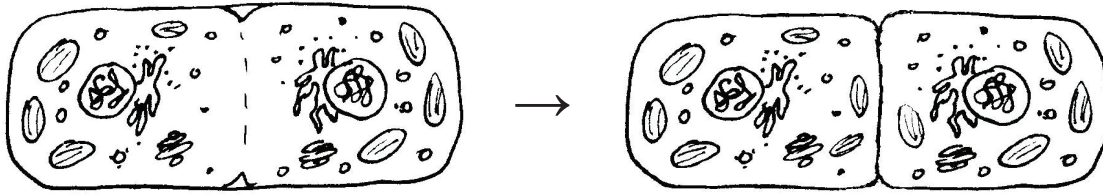


4) The membranes are complete. Now there are two separate, identical nuclei.



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," "metaphase," 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 micrographs" 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 two short video clips related to plant cell mitosis posted on the Botany playlist at [YouTube.com/TheBasementWorkshop](https://www.youtube.com/TheBasementWorkshop). The first one shows actual footage of a real nucleus dividing in half. The second one is very silly and shows some people in a swimming pool trying to imitate mitosis.

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](https://www.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.

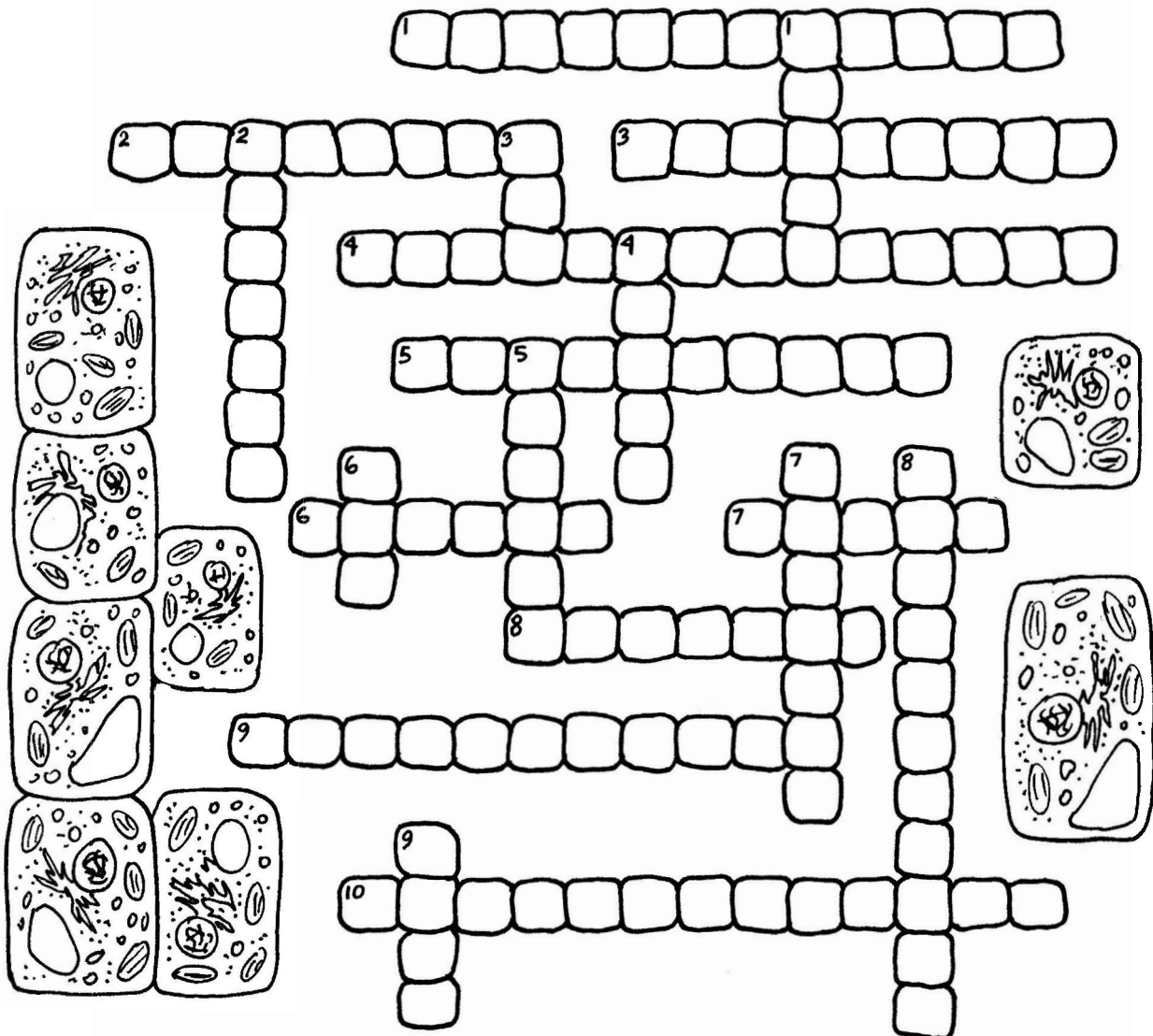
ACTIVITY 5: PHOTOSYNTHESIS/MITOSIS CROSSWORD PUZZLE

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.

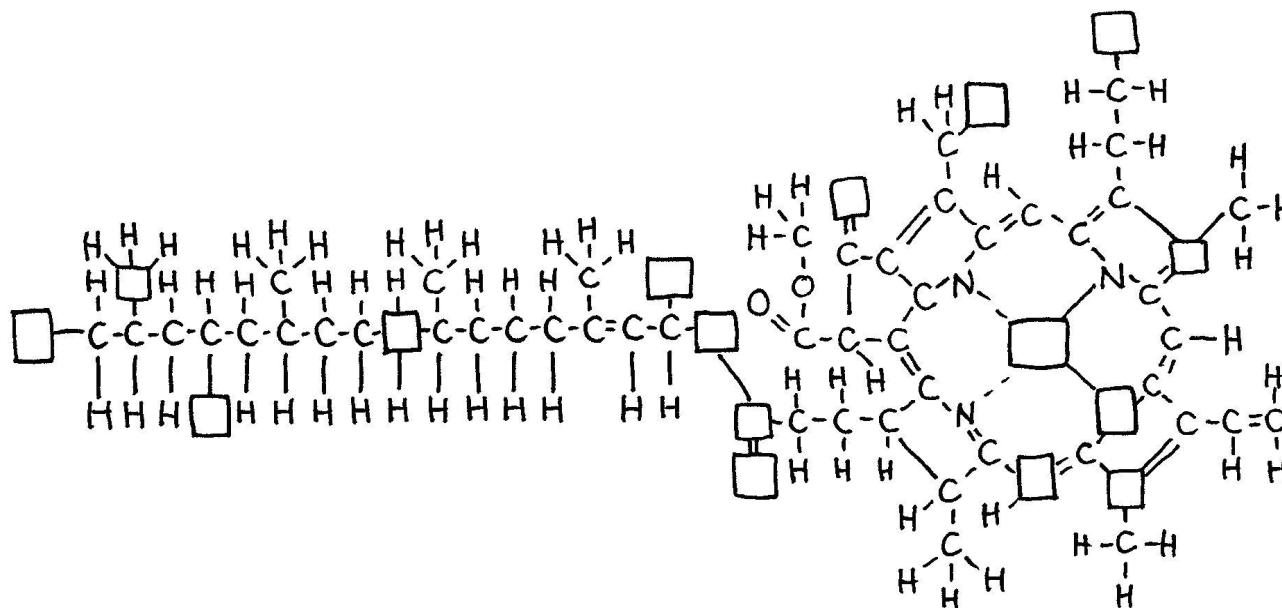
DOWN

- 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 _____.



ACTIVITY 6: FILL IN THE MISSING ATOMS IN CHLOROPHYLL

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



Bonus question: How many atoms of magnesium are in a chlorophyll molecule? _____

Bonus idea: Magnesium can only form two bonds with other atoms. In this diagram, there are four lines stretching out from the magnesium atom. Wait a minute—that math doesn't add up! All four nitrogens can't bond with the magnesium. The dotted lines are sort of like "impossible" bonds. This makes for an unstable situation. It's this instability, however, that makes the chlorophyll molecule able to capture the sun's energy!

ACTIVITY 7: 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
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MATCH:

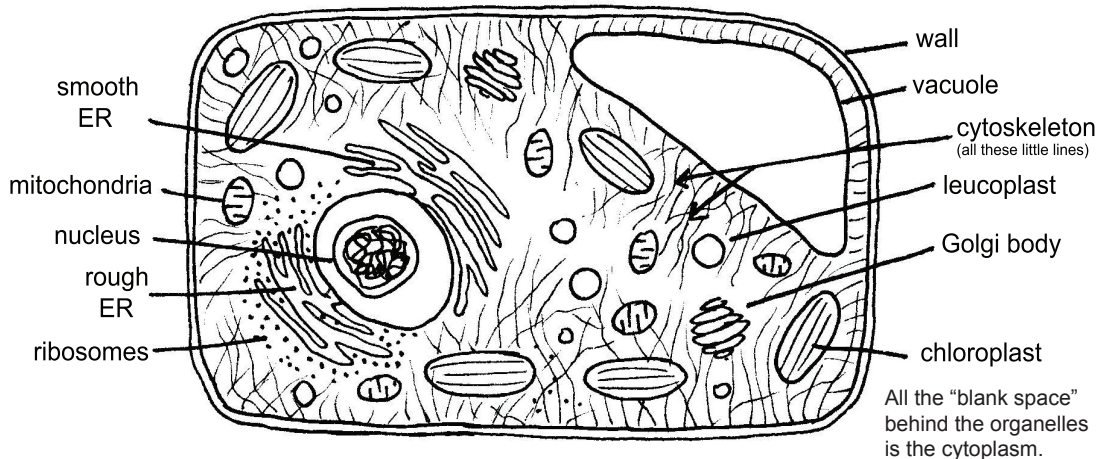
- | | |
|-----------------|-------------------------|
| 1) photo _____ | A) empty |
| 2) vacuus _____ | B) to make |
| 3) synth _____ | C) again |
| 4) chloro _____ | D) light |
| 5) nucula _____ | E) breath |
| 6) re _____ | F) greenish-yellow |
| 7) spiros _____ | G) leaf |
| 8) phyllo _____ | H) little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

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.

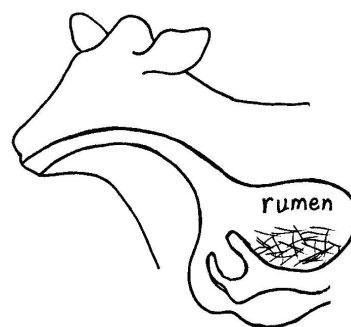
Leucoplasts: These are “storage tanks” for starches and lipids. (There are three different types of leucoplasts, the most common being the amyloplast. You will sometimes see “amyloplast” labeled on a cell drawing instead of “leucoplast.”)

Golgi bodies: These are sort of like warehouses where the products that the cell makes are stored and packaged for shipping to other areas of the cell. They contain proteins and lipids (fats) that will be used by the cell.

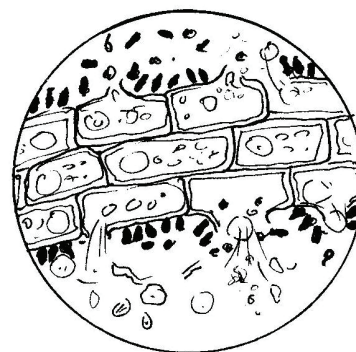
Endoplasmic reticulum (ER): This seems to do several jobs. One type of ER manufactures protein molecules. Another type of ER makes lipids (fat) molecules. Both types of ER help the cell to maintain its shape by providing a bit of internal structure. ER also helps to transport things about the cell. The ER is a busy place!

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 "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 and fats and sugars inside of them spill out and are then available for the cow's body to use.



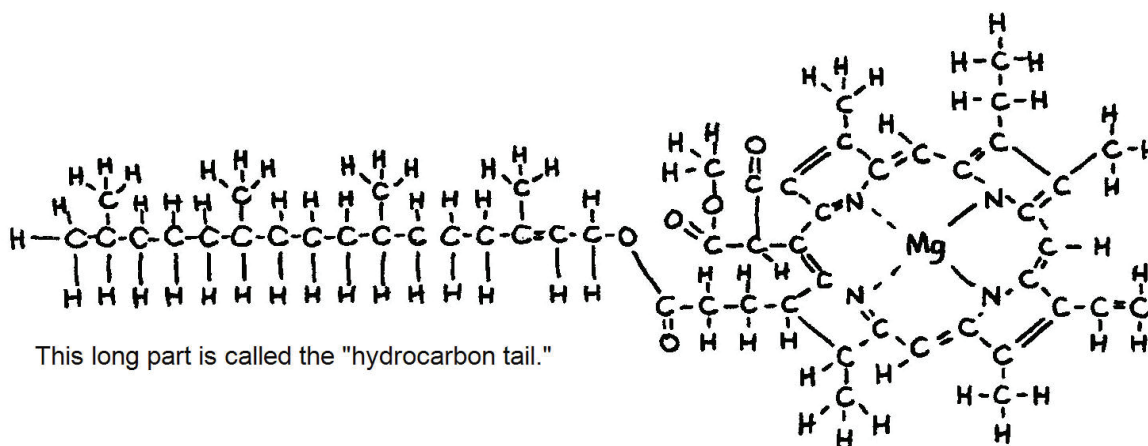
You don't have a rumen, so when you eat plant cells, they mostly just pass right through your system, undigested. This isn't bad for you, however. In fact, nutritionists call this plant material **roughage** or **fiber**, and they recommend that we eat plenty of it. The plants in our diet help to keep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



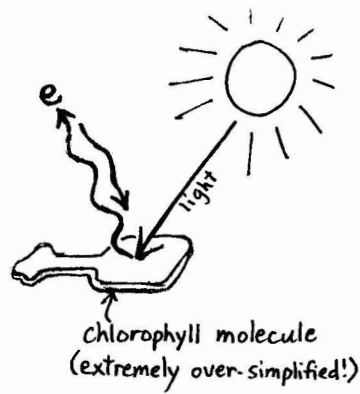
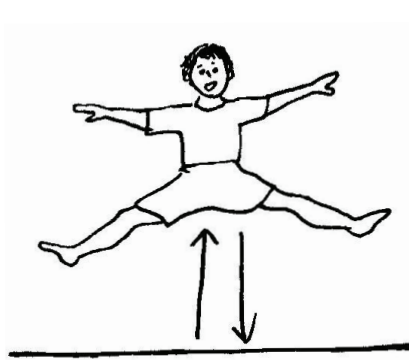
Just inside the cell wall there is a **cell membrane**. It is very thin and hard to see compared to the thick cell wall. Membranes are found in all types of cells, not just plant cells. They are fragile and come apart easily, but still have an important job. They control what comes into the cell, allowing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



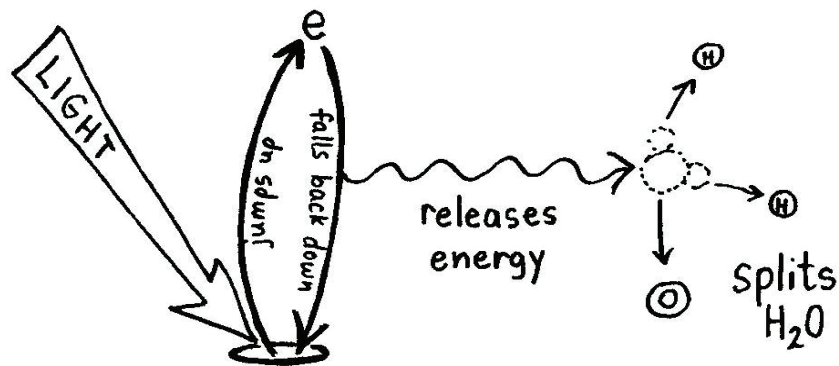
Let's discuss the process of photosynthesis again, this time taking a closer look at it. Just how does a chloroplast produce sugar? The process begins with the chlorophyll molecule. It has the amazing ability to turn light energy into chemical energy. The reaction center of the molecule is a magnesium atom surrounded by four nitrogens. The nitrogens would like to bond with the magnesium, but magnesium can only make a total of two bonds, so two of the nitrogens are out of luck. See the dotted lines? That is where those two nitrogens would like to put bonds, but can't.



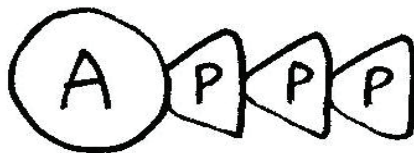
It's this chemical "problem," however, that makes life on Earth possible! These atoms are the ones that "catch" the energy from the sun and transfer it along to other molecules, providing energy for the process of photosynthesis. When a photon of light hits the reaction center of the chlorophyll, an electron from one of the atoms absorbs the energy and "jumps up." This is called the electron's **excited state**. (Do you jump up or stand on your toes when you are excited?)



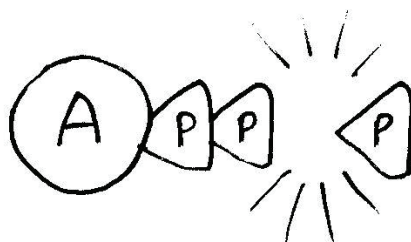
Just as you must obey the law of gravity and come back down again, the electron must also return to its normal state. On the way back down, though, it can pass its extra energy along to other molecules. (Where does the extra energy go when you jump up and come back down? Think about the thud you hear when you hit the floor.) This passed-along energy is put to work in the chloroplast. It is used to split water atoms into hydrogen atoms and oxygen atoms. Some of these freed oxygen atoms go off into the air and are breathed in by animals.



The energy contained in those released hydrogen atoms is used to prepare a molecule called ATP. The ATP molecule will then provide energy for the production of a sugar molecule. ATP stands for adenosine triphosphate. Notice that the word triphosphate begins with "tri." It means three, just as in tricycle or triangle. The adenosine has three phosphates. We could draw it like this:

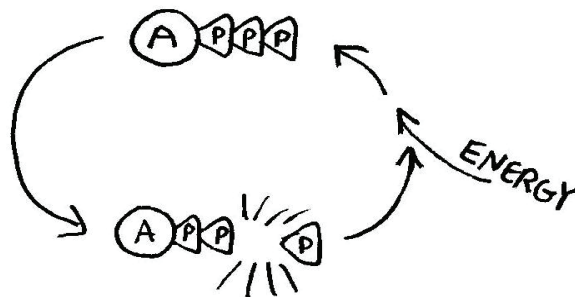


The way it releases energy is by losing one of its phosphates. The energy that kept the phosphate attached is released as the phosphate drops off.



ATP can be recycled by sticking the phosphate back on again. It takes energy to put it back on, of course, but since the plant uses light energy to recharge, it always has plenty of solar power available. ATP is sort of like a little molecular rechargeable battery.

Energy is used to put the P back on.



Energy is released when the P pops off.



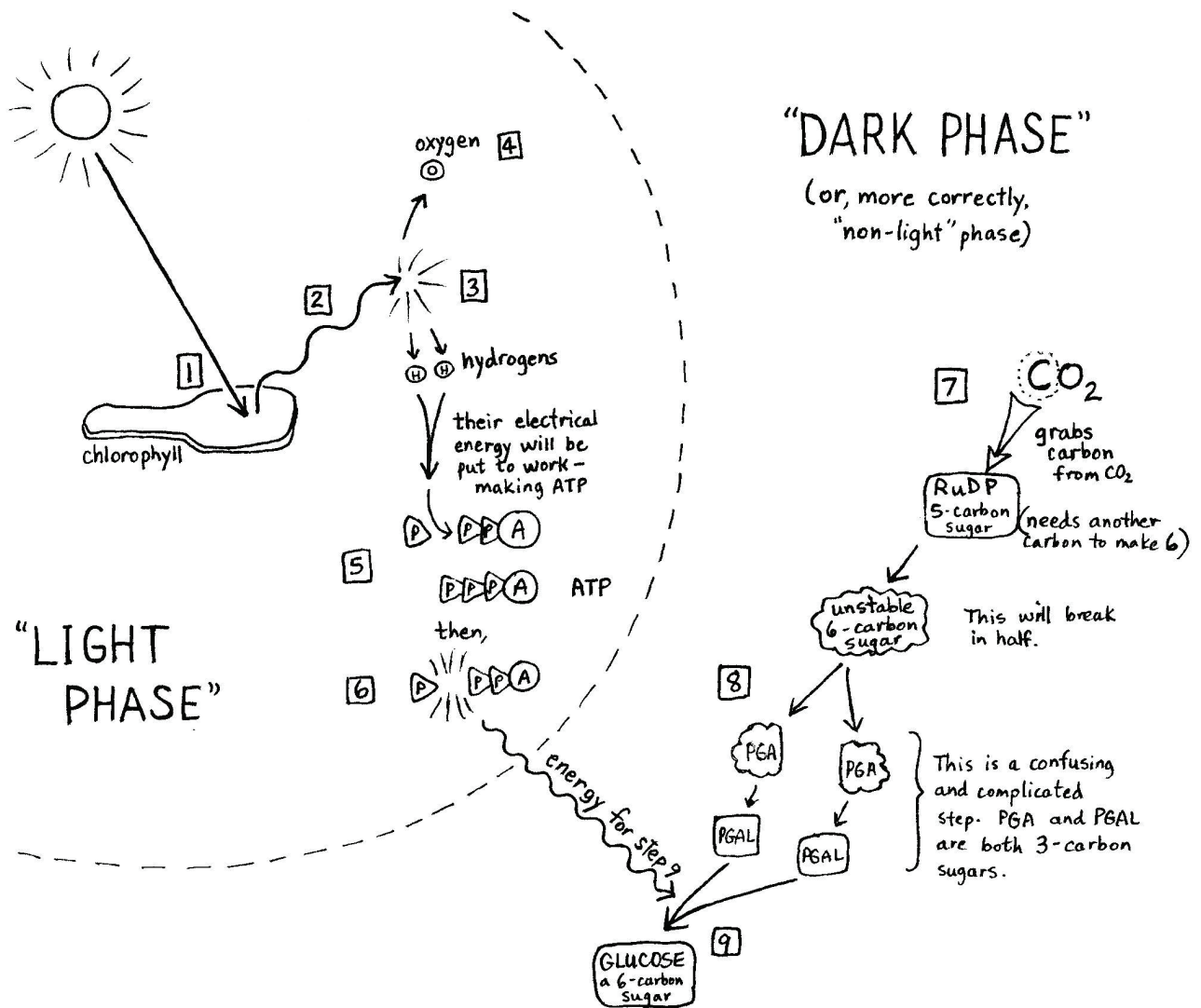
Now if you think this is starting to get a little complicated already, you are right. Photosynthesis is incredibly complicated. A basic first-year college text would describe this energy transfer using sentences like this: “As the excited electrons give up energy on their way down to the P700 chlorophyll energy transport chain, the thylakoid membrane couples the exergonic flow of electrons to the endergonic reaction of phosphorylating ADP to make ATP.” We will use much simpler explanations here to finish up our overview of photosynthesis.

What we have learned about photosynthesis so far is called the **light phase** of photosynthesis because it needs light energy. The second half of the process is usually called the **dark phase** because it doesn't need light. It doesn't need darkness, though--it can take place while it is light, it just doesn't *need* the light.

During the dark phase, the chloroplast uses the energy it just stored in the ATP molecules to put together molecules of sugar. It takes small molecules called PGA (phosphoglyceric acid), turns them into PGAL (phosphoglyceraldehyde), then puts several of these together to make a glucose molecule. And, oh yes--at the same time that glucose is formed, a molecule of RuDP is formed. RuDP is the molecule that “catches” the carbon dioxide out of the air and brings it into the cell. (And remember, it's actually more complicated than this!)

On the facing page is a very simplified diagram of how photosynthesis works. Follow along step by step as we describe the process:

- 1) A photon of light strikes the center of a chlorophyll molecule.
- 2) An electron is excited and releases energy.
- 3) This energy splits a water molecule.
- 4) The oxygen goes off into the atmosphere. (Actually, two oxygens always pair up and escape together as O₂.)
- 5) The energy in the hydrogens is used to make an ADP into ATP.
- 6) Then the phosphate is immediately ripped off again, releasing energy which is used for step 9.
- 7) Meanwhile, a 5-carbon sugar molecule called RuDP snatches a carbon dioxide out of the air and uses its carbon atom to make it into a 6-carbon sugar,
- 8) which immediately breaks down into two 3-carbon sugars.
- 9) These 3-carbon sugars are modified using energy from ATP and are put together to form one molecule of 6-carbon sugar, glucose.



ACTIVITY 1: MATCHING

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

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

- A) makes energy
- B) warehouses for packaging, shipping, storage
- C) jelly-like fluid
- D) an empty area
- E) network of fibers
- F) stores starches and fats
- G) uses light, water and CO_2 to make sugar
- H) assembles proteins
- I) assembles, transports, gives shape
- J) contains DNA instructions

ACTIVITY 2: MORE MATCHING

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

- | | |
|-------------------------------|---|
| 1) nucleus ____ | A) workers on the assembly line |
| 2) Golgi bodies ____ | B) foreman (boss) |
| 3) vacuole ____ | C) empty courtyard in middle of factory |
| 4) mitochondria ____ | D) storage tanks |
| 5) ribosomes ____ | E) sidewalks, roads |
| 6) leucoplasts ____ | F) warehouse and shipping area |
| 7) endoplasmic reticulum ____ | G) generator supplying electricity |
| 8) cytoskeleton ____ | H) assembly line |

ACTIVITY 3: ANSWER THESE QUESTIONS

- 1) In your own words, what does the chlorophyll molecule do? _____

- 2) What molecule provides the energy for the “dark phase” of photosynthesis, acting like a little rechargeable battery? _____
- 3) Does the “dark phase” need darkness? _____
- 4) What cellular process is the “opposite” of photosynthesis? _____
- 5) Can an electron stay in its excited state? _____
- 6) The energy released by the excited electron is used to do what? _____
- 7) What type of energy excites the electrons in chlorophyll? _____
- 8) Besides light, what else does a plant need for photosynthesis? _____ and _____
- 9) What part of ATP comes off in order to release energy? _____
- 10) Which phase of photosynthesis releases oxygen--light or dark? _____
- 11) What is the name of the molecule that “grabs” carbon from carbon dioxide? _____
- 12) What would happen if any one of the ingredients needed for photosynthesis was not available? _____
- 13) Plants both *use* water and *produce* water during photosynthesis. Are the water molecules that go into the leaf the exact same ones that come out? _____
- 14) What type of atom sits right in the middle of the chlorophyll molecule? (Hint--it’s the only one of its kind.) _____

LESSON 1

Level 1

Activity 5: (Crossword puzzle)

ACROSS: 1) chloroplasts 2) membrane 3) daughters 4) photosynthesis 5) elongation
6) energy 7) water 8) nucleus 9) chlorophyll 10) carbon dioxide

DOWN: 1) light 2) mitosis 3) eat 4) sugar 5) oxygen 6) DNA 7) vacuole 8) respiration 9) wall

Activity 6: Compare your drawing to the one in the chapter

Activity 7: 1)D 2)A 3)B 4)F 5)H 6)C 7)E 8)G

Level 2

Activity 1: 1)J 2)I 3)B 4)F 5)G 6)D 7)A 8)H 9)C 10)E

Activity 2: 1)B 2)F 3)C 4)G 5)A 6)D 7)H 8)E

Activity 3: 1) Answers will vary. 2) ATP 3) no 4) respiration 5) no 6) split water molecules
7) light 8) carbon dioxide and water 9) the P 10) light phase 11) RuDP
12) there would be no photosynthesis 13) no 14) magnesium

ACTIVITIES FOR LESSON 1

1) Plant cell “penny pitch” game

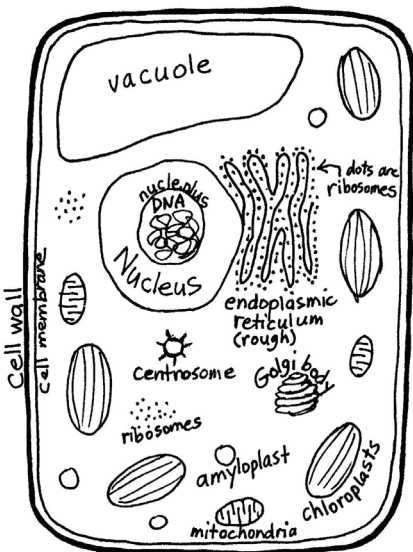
This game can be played indoors or out. You can adapt the size and scale of all the game parts to suit your playing area. For small areas, make the model a few feet in diameter, and pitch pennies. For large areas, make the model very large and pitch bean bags or shoes. (You could even use an empty parking lot and draw the model with chalk.)

You will need:

- A large floor area (can be an area in a room, or as large as a parking lot outdoors)
- A long rope (to represent the cell wall)
- Small objects to represent ribosomes (dried beans, dimes, raisins--whatever you have on hand)
- Yarn (three colors--one for the cell membrane, one for the endoplasmic reticulum, one for the vacuole)
- Green fabric, felt or paper than can be cut into chloroplasts
- Fabric or paper scraps of various colors and/or textures, for other cell parts
- Objects to pitch--such as pennies or bean bags, depending upon the size of your playing area. Beanbags are obviously better for very large areas, pennies for smaller areas.
- Scissors

Set-up:

Use the ingredients listed above to make a flat model of a plant cell on the ground, using the diagram as a guide. The organelles can be in any position. You may give the students freedom to arrange the cell however they want to. (The cytoskeleton is not used, as it would make things too complicated. Also, some of the parts are discussed only in Level 2. You can adapt this game to Level 1 by using only the cell parts mentioned in Level 1.)



CELL WALL: Outer layer--provides protection and support for cell
CELL MEMBRANE: Thin membrane that controls flow of water and chemicals in and out of the cell
NUCLEUS: Contains DNA (the instructions a cell needs for everything it does and everything it has to manufacture)
NUCLEOLUS: Contains the DNA that tells how to make ribosomes
VACUOLE: Empty “bubble” helps to maintain shape of cell.
CHLOROPLAST: Where photosynthesis occurs (Makes sugar from light, carbon dioxide and water.)
MITOCHONDRIA: The energy producers of the cell
CENTROSOME: Assists cell in mitosis (reproducing by splitting in half)
AMYLOPLAST (a type of LEUCOPLAST): Stores sugar and starch molecules made by the cell
ENDOPLASMIC RETICULUM: A series of tubes connected to the nucleus (Rough ER has ribosomes surrounding it.)
RIBOSOMES: The “factories” that produce proteins the cell needs
GOLGI BODIES: Process and package proteins and fats made by the cell (they look sort of like a stack of pancakes)

How to play:

If you have a lot of players, divide them up into teams. Make sure all players are standing the same distance away from the cell. Call out the name of a team and then the name of an organelle. The members of that team all pitch their objects, trying to land on the organelle you just called out. The team receives a point for every “hit.” Have the players reclaim their objects. Then call out another team and another organelle. Make sure all teams get a chance to aim for each organelle at some point in the game.

2) Photosynthesis game

You will need:

- A copy of the gameboard for each player
- Small “tokens” of at least three different kinds or colors, which will be used to represent carbon, oxygen, and hydrogen atoms. (Suggestions: small candies, different types of breakfast cereal, raisins, cranberries, nuts)
- One spinner (assemble and color the spinner according to directions) You will need scissors, glue, a paper fastener, and markers or crayons for this (and cereal box cardboard if you want to make the spinner sturdy enough to last for a while).

Directions:

This game can be played with any number of players. Divide the players up so that you have four teams. If you have only two or three players, the game will still work. Even one person can play it, although there won't be any competition, of course. (However, the satisfaction in having completed the task of photosynthesis might be enough.) The number of players per team does not have to be equal. Being on the same team simply means that all members of that team will receive the same spinner results on each round, and therefore will be doing the same thing at the same time. This can actually be very beneficial for those students who have trouble catching on to game formats. They can simply follow along with what their teammates are doing.

Each player/team is assigned a colored “arm” of the spinner. Each time the spinner is spun, the team (or individual player) will read the results from that color. For example, if you are on the red team, whatever the red arm lands on is your spin result. The blue arm is for all players on the blue team. Players on teams can take turns spinning the spinner, but the spin will be for everyone. There is no “down time” waiting for turns. All players do something each time the spinner is spun. (The exception being if you already have your slots filled for that item. If you already have a light token and light is spun again, you can't do anything on that turn.)

Each person decides what they will use to represent the atoms on their board: carbon, oxygen, and hydrogen. They will also need just one token to represent light. Make sure they choose their “code” ahead of time. For example: raisins for carbon atoms, Cheerios for oxygen atoms, small red candies for hydrogens, and a dried banana for light. Whatever the spinner arm lands on is what you build on your game board. If you or your team spins WATER, then you “build” one of the water molecules on the top portion of the board by putting two hydrogen tokens and one oxygen token right on top of one of the water molecules. You only need one light token, so if you land on LIGHT again, you just do nothing for that turn, since you already have light.

Once you have all the molecules filled up on the top half of the board, it then becomes a race (or a cooperation) to see how fast you can rearrange all the atoms to form the molecules on the bottom half of the board. Plants do this, too. They disassemble all the ingredient molecules and use them to form new molecules.

The advantage of using edible tokens is that whenever you have the bottom half of your board complete, you can reward yourself by eating the glucose molecule (and the other molecules, too, if you are still hungry!).

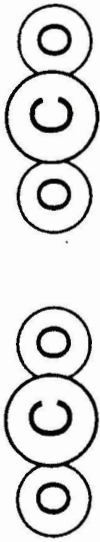
During the course of the game you will certainly hear the following comments. Here are some responses you could give.

“I keep spinning light. I don't need any more light!” *This is true for plants, as well. Plants living outdoors almost always have enough light. In fact, most of the sun's energy goes to waste. What limits photosynthesis is usually the amount of water available.*

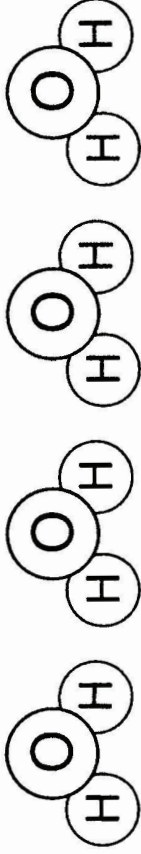
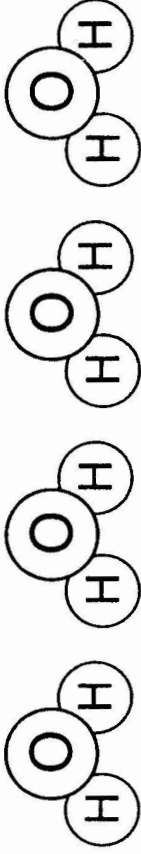
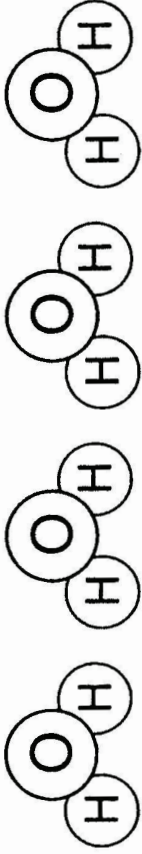
“I don't have enough water. I keep spinning carbon dioxide.” *This happens sometimes in real life, too. The weather can produce droughts. There is still plenty of carbon dioxide and light, but not enough water. If you keep spinning you are guaranteed to land on water eventually.*

“I have way too much water and not enough carbon dioxide.” *Plants could possibly have this problem, though it is less likely than a water problem. Some people claim that breathing on your house plants helps them to grow faster since your breath contains carbon dioxide. There could also be atmospheric conditions in some places that would make carbon dioxide less abundant. Plants submerged in water are not able to take in air.*

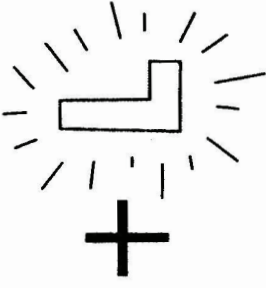
CARBON DIOXIDE



WATER



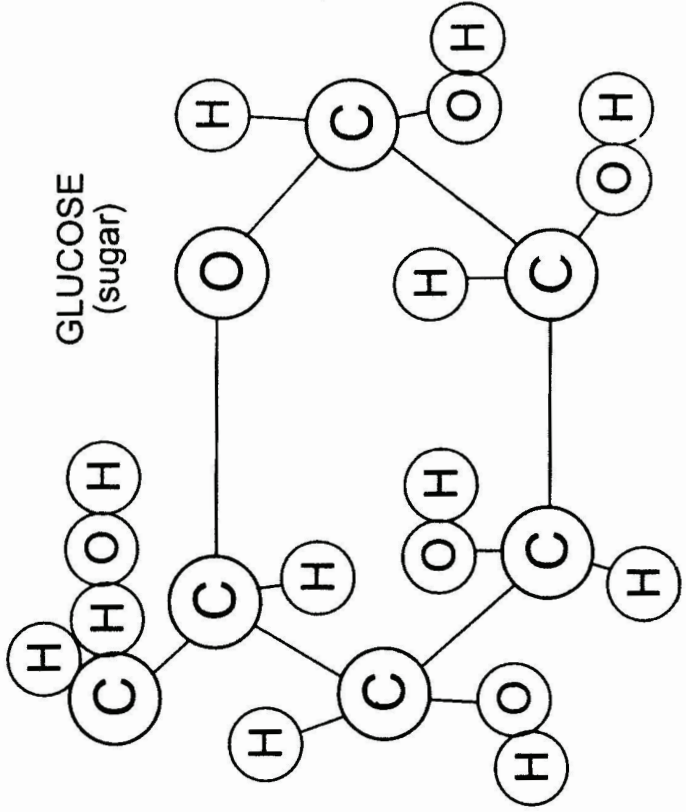
LIGHT ENERGY



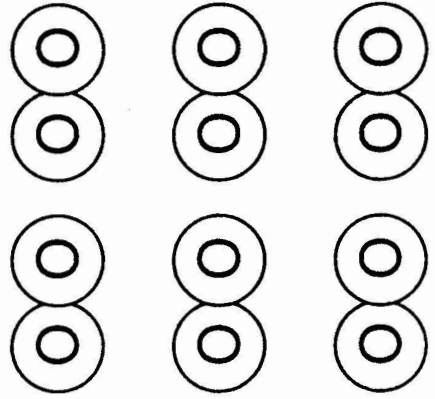
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↑ **PHOTOSYNTHESIS** ↓

GLUCOSE (sugar)

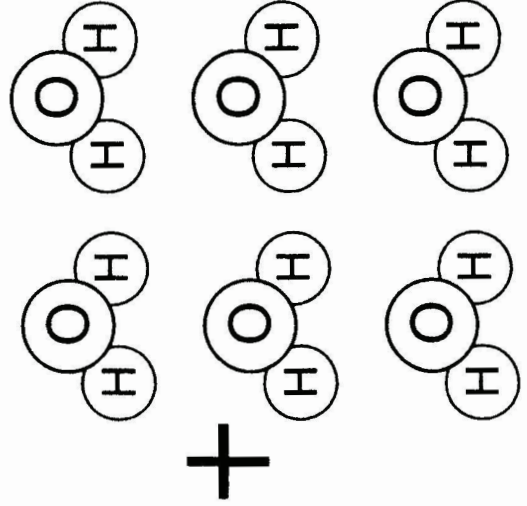


OXYGEN (O₂)

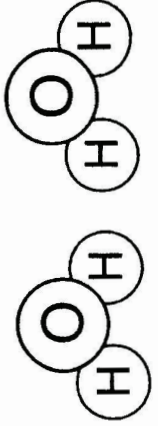


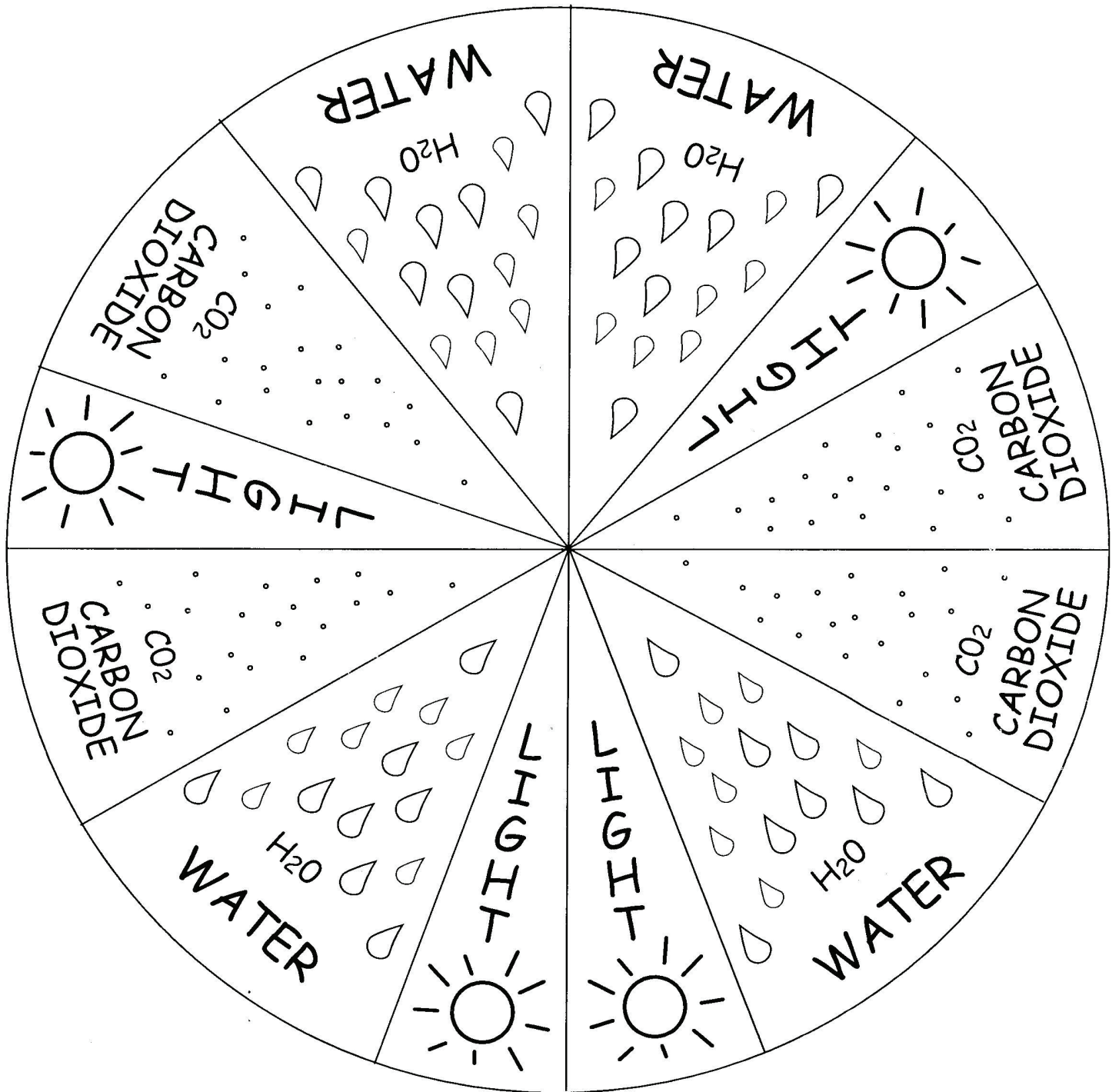
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WATER



+

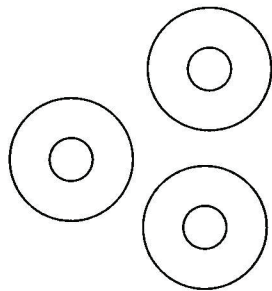
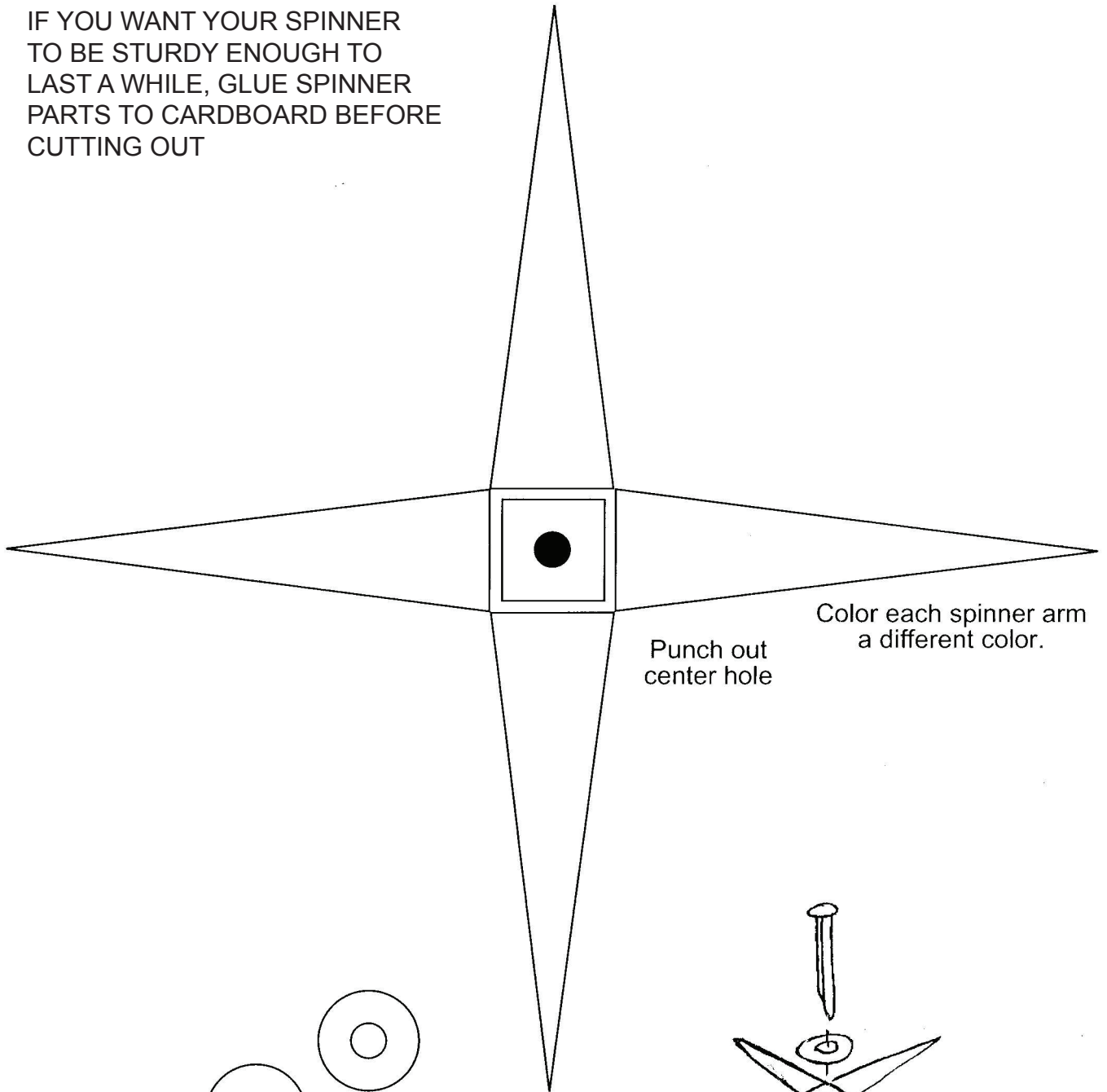




Do not cut out circle. Simply cut across this line.

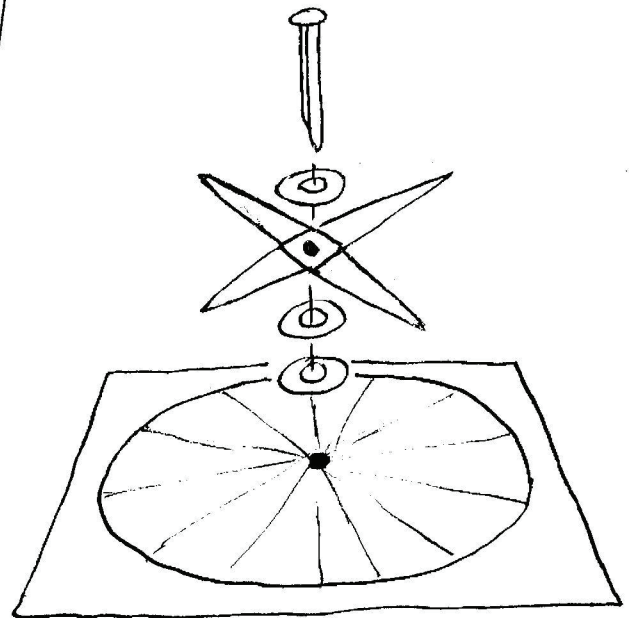
GLUE THIS SPINNER SQUARE TO CARDBOARD IF YOU WANT IT TO BE STURDY ENOUGH TO LAST A WHILE. (CEREAL BOX CARDBOARD IS FINE.)

IF YOU WANT YOUR SPINNER
TO BE STURDY ENOUGH TO
LAST A WHILE, GLUE SPINNER
PARTS TO CARDBOARD BEFORE
CUTTING OUT



PAPER WASHERS

(You can use a paper punch
to cut out centers.)



3) *Photosynthesis relay race*

The goal of this game is to reinforce the photosynthesis formula:



while at the same time allowing restless students to engage in active play.

You will need:

- Two pieces of green construction paper
- Four small (standard 3.5"x 6.5") envelopes
- Glue stick or white glue
- Marker
- Copy of the card pattern page with pieces cut out
- A flashlight for each team



The reverse side of the leaf will say "OUT."

Directions for assembly:

Cut two large green leaves. Cut the flaps off the envelopes, then glue an envelope on each side of each leaf, with the open side of the envelope facing out. Label the envelopes on opposite sides of the leaves "IN" and "OUT."

Photocopy the card pattern page onto card stock, if possible, to make the cards more durable. However, plain paper can be used as well. Cut out all the cards.

Optional: Decorate or color the cards to make them more readable at a quick glance. For instance, put a raindrop on the water cards.

How to set up the game:

You will need to prepare the leaves ahead of time by putting cards for WATER, OXYGEN and GLUCOSE in the OUT pocket of the leaves. Put WATER and CARBON DIOXIDE cards in neat piles at the start line. Put the leaves at a distance from the start line. (If your students need to stretch their legs, put the leaves really far away!) Put the flashlights next to the leaves.

How to play the game:

On the word GO, the first member of the team takes either a CARBON DIOXIDE or a WATER card, runs to the leaf, and puts it into the IN pocket of their leaf. They run back, tag the next player. The second player takes the other card (whatever the first player didn't take, either water or carbon dioxide) and runs to the leaf. He puts this into the IN pocket, then runs back. The third player runs to the leaf, turns on the flashlight, shines it on the leaf briefly, turns it off (leaves the flashlight there), and then runs back. Now the leaf has had all the necessary ingredients for photosynthesis! The fourth player runs to the leaf and takes out just one of the cards in the OUT pocket and runs (taking the token with him) back to team. The fifth player runs to the leaf, takes another card out of the OUT pocket and runs with it back to the team. The sixth player runs to the leaf and takes out the last card in the OUT pocket. When the last player gets back to his team with the last product of photosynthesis, the team is done. First team to accomplish all this wins the game.

Variations: This game is a lot of fun to play again and again if you change the method of locomotion to and from the leaf. Have them hop, skip, walk backwards, crawl, carry a ball between their knees, etc. This way they get the repetition of the photosynthesis formula without making them bored with the game. Even middle school and high school ages like the game when it is played with creative variations like this! It brings a lot of laughs, as well as a lot of learning.

WATER	WATER
WATER	WATER
CARBON DIOXIDE	CARBON DIOXIDE
OXYGEN	OXYGEN
GLUCOSE (SUGAR)	GLUCOSE (SUGAR)

4) Streaming chloroplasts “flip book”

You will need:

- Scissors
- White glue
- Copies of the pattern pages printed onto white card stock
- Optional: colored pencils or crayons, fine sandpaper

Directions:

Do any coloring you want to do before you cut apart the pages or assemble the booklet. (However, coloring is still possible after the pages are cut and after the booklet is assembled, as long as the glue is dry enough so that the pages will not come apart.) The most important coloring is to make the chloroplasts green so that they will show up nicely when the pages are flipped. If you want to color other parts of the cell, you may do so, as long as you are consistent and do the same thing on every cell.

Cut out all the pages. Glue will be applied right where the numbers are. Use glue sparingly. Half a drop is enough if it is spread out! No oozing glue! Stack the pages, putting 1 on the bottom and working upward until the cover (which would be number 24) is on the top.

IMPORTANT: Match the edges on the right side of the book--the side away from the numbers. Don't worry if the number sides match up evenly. You want the side you will flip to be smooth. You can even take a piece of fine sandpaper to smooth the flipping edge once the booklet is dry. Hold that edge tightly, put the sandpaper on the table, and rub the booklet across the sand paper. The table will give you a firm surface on which to rub the edge of the booklet.

Let the book dry completely before sanding or flipping the pages.

PAGE 1 GOES ON THE BOTTOM.

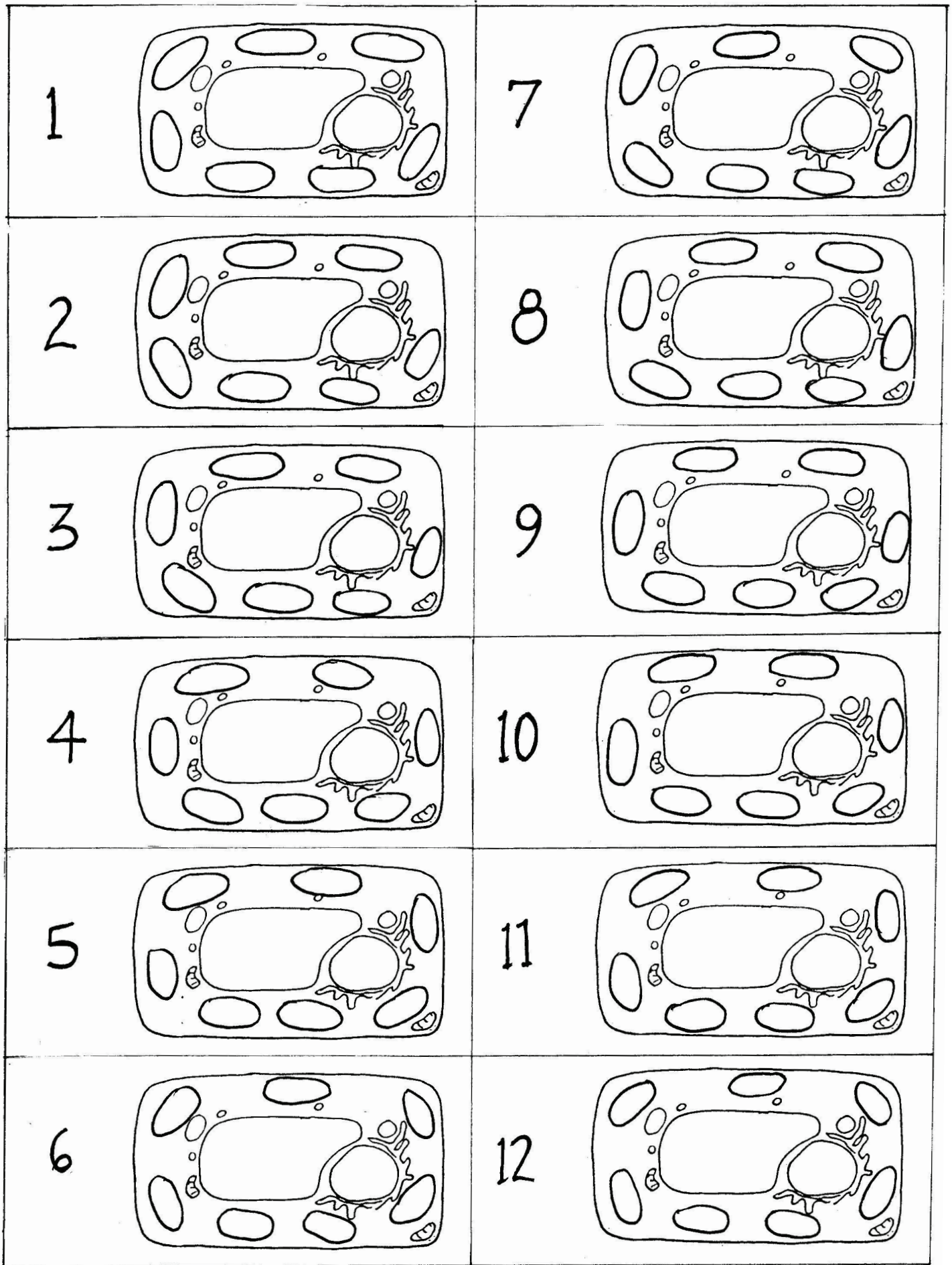
WORK YOUR WAY UP TO 23 ON THE TOP, THEN THE COVER.

4) Look at real plant cells under a microscope

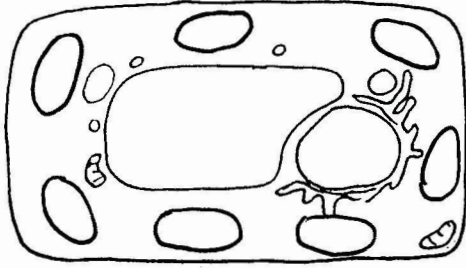
If you have a microscope available (100x or greater) you can easily observe plant cells by using the thin membrane layer of an onion. Peel the tough, yellowish-tan layers off the outside of the onion. Before you get into the white layers, you will find an incredibly thin membrane--so thin you can easily see through it. This layer is perfect for viewing under a microscope. Put a small piece of this membrane onto a microscope slide and put it under 100x. You should be able to see rows and rows of cells.

5) Extra reading material about photosynthesis

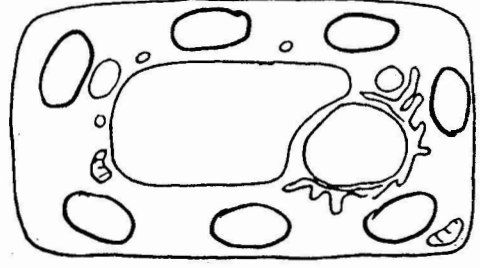
If reading forms a large part of your educational program, you may want to consider purchasing a copy of the book How Did We Find Out About Photosynthesis? by Isaac Asimov. This book is written for ages 9-13 and tells the story of how scientists across the centuries (starting back in the 1700s) have gradually learned more and more about how plants work.



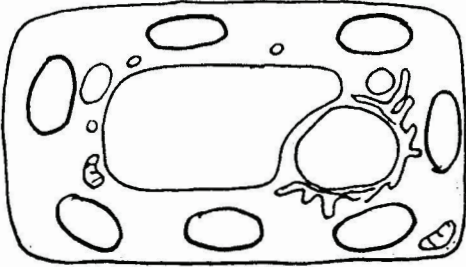
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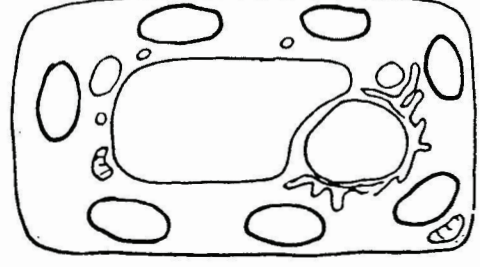
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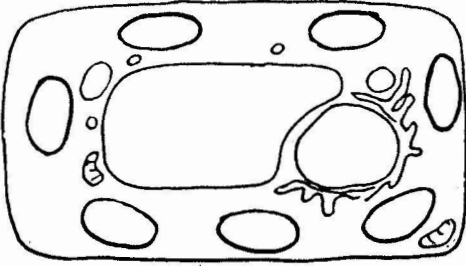
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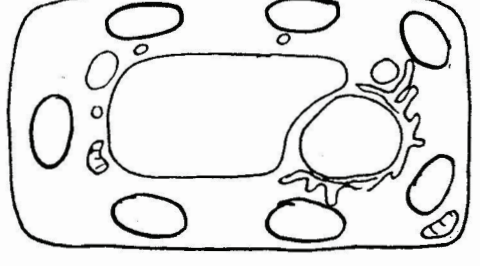
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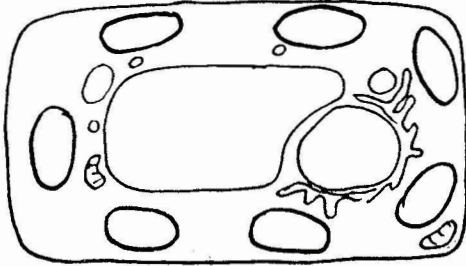
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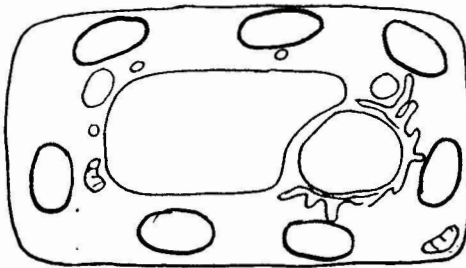
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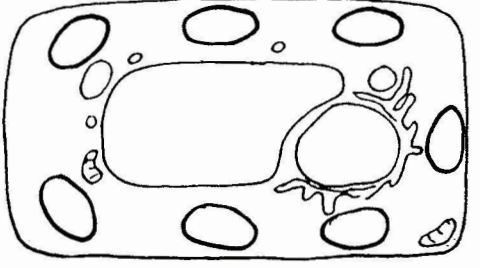
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