SUPPLEMENTAL ACTIVITIES

LESSON 1

1) PLANT CELL "PENNY PITCH" GAME

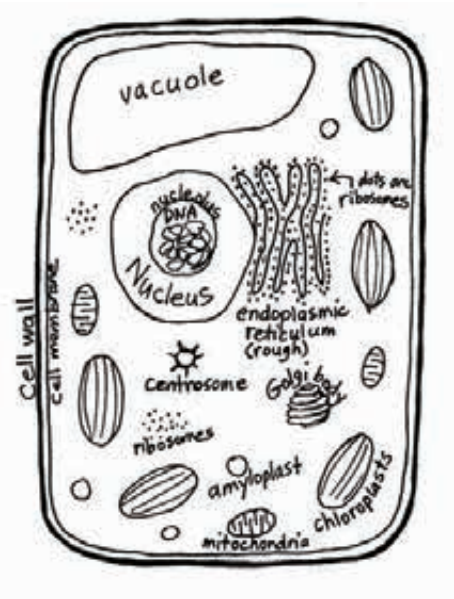
This game can be played indoors or out. You can adapt the size and scale of all the game parts to suit your playing area. For small areas, make the model a few feet in diameter, and pitch pennies. For large areas, make the model very large and pitch bean bags or shoes. (You could even use an empty parking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

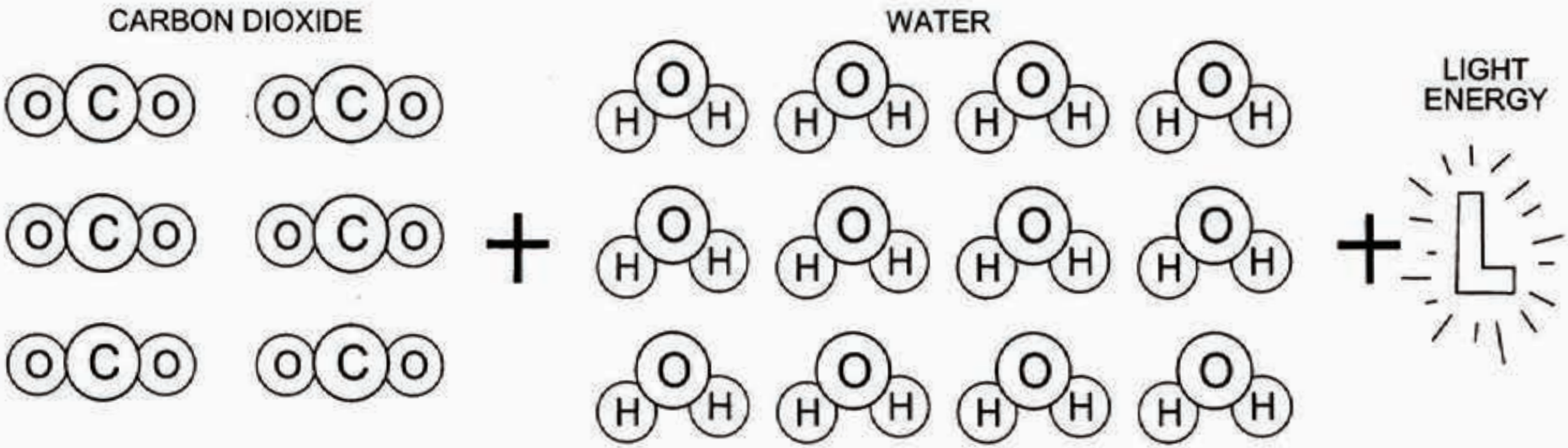
The advantage of using edible tokens is that whenever you have the bottom half of your board complete, you can reward yourself by eating the glucose molecule (and the other molecules, too, if you are still hungry!).

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

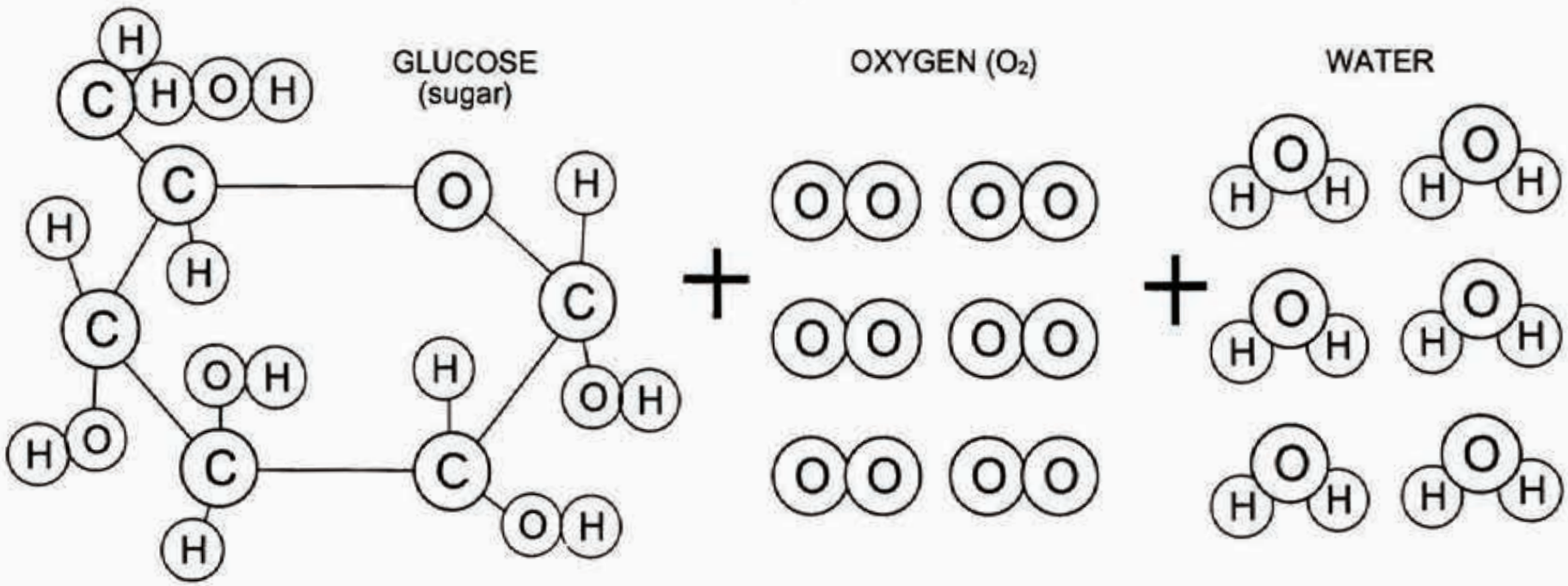
"I keep spinning light. I don't need any more light!" *This is true for plants, as well. Plants living outdoors almost always have enough light. In fact, most of the sun's energy goes to waste. What limits photosynthesis is usually the amount of water available.*

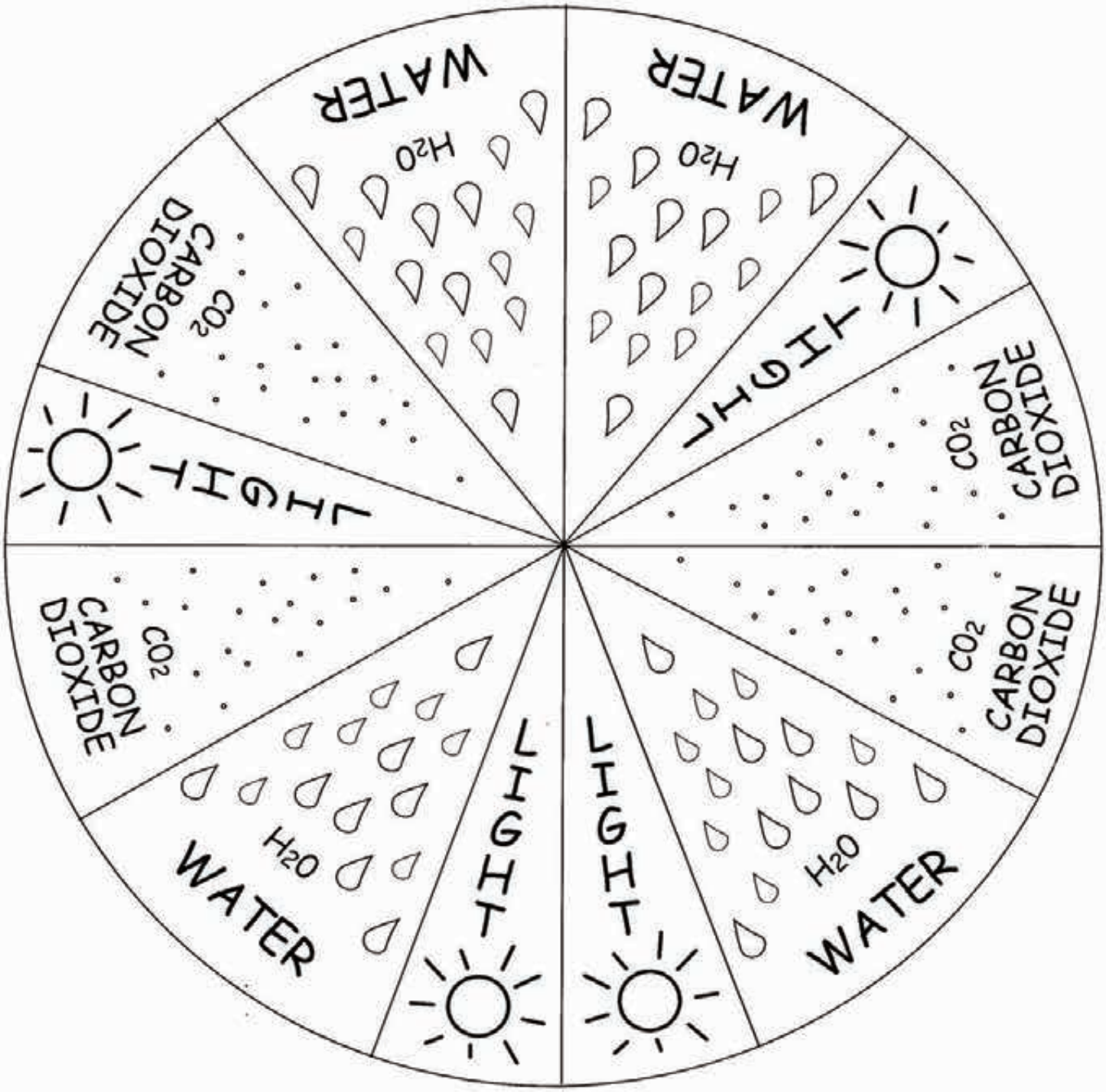
"I don't have enough water. I keep spinning carbon dioxide." *This happens sometimes in real life, too. The weather can produce droughts. There is still plenty of carbon dioxide and light, but not enough water. If you keep spinning you are guaranteed to land on water eventually.*

"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.*



PHOTOSYNTHESIS

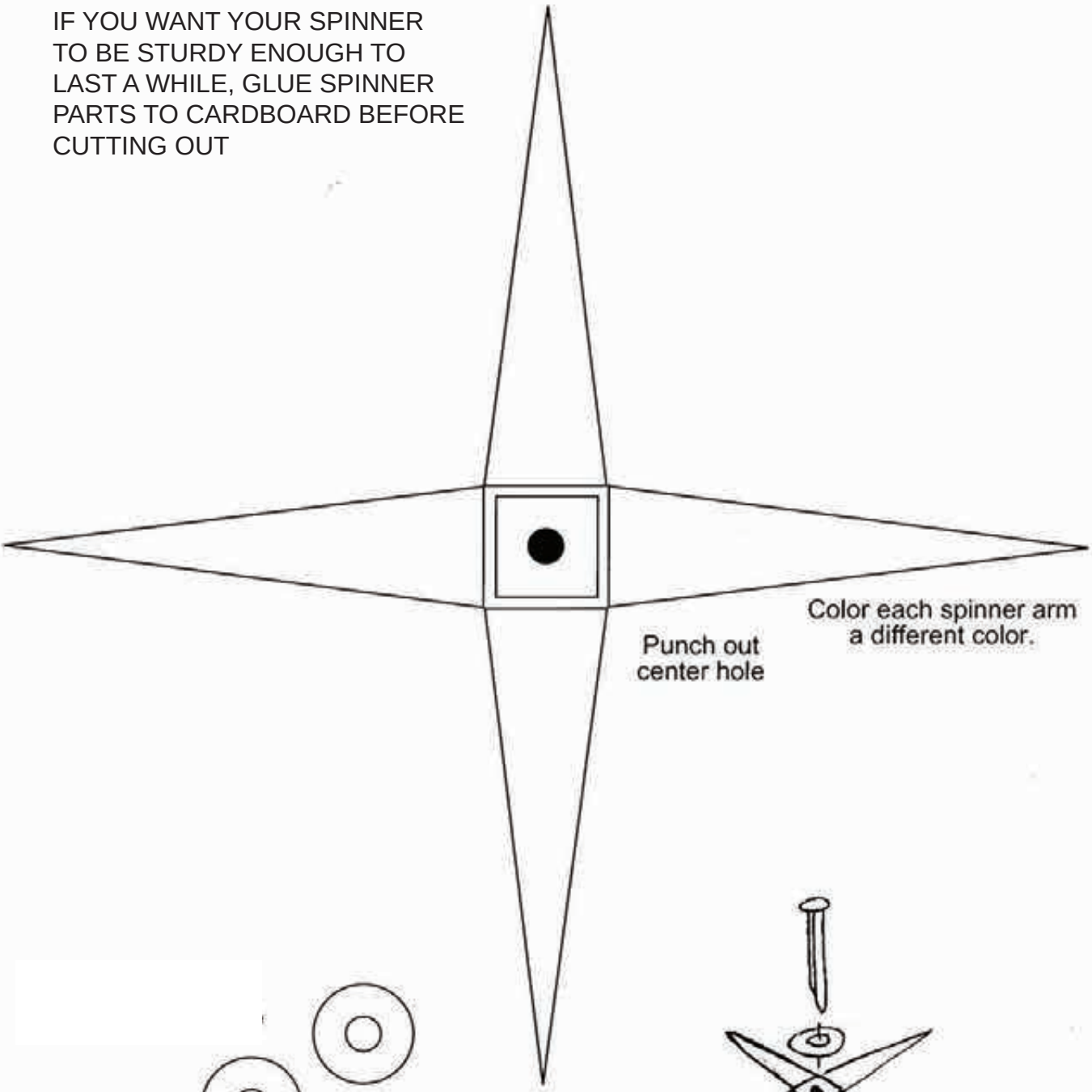


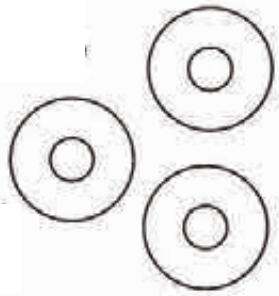


Do not cut out circle. Simply cut across this line.

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

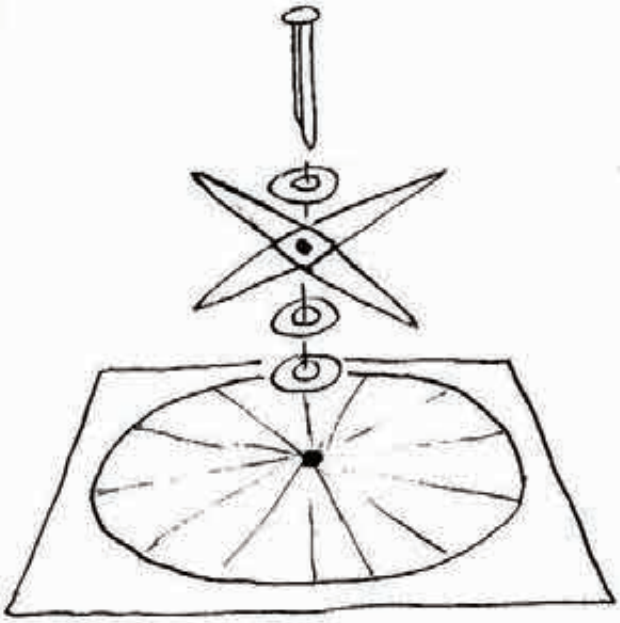
IF YOU WANT YOUR SPINNER TO BE STURDY ENOUGH TO LAST A WHILE, GLUE SPINNER PARTS TO CARDBOARD BEFORE CUTTING OUT





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

WATER + CARBON DIOXIDE + LIGHT → OXYGEN + SUGAR + WATER

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

The reverse side of the leaf will have an envelope that says "OUT."

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

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. He runs back and tags 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 the 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. 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 (can substitute glue stick if it is high quality, not "school" quality)
- 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 use 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.

5) 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.

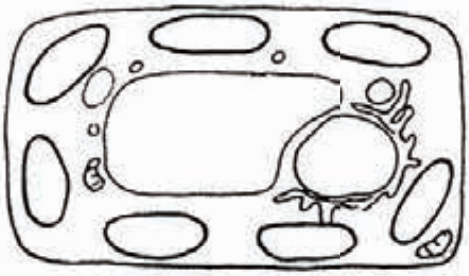
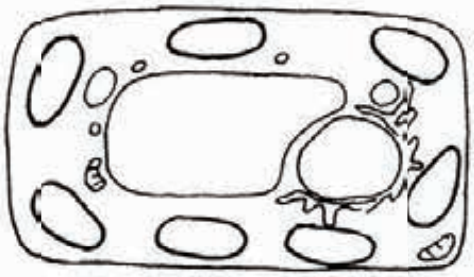
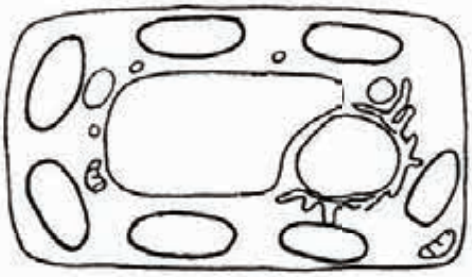
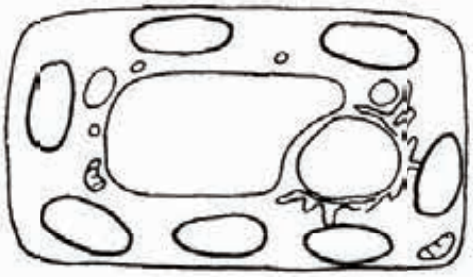
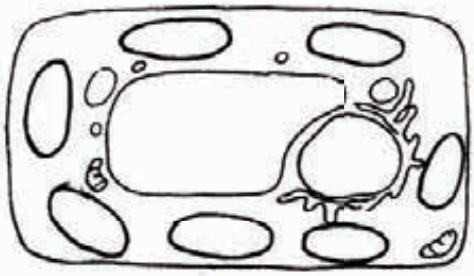
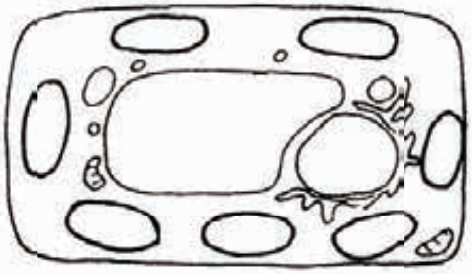
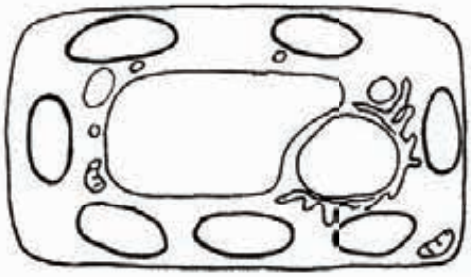
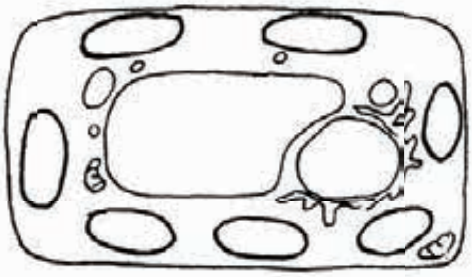
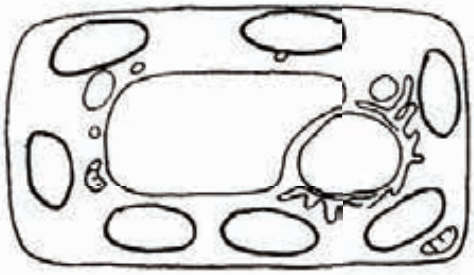
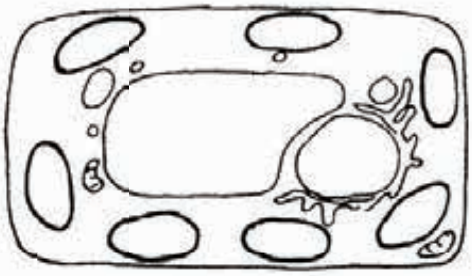
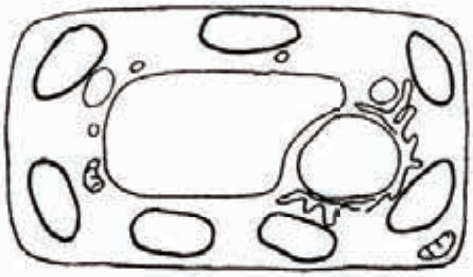
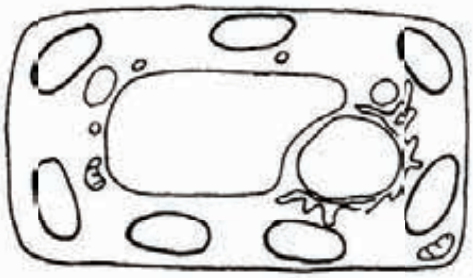
6) EXTRA READING MATERIAL ABOUT PHOTOSYNTHESIS

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.

7) SIMPLE COMPUTER ANIMATION OF CALVIN CYCLE

This is a very short overview of the Calvin Cycle with a simple quiz at the end where you drag and drop the correct terms into the boxes. Good review after reading level 2 of the text.

http://sjbscience.weebly.com/uploads/2/7/5/3/2753626/calvin_benson_v2.swf

1		7	
2		8	
3		9	
4		10	
5		11	
6		12	

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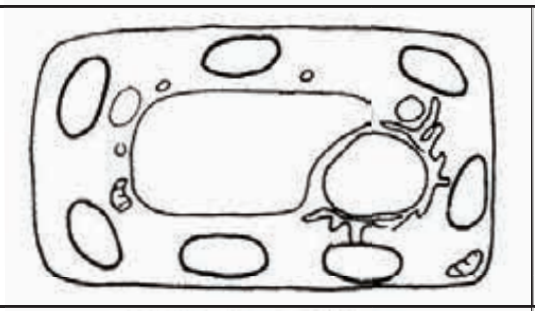
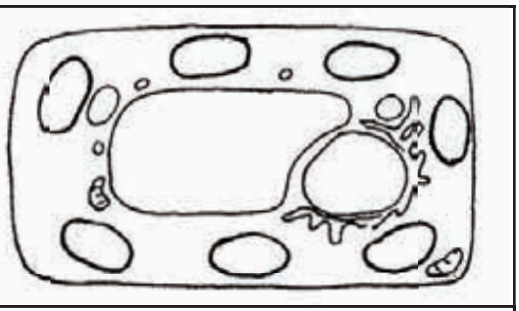
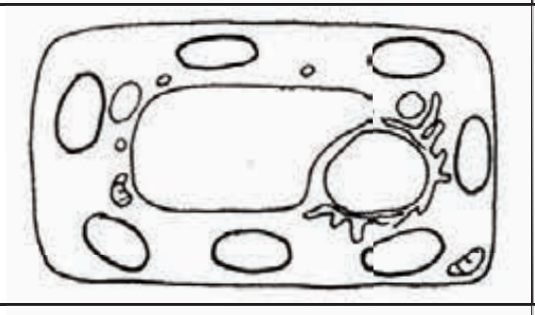
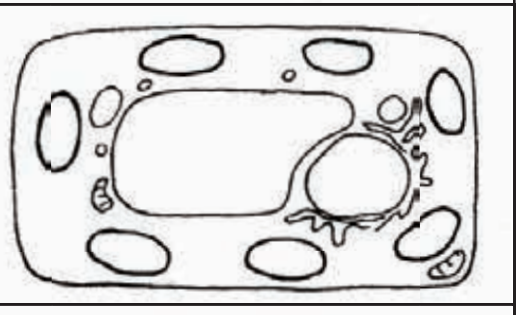
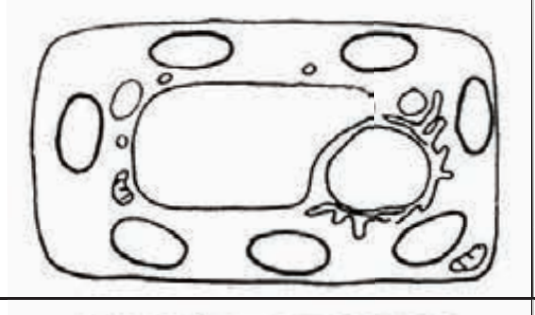
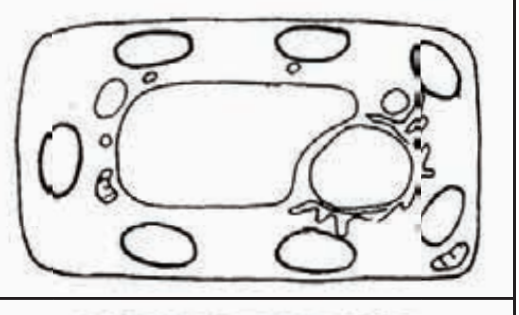
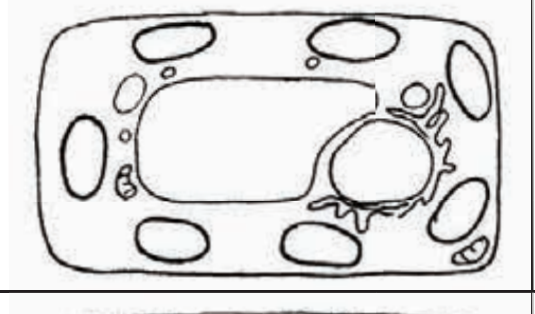
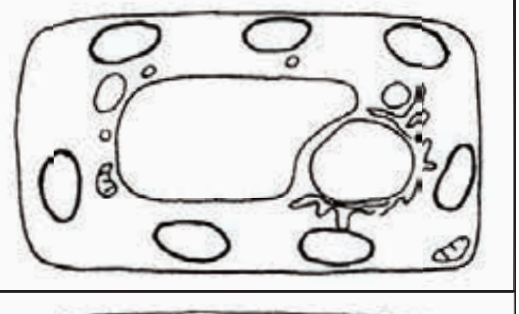
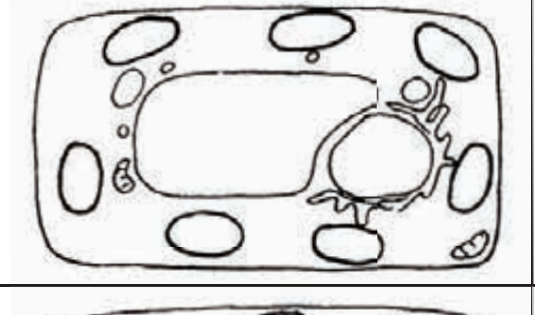
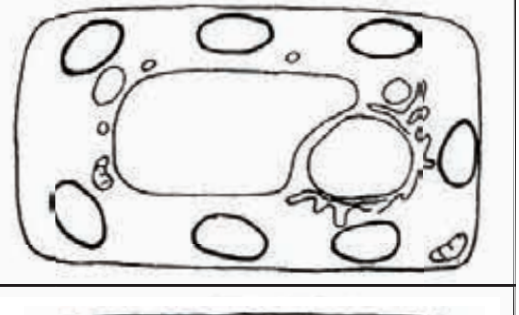
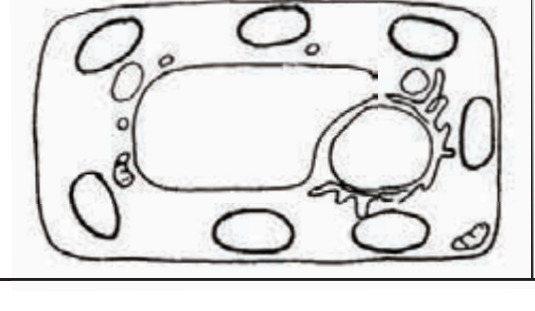
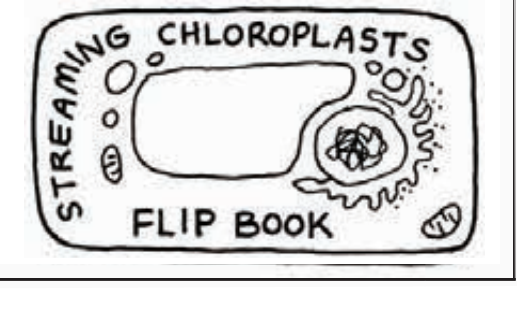
13		19	
14		20	
15		21	
16		22	
17		23	
18			

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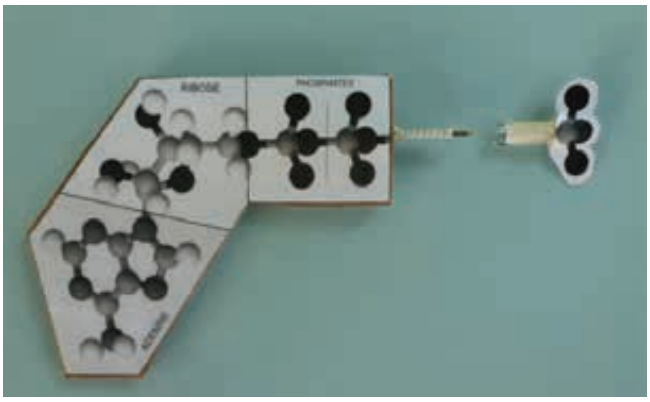
7) ATP "POP GUN"



Here is a fun way to help your students remember what ATP is and what it does. This toy has a lot of science packed into it! The gun is labeled showing the chemical structure: adenine (the same adenine found in the rungs of DNA), ribose (very similar to the ribose sugar found in the "backbone" of DNA), and three phosphate groups. The third phosphate acts as the "bullet" and pops off, just like in real ATP. So the gun itself, without the bullet, is ADP.

The springs that launch the phosphate bullet represent the repelling forces between the oxygen molecules on the phosphates. The oxygens have a negative charge. According to the basic rules of chemistry, "like" charges repel and opposites attract. So the oxygens don't want to be next to each other. This repelling force is overcome, however, by the strength of the chemical bond, represented by the metal clip that holds the phosphate bullet in place until released. There is a fine balance between holding and repelling.

You will need:

- A copy of the following pattern page (there are two guns per page, so you'll only have to make one copy per two students)
- A piece of corrugated cardboard for each gun (the piece must be large enough so that you can orient the corrugate line to go parallel to the barrel of the gun)
- Optional: a sharp craft knife (a kitchen knife with serrated edge) for cutting the cardboard
- Two ball point pens per gun (the kind of pen that has a clicking button at the top, not the kind that has a removable cap)
- Three paper clips per gun
- White glue (a glue stick if you are using regular paper—glue stick will wrinkle the paper less)
- Needle nose pliers (pliers with a very pointed end)
- Scissors
- Tape: Masking tape is best, duct tape is a little thick but would work, clear tape is third choice because it will be hard to glue patterns on top of it. (If all you have available is clear tape, don't let this stop you from doing the project.)
- Possibly helpful: A tube of all-purpose craft glue (the smelly stuff that comes in a tube and promises to stick to plastic, wood, paper and metal) This is just in case you have trouble getting the springs to stay in.

Construction:

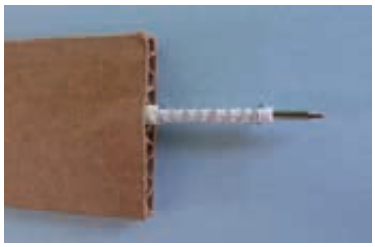
1) Copy the pattern page into heavy card stock if possible. (If you can't get card stock, you can make do with regular paper.) If you want your students to label the atoms, there is a labeling guide on page 222.

2) Cut out the gun patterns. Cut off the third phosphate on the end; it will be turned into the bullet. You can simply cut a rectangle around this phosphate, or you can trim around the shape more closely. Trimming can be done as the last step. For right now, set these pieces aside.

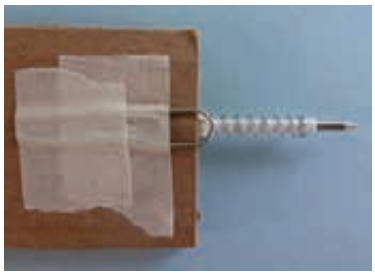
3) Take one of the gun patterns you have cut out and place it on top of the corrugated cardboard. You must be very careful to place the pattern so that the corrugate lines are going parallel to the barrel. Cut out the cardboard shape. Do not glue the gun pattern on top yet. This will happen in a later step.

4) Take apart the pens. Salvage both springs and one of the ink tubes. Take one spring and put it on the end of the ink tube and secure in place with a tiny strip of tape.

5) Slide the ink tube into one of the slots in the barrel section of the corrugated cardboard gun. Make sure it is secure. If it wants to slip back out, put a dab of all purpose glue on the tube before sliding it back in. (If you have no glue available, you can secure it at the end with a thin strip of tape. Tear the tape lengthwise so that it is only a third of its original width.)

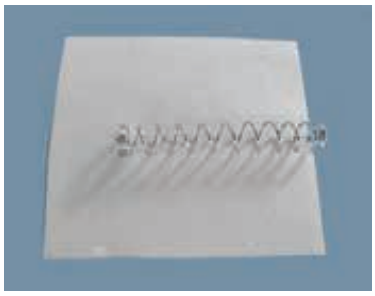


6) Take two of the paper clips and bend them just slightly on one end. Tape the paper clips right at the end of the barrel so that the end of the clip sticks out just a bit. You should be able to squeeze the clips together a few millimeters and have them bounce back to their original position. This will be the release mechanisms that fires the phosphate bullet.



7) Now you can glue the pattern pieces to the sides of the cardboard. You have now finished the ADP section of the project. Remember, ATP without that third phosphate is ADP. See the picture on the previous page for an image of the completed ADP gun.

8) Cut a piece of regular paper 3 centimeters square (1 1/4 inches). You might be able to use a scrap of your card stock, but since this square will be rolled up, the card stock might be too thick. Set the spring on the edge of the paper, with one edge of the spring flush with the end of the paper, and roll the paper around the spring. The tricky part of this step is to make the roll snug but not so tight that the spring can't move inside the tube. The spring will need to be able to contract and spring back inside the tube. Once you get it wound just right, secure the roll with tape.



9) Pinch the end of the tube that has a bit of extra space. Secure with tape.

10) Take the remaining paper clip and snip off the small inner portion so that you are left with a long U shape. Make tiny bends in the ends that form angles of about 45 degrees. It is important to make these bends as small as possible. If they are too long you will have trouble releasing the bullet. You may have to make small adjustments to these hooks later on if your gun will not fire properly. (Some troubleshooting is to be expected!)

11) Tape this U-shape onto the paper tube so that the ends stick out over the open end of the tube. Secure with tape.

12) Glue the phosphate pieces back to back at the end of the bullet tube. Don't use too much glue. If there is glue seeping out, you've used too much. Press and hold the phosphates for at least about twenty seconds. White glue usually sticks well enough after twenty seconds that you can let go.

13) Now you are ready to try out the gun. You will probably have to make small adjustments to get it to fire perfectly every time. (But it can be done, and they often will shoot the bullet a distance of several meters (over 10 feet).

How to fire the gun:

Slide the bullet onto the end of the ink tube. The two springs will compress (representing the repelling forces of the negatively charged atoms that do not want to be next to each other). Pinch the two clips at the end of the barrel so that they get closer together. This should give you enough space to be able to slide the hooks over the clips. Slowly release tension on the end clips. The tension of the end clips pushing outward should keep the bullet hooks in place. When you let go, the bullet should stay in place.

To fire the gun, simply press the barrel's end clips together. The bullet should shoot quite a distance.

An extra feature you can add:

In a real ATP molecule, the release of the third phosphate is caused by a water molecule. It pops apart into an H and an OH. (These split-up pieces are called ions.) The H has a positive charge and is written like this: (H^+). The OH has a negative charge and is written like this: (OH^-). These two pieces can "plug" the electrically awkward "gaps" left behind by the third phosphate when it goes flying off. (After all, electrical bonds are broken when an atom leaves a molecule. Often there are some unhappy atoms or electrons left behind!)

You can make a hands-on way to remember how a real ATP fires its phosphate. Cut two paper circles and label one (H^+) and the other (OH^-). Tape one circle to your thumbnail and one to the nail of your index finger. (Or you can take a permanent marker and draw these letters on the fingernails. Permanent marker scrubs off fingernails fairly easily.)

With your thumb and index finger labeled correctly, you can scientifically fire your ATP gun using a water molecule. When water splits something apart it's called ***hydrolysis***. "Hydro" means "water," and "lysis" means "split." (Actually, to be perfectly accurate, your thumbnail (with the OH on it) would have to go flying off with the phosphate bullet!) If the students simply remember that water is involved in splitting off the third phosphate, that will amaze all their future teachers until they get to AP biology or college biochem.

TROUBLESHOOTING TIPS:

1) If your bullet will not stay clipped, you need to check two things. First, make sure that the hooks on the end of the bullet are bent in far enough. They don't need to be completely at a right angle, but they need to be at enough of an angle that they catch onto the ends of the paper clips adequately. Second, you may need to adjust how much the end paper clips are bent. They need to be far enough apart that they can apply adequate outward pressure on the bullet clips.

2) If your bullet won't release and fly, check to see if the clips on the end are spread too far apart. You might have too much tension on the bullet hooks. Also, your bullet hooks might be too long. You may need to clip them a bit.

3) If your bullet doesn't go very far, check to see if both springs are operating as they should. If only one spring is providing impetus, the bullet will only go half as far as it should. Check to see if the spring inside the bullet is stuck. This spring should be able to contract and release even though it is inside the paper tube.

NOTE: Tips 1 and 2 are demonstrated on a video posted at www.YouTube.com/TheBasementWorkshop, Botany playlist or Project Demo playlist.

ONE FINAL SCIENCE NOTE:

To state the obvious, your ATP gun is not very powerful. It launches a tiny, lightweight paper bullet. It might be able to knock down a small paper target but it certainly isn't going to cause any damage to anything. Real ATPs are a bit like this, too. They release only a miniscule amount of energy. Your body must make and use trillions of ATPs every day. If you could collect all the ATPs your body makes and uses in one day, you'd find that your bucket full of ATPs would weigh almost as much as you do. That's millions of ATPs per second.

The fact that ATPs release only a small amount of energy is not a bad thing. If they released a lot of energy they would damage cells. ATPs are the perfect size for cellular tasks.

PHOSPHATES
RIBOSE
PHOSPHATES
RIBOSE
ADENINE
ADENINE

PHOSPHATES
RIBOSE
PHOSPHATES
RIBOSE
ADENINE
ADENINE

8) ANOTHER GAME ABOUT PHOTOSYNTHESIS: "C3"

This game correlates with the photosynthesis information in level 2, so if you are only doing level 1 you'll have to skip this activity. (You can always come back to it at some point in the future!)

You will need:

- Copies of the following pattern pages (see options below)
- Glue stick and/or clear tape (wide packaging tape if possible)
- Scissors
- A number cube (dice)
- A large plastic bag (such as a gallon-size ziplock) for storing all the pieces (and maybe some small bags, too, so you can keep all the colored pieces sorted)

Options for making the game board:

There are several ways you can make the game board.

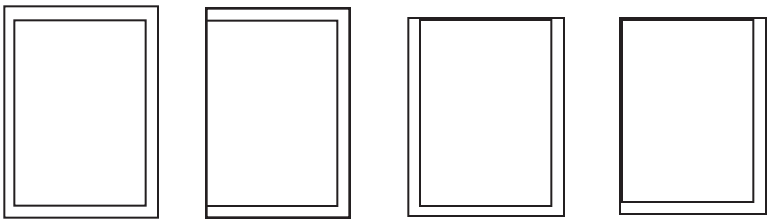
1) The first option is to use the black and white pattern pages (following) and have your students add color. Copy the pages onto heavy card stock if you want the board to be durable. The circles in photosystems 1 and 2 should be mostly green (chlorophyll) but should also include a few yellow or orange (or even red) circles to represent other pigment molecules. (NOTE: Biology books usually use red to represent phospholipid heads. There is no particular reason for this. You may make your phospholipid circles a different color if you wish.)

2) The second option is to use the color pages provided at the back of this booklet. You can cut them out of the book and assemble them.

3) The third option is to acquire a digital copy of the game by going to www.ellenjmchenry.com and clicking on FREE DOWNLOADS, then on PLANTS, then on "Printable pages for *Botany in 8 Lessons*." This will give you a digital copy of the pattern pages. You can print these pages using your own computer printer, or you can get a print shop to print them for you.

PUTTING THE GAME BOARD TOGETHER:

For best assembly results, trim off each page as recommended below. Then overlap the pages as suggested. You'll end up with a white border all around the edge of the game (though the border is not necessary and can be trimmed off).



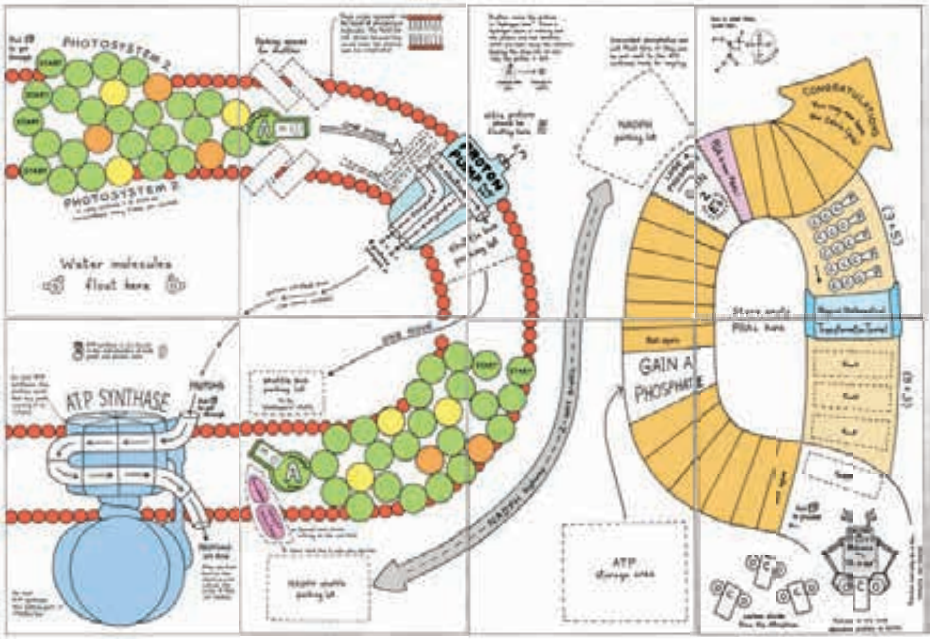
Don't trim page 1 at all. | Trim pages 2, 3 and 4 like this. | Trim page 5 like this. | Trim pages 6, 7, and 8 like this.

Apply some glue stick onto the right hand edge of page 1. Set page 2 onto the glued strip so that the patterns line up. Apply glue to the right hand strip of page 2, then set page 3 onto it, lining it up. Do page 4 the same way.

Then apply glue stick to the bottom of page 1. Set page 5 onto it so it lines up. Then apply glue to the bottom of page 2 and the right hand side of page 5. Set page 6 on. Continue like this with pages 7 and 8.

Once you have everything tacked together with glue stick, you should run some clear tape down the seams on the back of the board. Packaging tape is ideal because it is extra wide.

page 1 page 2 page 3 page 4



page 5 page 6 page 7 page 8

Cut slits along the sides of the ATP synthase. The ATP molecules will slide into the slit just far enough to hide the third phosphate.

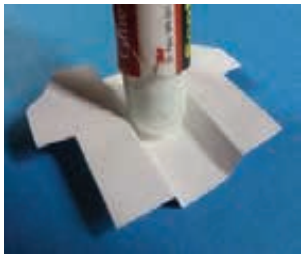
Assembly of tokens:

Make a copy of the token page for each player. If possible, print each player's page onto a different color. If you want the tokens to be durable (re-usable) print them onto card stock. (Most computer printers will accept card stock.) If you have only white paper, just tell each player to add color (or a design) to all their tokens so they can identify them.

Make one copy of the WATER MOLECULES page per game (not per player). You can print on white card stock, or you can choose a color (a pastel color, perhaps) that does not match any of the players' colors.

Assembly of shuttles, truck, PGA(L) and RuBP:

This is the basic folding method for all tokens.



You can apply some glue stick to the inside of the bottom.

All tokens are sized so that a piece of clear tape will fit around the ends.

When finished, the tokens should be like this.

Assembly of photon:

Apply glue stick to inside of token. Press and hold so that it looks like the picture on the the right.

Assembly of ATP:

Apply glue stick to inside, between the A circles.

Fold a piece of tape all the way around the end of the last P (as shown), to form a “pocket” that will hold the individual P.

Slip the individual P into the “pocket.”

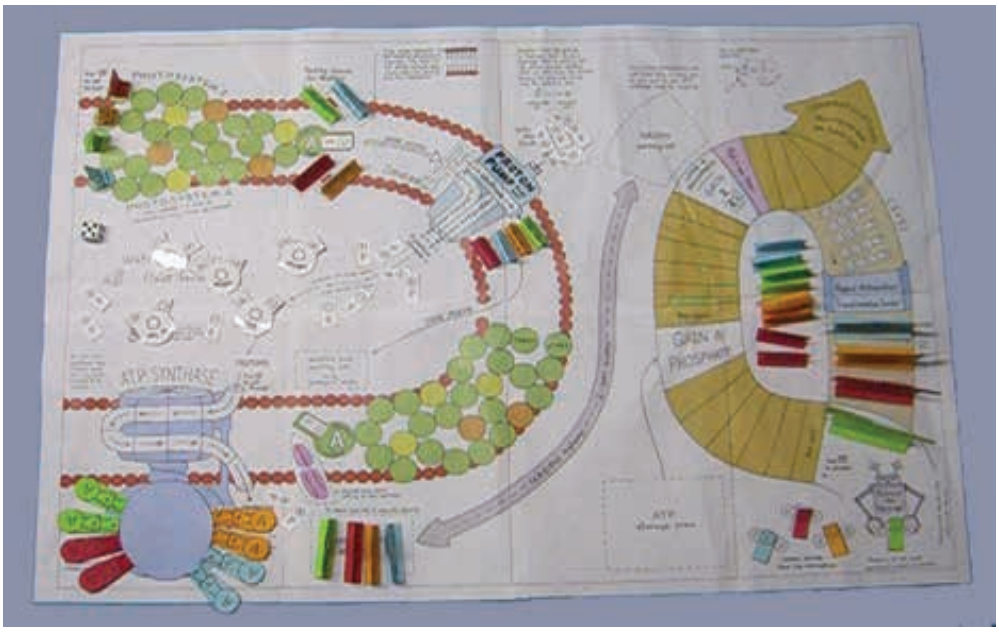
Assembly of water molecules:

Fold the paper molecule in half and put a strip of tape across the center. Fold tape over on both sides. Put pairs of electrons and protons into the oxygen circle. (Remember, a hydrogen atom is nothing more than one electron and one proton.)

How to set up the board:

1) The photon tokens are placed on the start circles of photosystem 2.
2) Place an electron on the chlorophyll A in photosystem 2.
3) The assembled water molecules are placed inside the thylakoid, under photosystem 2.
4) Protons are placed around the outside of the proton pump. (2 for each player)
5) The plastoquinone Qb shuttles are placed in their “parking spaces” outside of photosystem 2.
6) The plastocyanin shuttles are placed in the parking area beneath the proton pump.
7) The assembled ATPs are inserted into the slots in the bottom of the ATP synthase machine so that the third phosphate is hidden. (This makes them look like ADPs that are waiting to be turned into ATPs.)
8) The NADPH trucks are placed in the parking area underneath photosystem 1.
9) The RuBPs (with the 3-carbon and 2-carbon molecules in them) are placed on the indicated rectangles in the Calvin Cycle.
10) The PGA(L)s start out empty and are placed inside the Calvin Cycle circle.
11) Individual carbons are placed on the C rectangles in the carbon dioxide molecules near Rubisco. It does not matter whose carbons go on which rectangles. Just choose any rectangle.

NOTE: There is a video posted on the Botany playlist showing how to set up and play this game. If you have trouble following these written directions, the video might be a big help.



How to play:

Stage 1: Going through photosystem 2

Put your photon token on one of the start circles. Roll the number cube (dice) to get through the photosystem. Only one photon per circle. You can only move to a circle that is touching the circle you are on. In other words, you have to follow a path of touching circles. (Nothing special happens when you land on an orange or yellow circle. Treat them the same as green ones.)

You can't land on a circle that already has a photon sitting on it; you'll have to go around it if you can. There might be times when you are temporarily blocked and can't move. But don't worry, everyone will get through eventually! When you get to the end, you land on chlorophyll A.

The reaction center consists of two chlorophyll A molecules that are in close association with each other. All the gathered energy is focused down to these two molecules, which vibrate in such a way that an electron is released. When you land on chlorophyll A, you release the electron that is sitting there. You can pick up this electron card and move it to your shuttle. Then you will need to replace the electron you took. You take apart a water molecule and use one of its electrons. If there is already a water molecule torn apart from someone else's move, you can use that remaining electron.

After moving the electron to the shuttle, you will need to move your photon back to a start circle and repeat the whole process again, so that your shuttle contains two electrons.

Stage 2: Moving the shuttle to the proton pump

You don't need the number cube for this move. On this turn, the first thing you do is put two protons into the shuttle if you have not done so already. Then you simply move your shuttle across the arrow to the proton pump. The electrons will go through the pump and end up in the smaller shuttle on the other side. The protons from the shuttle, plus two protons from outside the pump, will go through the pump and into the lumen (inside) of the thylakoid. All of this happens as part of this turn. At the end of this turn, your large shuttle will be empty and will be back at its original starting place, 4 protons will have been pumped into the lumen, and your two electrons will be in the small shuttle.

Stage 3: Generating 2 ATPs and getting your shuttle over to photosystem 1

To generate ATPs, you roll the number cube to move protons along the track that goes through the ATP synthase machine. When a proton comes out the other side, an ATP can be removed from the bottom and moved over to the ATP parking lot near the Calvin Cycle.

One move is required to get your small shuttle down to the waiting area above the chlorophyll A of photosystem 1. Upon arrival, take the two "tired" electrons out of the shuttle and lay them somewhere inside the parking lot. They will wait there until they get a chance to go over to chlorophyll A and get recharged.

Stage 4: Loading your NADPH truck

To load your NADPH truck, you will need to move your photon through photosystem 1. Put your photon on one of the two start circles, and transfer one of the "tired" electrons from the shuttle onto chlorophyll A. (If both start circles are occupied by other players' photons, you'll have to wait a turn. However, chances are good that one of them will be open.) The rules from photosystem 2 apply to photosystem 1. One photon per circle, etc.

When your photon lands on chlorophyll A, move the electron card to the carriers (ferredoxin and NADP reductase). Then move your other "tired" electron to chlorophyll A. Remember, electrons are non-specific and don't actually belong to any player, so if another player lands on chlorophyll A before you do, they can take the electron you put there and replace it with one from their shuttle. (In real life, the action of photosystem 1 is so fast that it's more like a blur of electrons flying around.)

On your next move, you may take the electron off the carriers and put it into the truck.

Now you must put your photon through the photosystem again to get another electron. Once you have two electrons, pick up a proton and put it into the truck also.

On your next move, drive your truck (containing two electrons and one proton) up to the NADPH parking lot at the top of the Calvin Cycle.

Stage 5: Fixing carbon

Take the 3-carbon and 2-carbon molecules out of your RuBP and place each one in a PGA token. Pick up the single carbon atom (from the carbon dioxide molecule) and put it into the tray with the 2-carbon molecule so that the tray now has 3 carbons. You now have two 3-carbon PGAs.

Stage 6: Going through the Calvin Cycle

Choose one of your PGAs and roll the number cube to proceed around the oval. When you get to the GAIN A PHOSPHATE space, stop there and put a phosphate from an ATP into the PGA token. (Just stick it in—it won't match the other one sticking out to the side, but that's okay.)

When you get to the GAIN 2 E's space, put the two electrons and also the proton from the NADPH truck into the PGA token. Remove the phosphate (yes, you just put it in, but take it out now) and set it anywhere. The phosphate can float right there near the parking lot or it can be put down next to the synthase machine. It can go anywhere because in reality, phosphate molecules are floating around all over the place inside cells.

After losing the phosphate and gaining the electrons and proton, the PGA is now officially PGAL. Use the number cube to move it out of the cycle. It is now free to be used by the cell to make glucose or for other purposes.

NOTE: If you have limited time, you can choose to end the game here, with just one PGAL made. If you have enough time, require that 2 PGALs be made, so that a glucose molecule can be manufactured. (Glucose is a 6-carbon sugar, so two 3-carbon PGALs are needed.)

Stage 7: Making a second PGAL

Move the empty NADPH truck back down the road to the parking lot under photosystem 1. You will need two more electrons and another proton. Where do you get super-charged electrons? That's right—you'll have to go back to the beginning of the process and move photons of light through the photosystems.

However, on this second time around you can speed things up by DOUBLING THE VALUE OF THE NUMBER CUBE. In other words, if you roll a 3, you can turn it into a 6, and a 6 becomes a 12. Not bad!

You will probably already have a second ATP waiting. If not, you'll need to make another one.

The game is over as soon as one player gets his second PGAL made.

NOTES THAT CAN BE READ ALOUD TO THE PLAYERS BEFORE THEY BEGIN THE GAME:

This game is about the most common kind of photosynthesis, C3. Two other types of photosynthesis, C4 and CAM, are used by plants that need to survive dry weather conditions. (Some microscopic organisms such as bacteria and algae also do photosynthesis, and they have their own variations of it.) C3 photosynthesis is the most common type of photosynthesis and is therefore the one that students are expected to learn the most about.

You'll notice that the numbering of the photosystems seems backwards. You go through photosystem 2 before you go through photosystem 1. This is because photosystem 1 was discovered first. When another photosystem was discovered, they had to call it photosystem 2. We've been stuck with those names ever since.

The circles in the photosystems represent pigment molecules. They are drawn as circles, omitting the hydrocarbon "tails," just to make the board look less confusing. Most of the circles represent chlorophyll, but a few are other pigments such as carotene and xanthophyll. The job of the other pigments is to respond to wavelengths of light that chlorophylls miss.

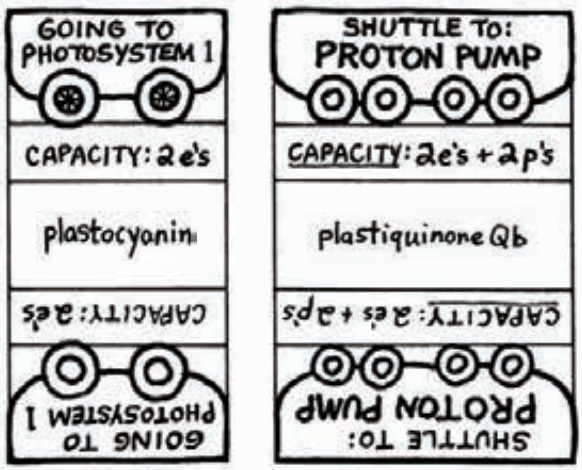
The reaction center consists of two chlorophyll molecules working together. (We've drawn the "tails" on these since we had to have a place to put the electron card.) Notice that the chlorophyll A molecule in photosystem 2 is "P680" and in photosystem 1 it is "P700." The numbers 680 and 700 are wavelengths of light in nanometers. These are the wavelengths at which you find peak absorption by these molecules.

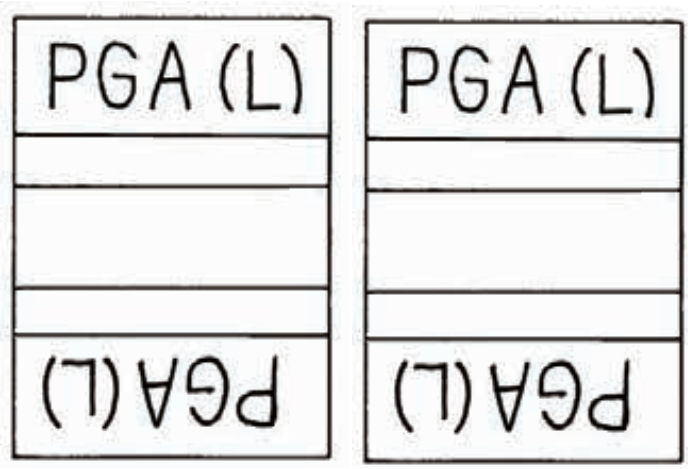
Photosystem 2 is not very stable and usually falls apart in a matter of seconds. The chloroplast must be constantly repairing the photosystem 2's and manufacturing new ones. Photosystem 1 is much more stable and can remain intact for a few days before needing to be repaired or replaced. (Solar energy researchers are learning how to harvest the electrical energy generated by photosystem 1. They've actually built organic solar panels out of living plant cells. It will be a long time until these biological panels are ready to be installed on our roofs, but the initial research looks very promising.)

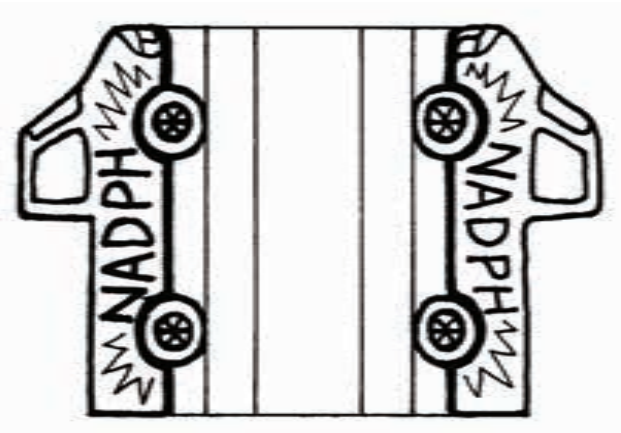
The game board has two parts—the light-dependent processes in the thylakoid membrane, and the light-independent Calvin Cycle. It is important to remember that although the Calvin Cycle looks circular here on the game board, it would not be an identifiable circle in a cell. You don't see the Calvin Cycle when you look at a cell. You see thylakoids, but you don't see Calvin Cycles. The circle just helps us to understand some very complex chemistry that is going on everywhere in the stroma of the chloroplast.

During the game, you will have some loose electrons, protons and phosphates floating around. In the game there will be just a few of these, but in reality, the chloroplast is full of loose molecules and ions. The large quantity of available molecules and ions assures that at least some of them will end up where they need to be. A proton doesn't know that it needs to go down and go through the ATP synthase machine. The inside of the thylakoid gets so full of protons that they eventually end up getting pushed through the synthase machine. There are so many phosphates and ADPs floating around in the vicinity of the synthase machine that some of them happen to get trapped in the turning machinery and are snapped back together. The phosphates and ADPs don't "know" to go over to the machine to recharge. It's more like they accidentally bump into it. Also, the NADPH shuttle doesn't "know" to go back down and pick up more electrons. There are so many of them drifting around that there is a constant supply available for recharging. However, the game board would be way too cluttered if we attempted realism and had oodles of shuttles and molecules floating around everywhere. It's better to keep the game board neat and tidy and just move a few pieces around the board.

One final note—as complicated as this game board might seem, it is highly simplified. We've said this before, but it bears repeating: *photosynthesis is extremely complicated*. There are biochemists who spend most of their lives studying just one part of this process. Some details about photosynthesis still remain a mystery!



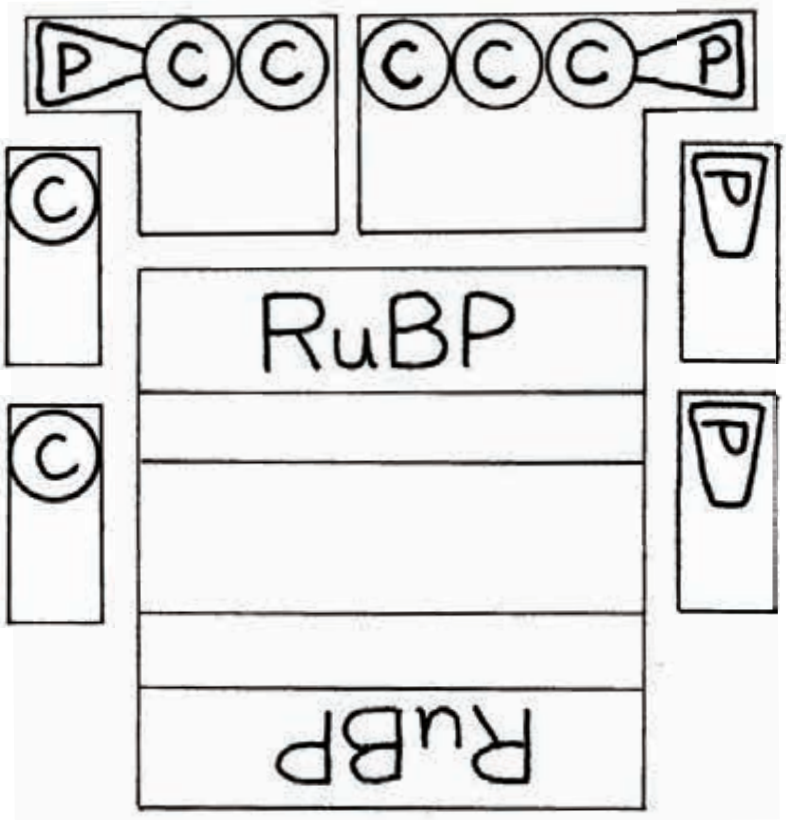


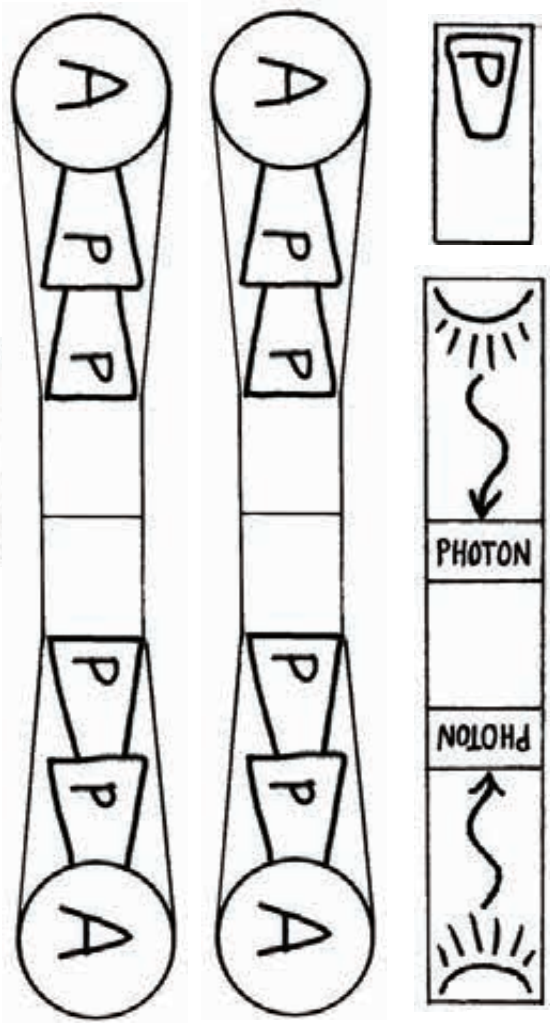


EACH PLAYER NEEDS A COPY OF THIS PAGE.

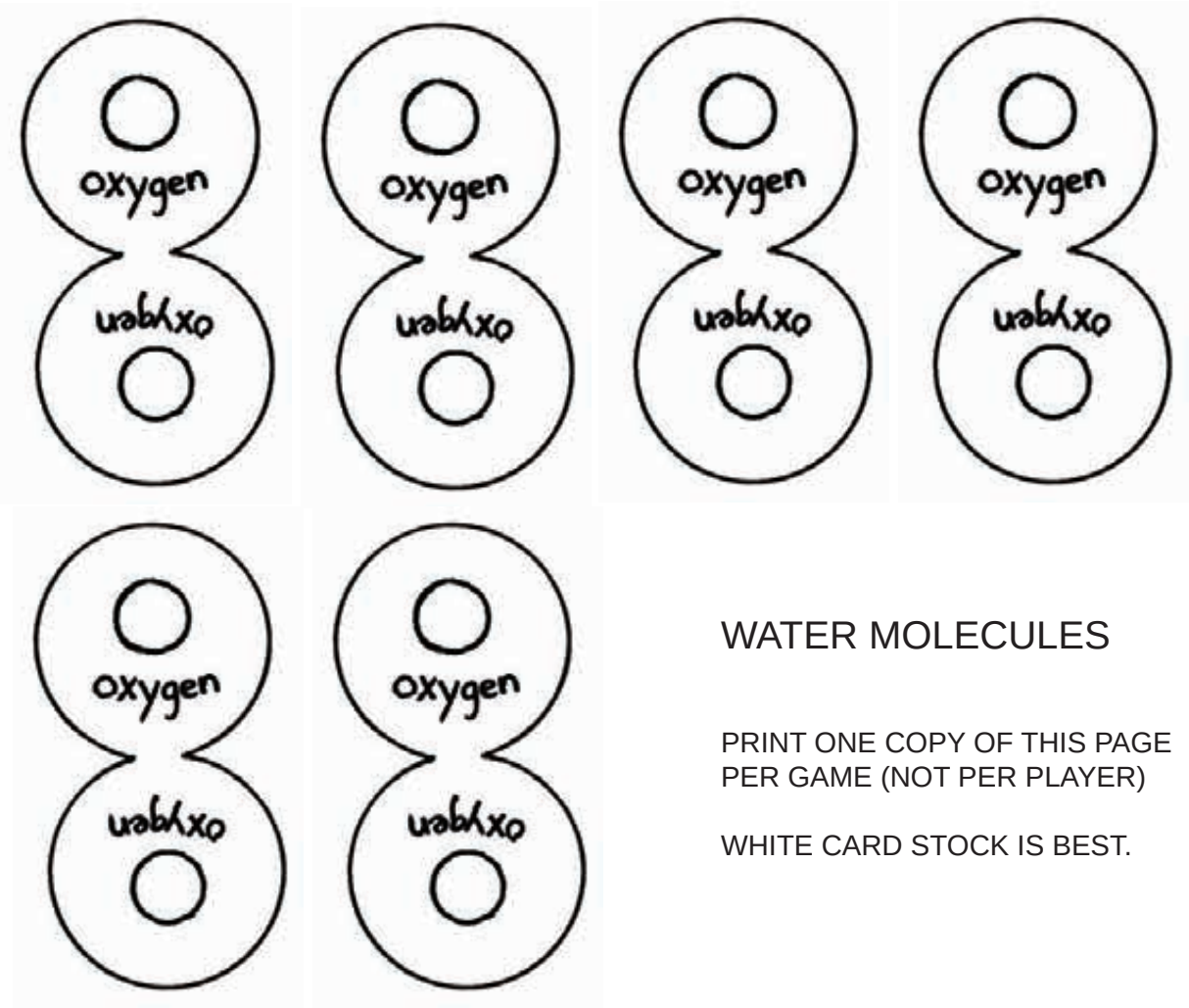
IF POSSIBLE, MAKE EACH COPY ON A DIFFERENT COLOR OF PAPER. IF COLORED PAPER IS NOT AN OPTION, EACH PLAYER SHOULD USE A MARKER OR COLORED PENCIL TO PERSONALIZE THEIR PIECES SO THAT THEY CAN IDENTIFY THEIR PIECES DURING THE GAME.

We've added an extra carbon and an extra phosphate. These are tiny pieces and can get lost easily, so you have an extra.





YOU NEED ONLY ONE COPY OF THIS PAGE PER GAME (up to 4 players)

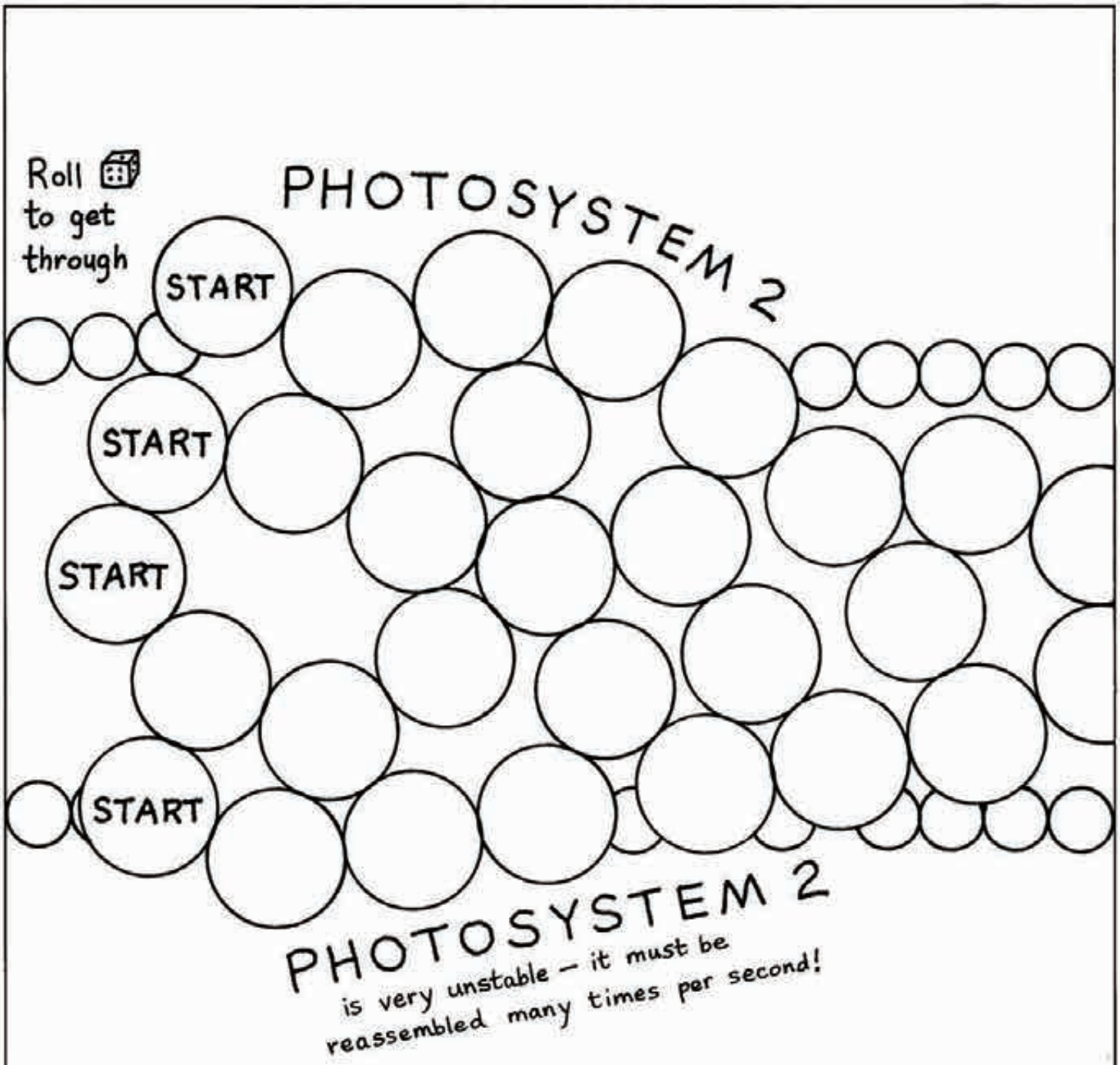


WATER MOLECULES

PRINT ONE COPY OF THIS PAGE PER GAME (NOT PER PLAYER)

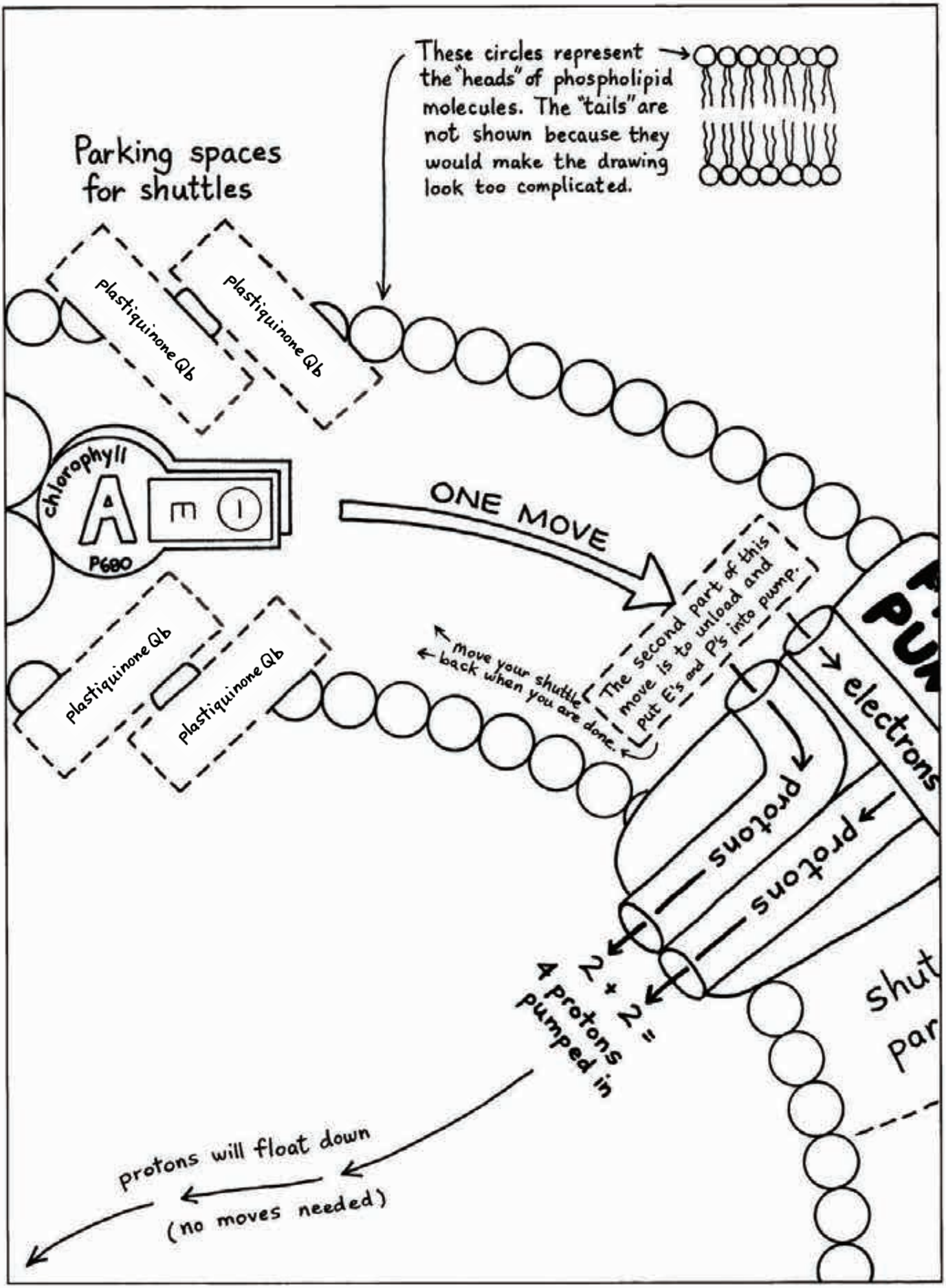
WHITE CARD STOCK IS BEST.

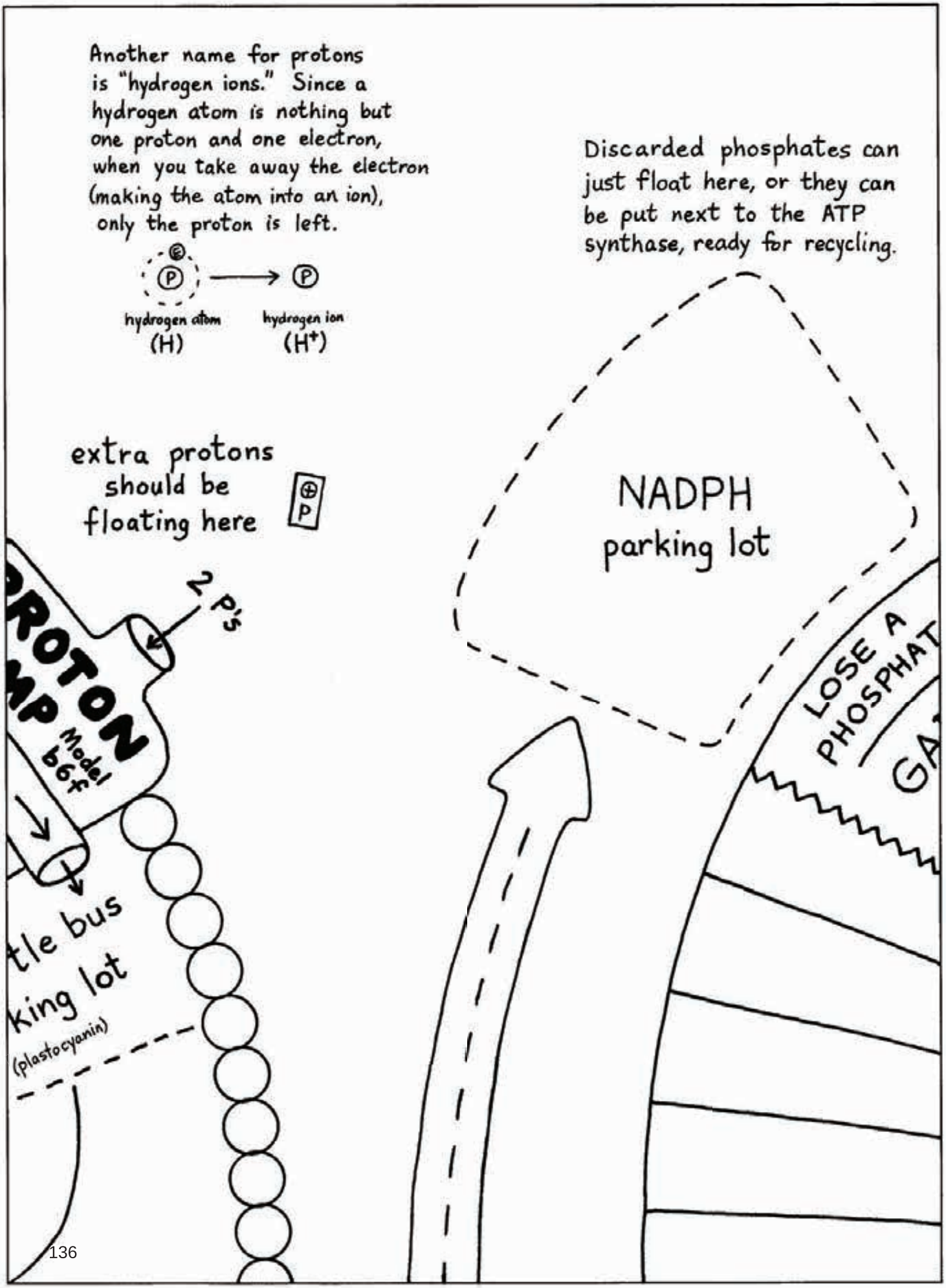
⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P
⊖ E	⊖ E	⊖ E	⊖ E	⊖ E	⊖ E	⊖ E	⊖ E	⊖ E	⊖ E	⊖ E	⊖ E
⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊕ P	⊖ E	⊖ E

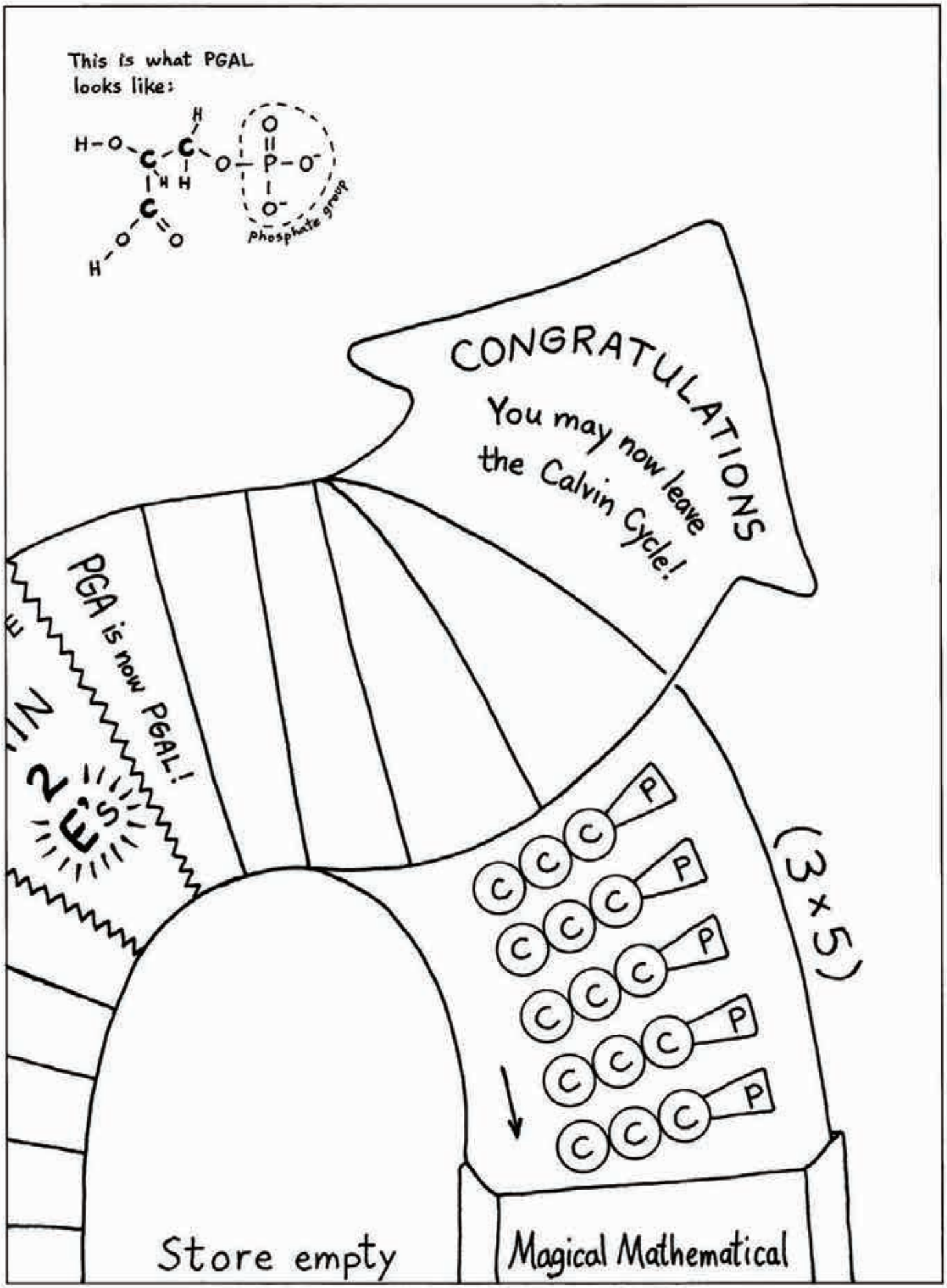


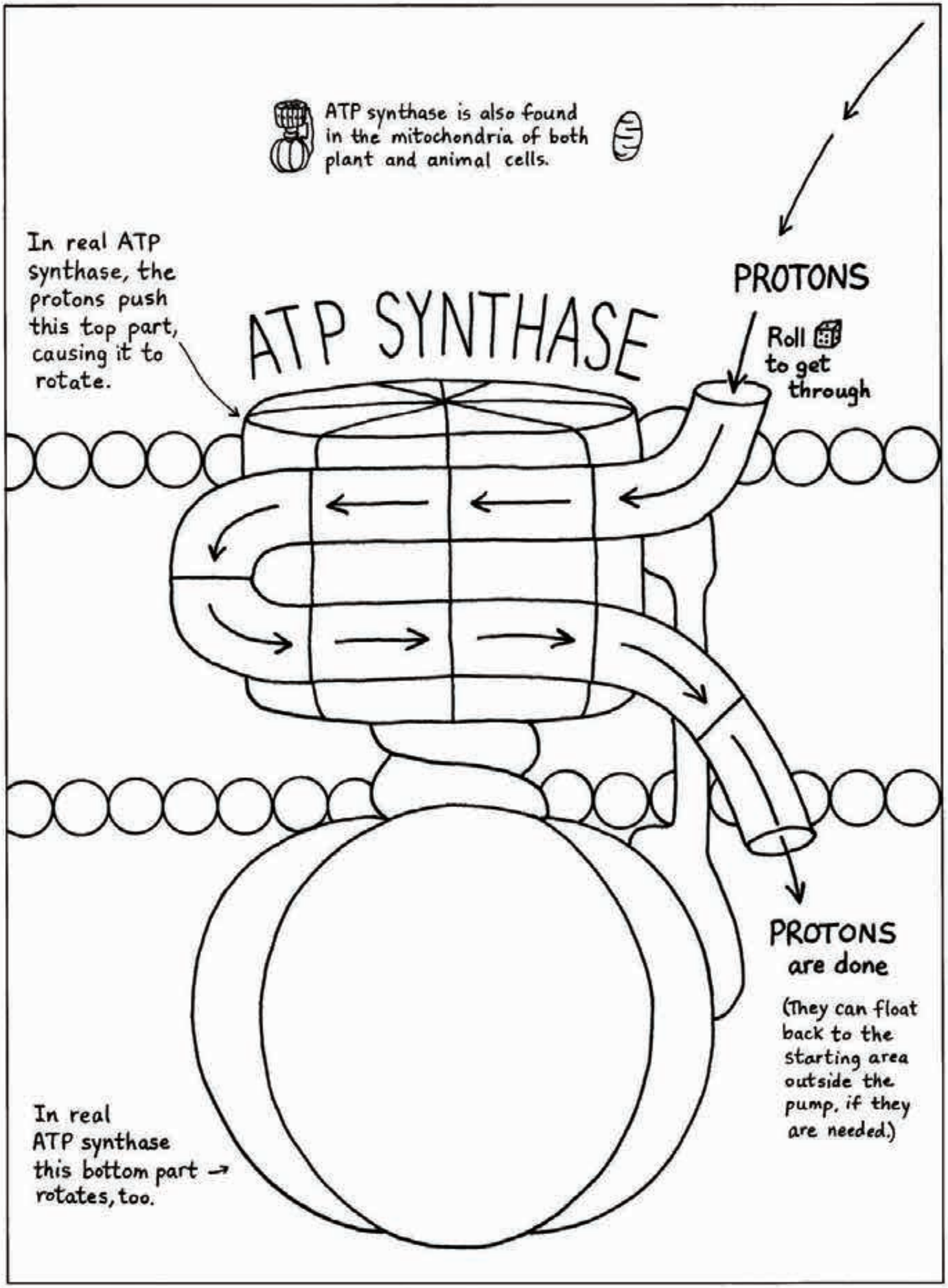
Water molecules

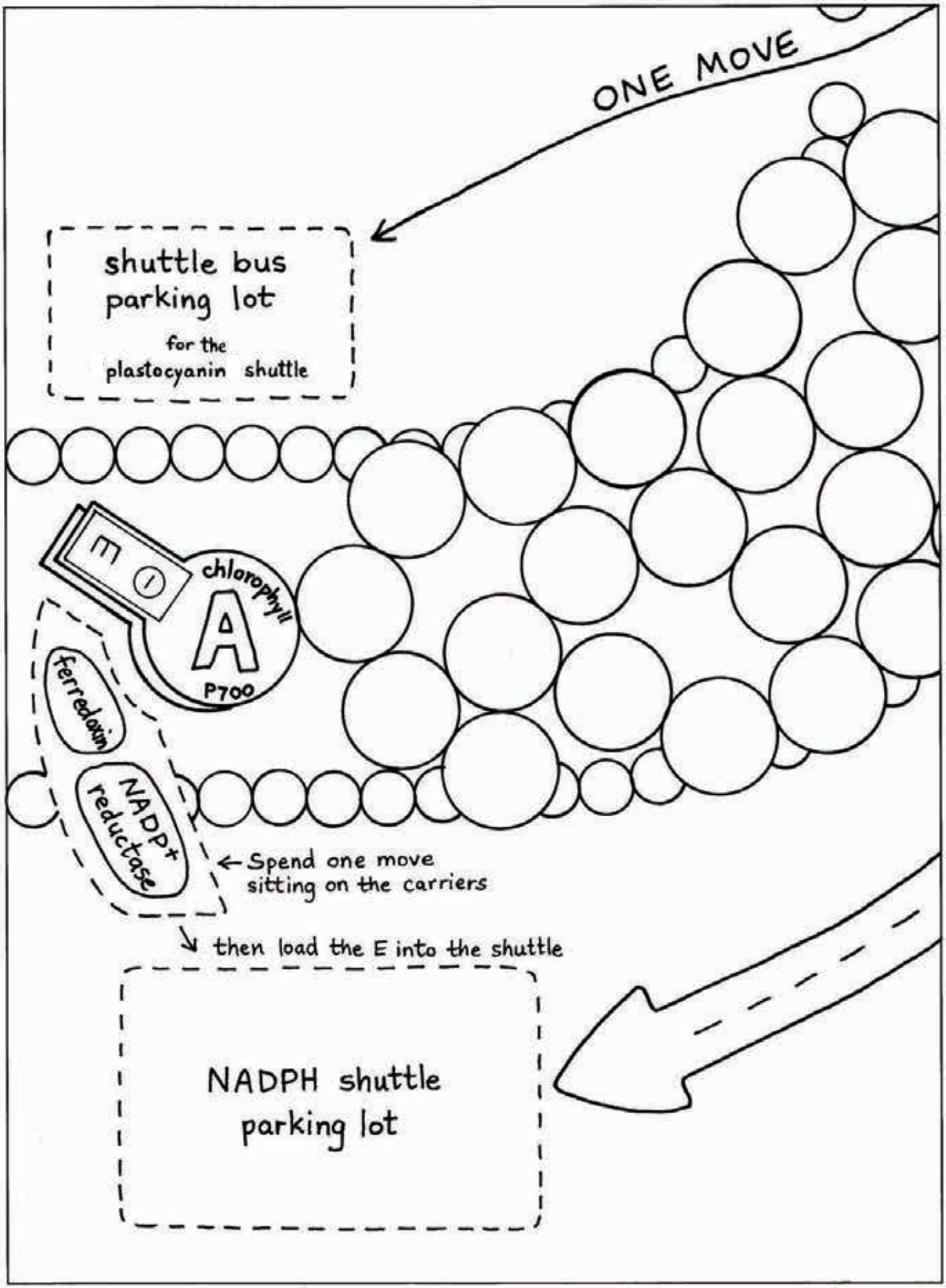
float here

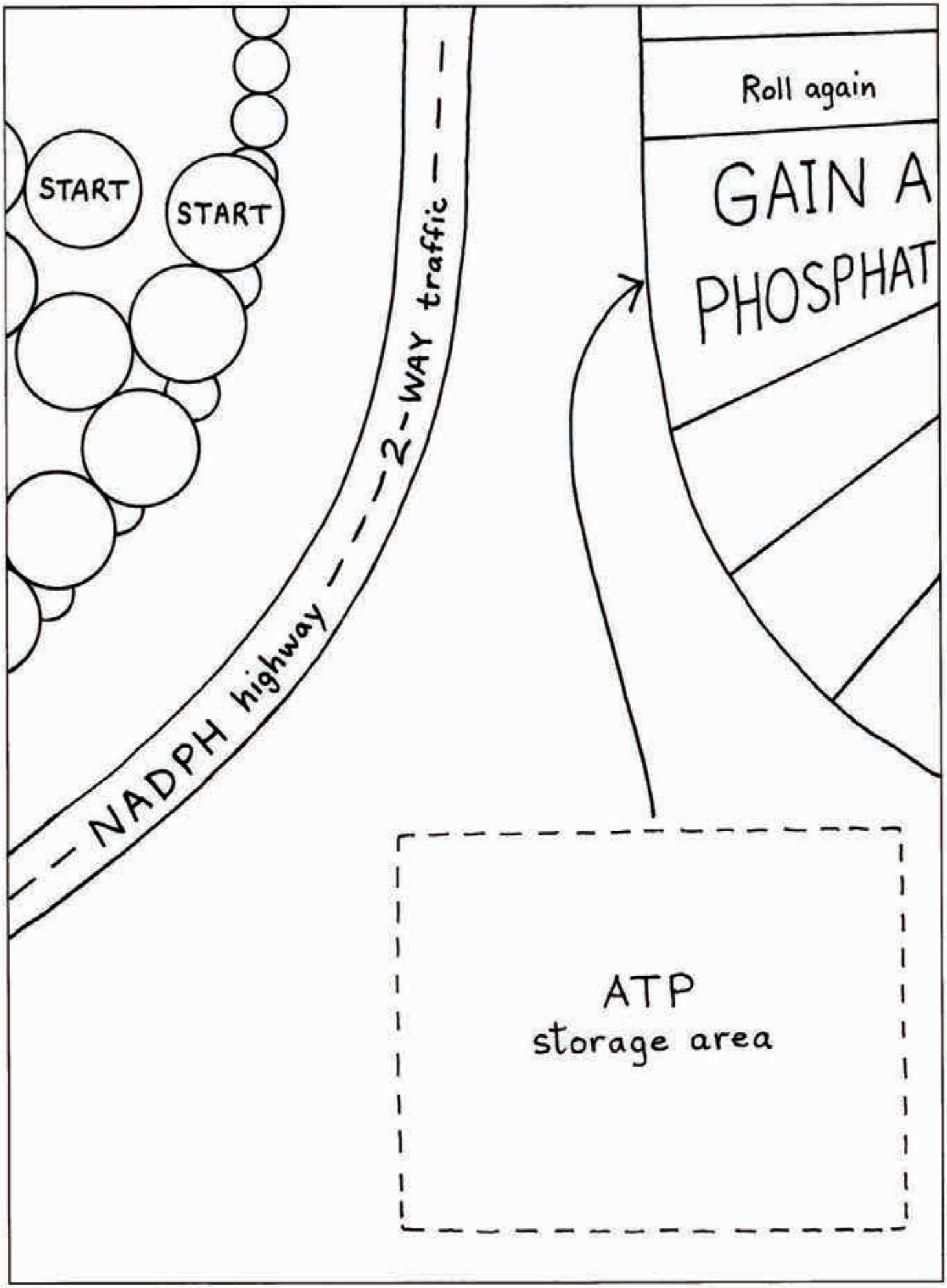

These circles represent the "heads" of phospholipid molecules. The "tails" are not shown because they would make the drawing look too complicated.
Parking spaces for shuttles
plastiquinone Qb
plastiquinone Qb
chlorophyll
A
m
1
P680
ONE MOVE
plastiquinone Qb
plastiquinone Qb
move your shuttle back when you are done.
The second part of this move is to unload and put E's and P's into pump.
electrons
protons
protons
2 + 2 =
4 protons pumped in
shut
par
protons will float down
(no moves needed)

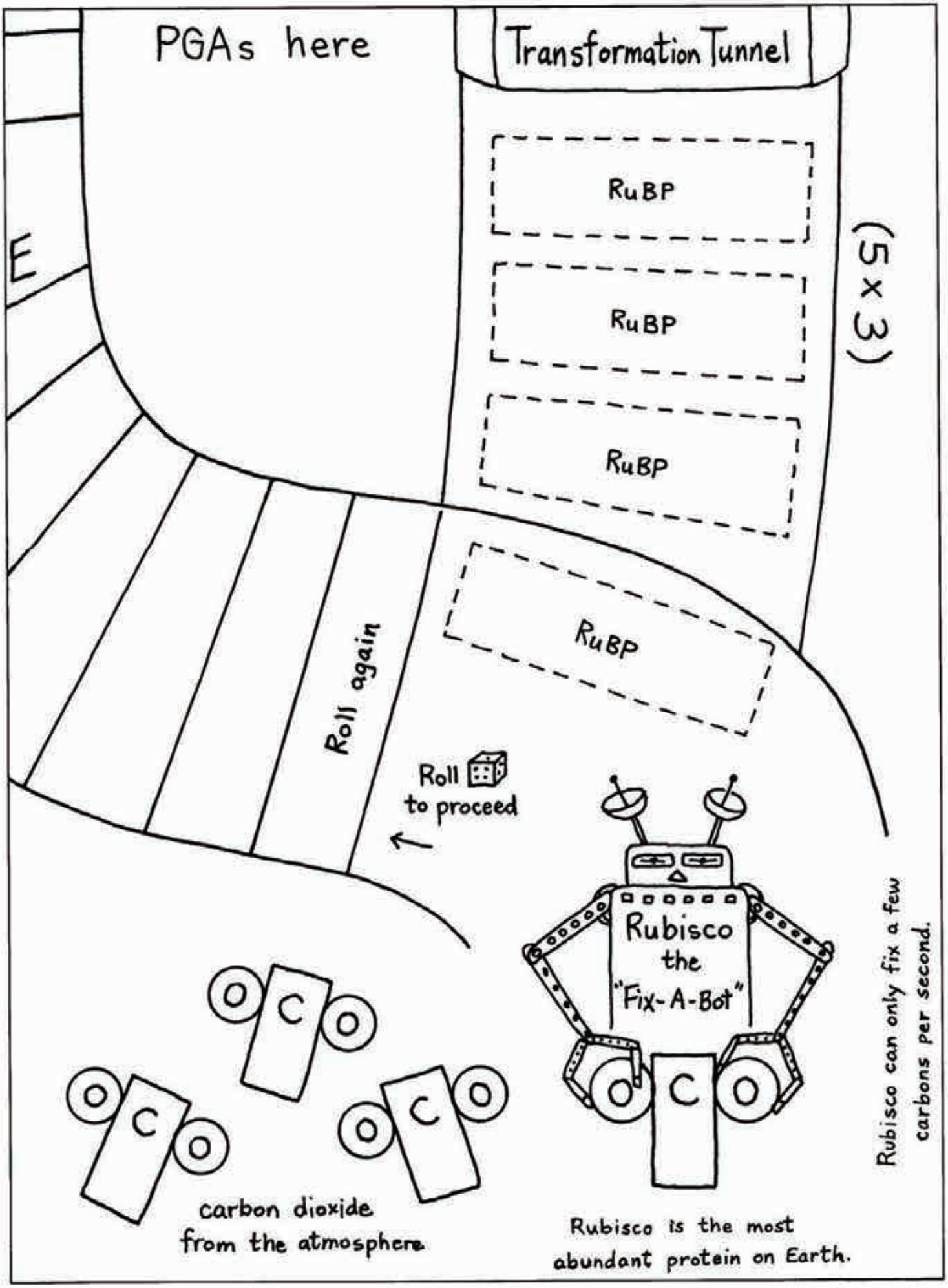

Another name for protons is "hydrogen ions." Since a hydrogen atom is nothing but one proton and one electron, when you take away the electron (making the atom into an ion), only the proton is left.
hydrogen atom (H)
hydrogen ion (H+)
Discarded phosphates can just float here, or they can be put next to the ATP synthase, ready for recycling.
extra protons should be floating here
NADPH parking lot
2 P's
ROTON
MP
Model b6f
tle bus
king lot
(plastocyanin)
LOSE A PHOSPHAT


This is what PGAL looks like:
phosphate group
CONGRATULATIONS
You may now leave the Calvin Cycle!
PGA is now PGAL!
2 E's
(3×5)
Store empty
Magical Mathematical


ATP synthase is also found in the mitochondria of both plant and animal cells.
In real ATP synthase, the protons push this top part, causing it to rotate.
ATP SYNTHASE
PROTONS
Roll to get through
PROTONS are done
(They can float back to the starting area outside the pump, if they are needed.)
In real ATP synthase this bottom part rotates, too.


ONE MOVE
shuttle bus parking lot
for the plastocyanin shuttle
E
1
chlorophyll
A
P700
ferredoxin
NADP+ reductase
Spend one move sitting on the carriers
then load the E into the shuttle
NADPH shuttle parking lot


START
START
NADPH highway
2-WAY traffic
Roll again
GAIN A
PHOSPHAT
ATP
storage area


PGAs here
Transformation Tunnel
RuBP
RuBP
RuBP
RuBP
(5 x 3)
E
Roll again
Roll
to proceed
Rubisco
the
"Fix-A-Bot"
C
O
carbon dioxide
from the atmosphere
Rubisco is the most
abundant protein on Earth.
Rubisco can only fix a few
carbons per second.

LESSON 2

1) LEARN HOW TO PRONOUNCE SCIENTIFIC LATIN

To learn more about how to pronounce Latin plant names, check out this site by the Florida Department of Agriculture: **http://botanicallatin.org/latinhandout.doc**

2) WANT TO HEAR MORE STORIES ABOUT HOW FLOWERS GOT THEIR NAMES?

To learn more about the names of flowers, you might want to read this book: 100 Flowers and How They Got Their Names by Diana Wells. (If your library doesn't have it, you can find inexpensive used copies on Amazon.com.) There's only about a page per flower—just enough info to keep you interested but not enough to bog you down. This book isn't intended for a juvenile audience, but literary-type kids might think it's interesting. Read just one or two flowers per day—maybe even as a short bedtime story!

3) A BOOK ABOUT PLANT FAMILIES

If you've got a future botanist in the family, you might want to consider purchasing this book: Plant Families by Carol Lerner. (The hardback version is ISBN 0-688-07882-6.) It is intended for a young audience, but has more than enough information to satifsy most adults, even those of us who enjoy science. The left side of each page has information about a popular plant family and the right side has beautiful botanical illustrations. The plant families include: buttercup, mustard, mint, pea, parsley, "pinks," arum, rose, composite, lily, grass and orchid.

3) A GAME ABOUT PLANT FAMILIES

If you like card games and are willing to spend $12.50 plus shipping, I recommend the following: **"Shanleya's Quest; A Botany Game"** by Thomas Elpel. The game is designed to go with a book by the same name, but can be used independently of the book. This book covers basically the same information as the book listed above in (3), though this one goes into a little more depth and is written around the theme of Native North American folklore.

The cards feature photographs of the flowers of members of various plant families. You learn to recognize members of the same plant family while playing games with the cards. The game is usable for students of any age, from elementary to high schoolers. (There is a video advertisement for this game on the Botany playlist. I posted the ad because there is so much information in it that it's worth watching it even if you don't buy the game.)