Photosynthesis

Photosynthesis is the process by which plants use sunlight energy to make new plant tissue, and in doing so, they create the by-product of oxygen, which animals need.

All chemical reactions involve changes in the electrons of atoms. The key to ***photosynthesis*** is a special molecule called ***chlorophyll***. This large and complex molecule has electrons that become "activated" when light shines on it. This reaction is unusual because most substances only heat up when exposed to sunlight; that is, their electrons aren't "activated" by light energy. But the electrons in chlorophyll are activated by light, and this electron energy is used to make new plant tissue ($C_6H_{12}O_6$).

This week's lab on photosynthesis focuses on the association between animals and plants. This relationship is so important, that without it, all animals (including humans) would quickly die.

- *Plants* change the energy of light into food energy.
- *Plants* also provide us with our oxygen.
  In the early history of our planet, 4 to 5 billion years ago, there was no oxygen in the atmosphere.
  Oxygen was released into the air only *after* photosynthesis evolved.

Water	+	Carbon Dioxide Gas	(Light Energy) → (Chlorophyll)	Organic Molecules	+	Oxygen Gas
H_2O		CO_2		$C_6H_{12}O_6$		O_2

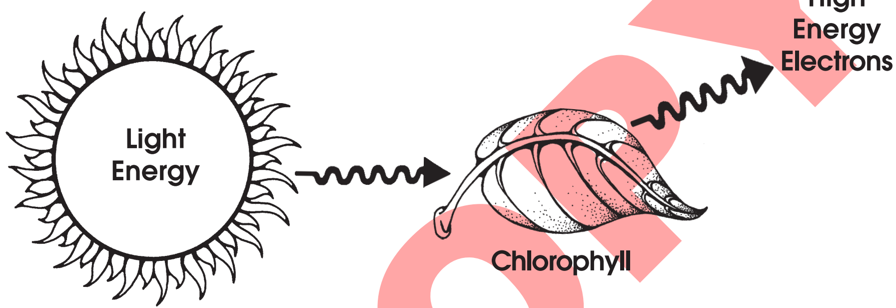
Special Note: Exercises #3 and #4 will require about an hour of your time. You should set up these two experiments *early* in the lab so that you won't run out of lab time to finish them.

EXERCISE #1

"Light Activation of Chlorophyll"

Botanists tell us that the electrons of the chlorophyll molecule are "charged up" by light energy, and those electrons release that energy immediately to make organic molecules (food) during photosynthesis.

In this Exercise, you will see for yourself whether chlorophyll can be "charged up" by light.



Procedure

[1] Your instructor will take you into a dark room and shine a blue light on a *pure chlorophyll solution*. Blue light contains no other light colors in it. (Or, your instructor may use a long-wave UV light that also produces a lot of blue light.)

[2] Your group is to observe. Then, go out of the room and discuss what you saw. (Your instructor may shine the blue light on green food coloring as a control experiment.)

Hint: Pure chlorophyll cannot pass any energy onto the rest of the photosynthesis process (to make food) unless the chlorophyll is contained in the chloroplast. That does not mean that the chlorophyll can't react. It only means that it can't make food.

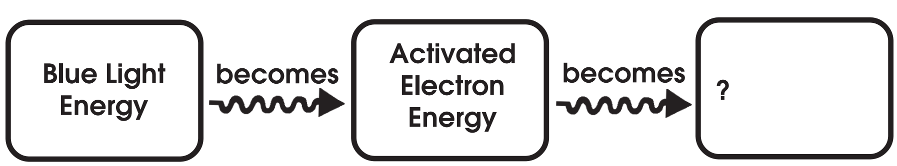
? QUESTION

1. When light activates the electrons of chlorophyll, then those electrons have . . . (circle your choice)

Less energy or More energy

2. Physics tells us that if a substance absorbs energy, then eventually it will lose that energy in one form or another. What did you observe about the chlorophyll solution when the light was shined on it?

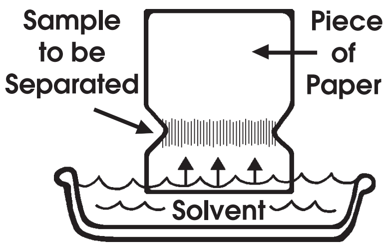
3. Based on the results of this experiment, fill in the empty box.



4. Plant cells, *under normal conditions*, convert activated electron energy into what?

EXERCISE #2

"Leaf Pigments"



There are many thousands of different kinds of organic molecules, and sometimes they can be all mixed together in something that we want to analyze. A sample may appear to be *one* substance, but it often is a mixture of *many* different substances.

Chromatography is a very basic chemical process used to separate organic molecules from each other. During this process a solvent passes through a sample that has been impregnated on a piece of paper.

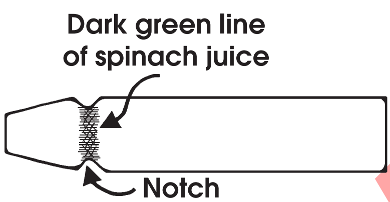
As the solvent travels up the paper, *heavier* or more chemically charged molecules will be left near the *bottom*. The other molecules (lighter or less chemically charged) will be carried *up* the paper.

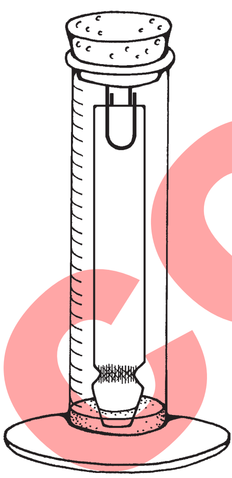
The secret to understanding the results that you see here is that each *different kind* of organic molecule in the sample will be picked up by the solvent at different rates. (This depends on the individual characteristics of each substance.) Therefore, the organic molecules will be spread out along the paper according to their individual qualities.

Materials

- A chromatography jar and cork.
- A chromatography paper and scissors.
- A spinach leaf and a penny.

Procedure





1. Wash your hands with soap so that the substances normally on your hands (French fry grease and hamburger relish) don't become part of the chromatography separation.
2. Cut a point on the end of the chromatography paper. Cut two small notches in the sides about 1.5 cm up from the point. These notches force the solvent to go through the spinach juice.
3. Roll a penny across a spinach leaf to squash a line of juice between the two notches. Make sure this line is dark green. Go over it several times. (The ridges of a quarter will work even better than a penny.)
4. Set up the chromatography jar. Place the notched paper so that when it hangs from the cork, the point *just touches* the bottom of the jar.
5. You must do the rest of the experiment *under a fume hood* or outside in the open air. ***Be careful! The solvent you are using is highly flammable!***
6. Pour the solvent into the chromatography jar to a depth of about 0.5 cm. Plug the cork with the hanging paper into the jar. Leave the jar under the fume hood and *don't move it.*

Observe

During the next 10–30 minutes, the spinach juice will be separated into its individual pigments. Determine how many pigments are present. Each may be a slightly different shade, or might be the same color, but at a different location on the chromatography paper. *Present your answer, and show the evidence to your instructor.*

In Conclusion

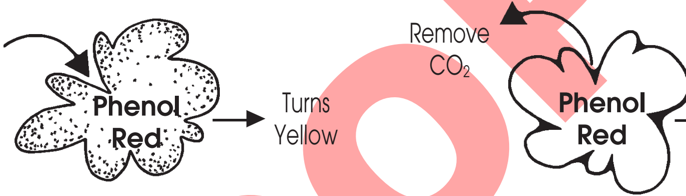
When you have finished the chromatography separation, pour the solvent into the waste jar in the fume chamber, and return the chromatography setup to the lab classroom. ***Do not wash out the setup!*** Solvents collect in the air spaces of city drain systems, and can be deadly to sewer workers.

EXERCISE #3

"CO_2 Uptake by Plants"

The photosynthesis equation: $H_2O + CO_2 \xrightarrow[\text{(Chlorophyll)}]{\text{(Light Energy)}} C_6H_{12}O_6 + O_2$ says that carbon dioxide is used to make part of the organic molecule product (food) during the process of the reaction. If this is true, then we should be able to observe that happening.

There is a very simple way to show changes in CO_2 level. Phenol red is a substance that turns yellow when CO_2 is added, and then it turns back to red when CO_2 is removed.



Experimental Question

We can use phenol red as an experimental tool to answer the question:

"Do plants use CO_2 during photosynthesis?"

Experimental Setup

1. First, "charge up" the phenol red with CO_2 using your own breath. The easiest way is to pour one test tube full of phenol red solution into a small beaker. Blow very carefully through a straw into the solution until it turns yellow. (Don't blow so forcefully that you make a mess.)
2. Pour the yellow solution back into your test tube. Add a small piece of *Elodea* plant (about 10 cm).
3. *Carefully* put the bent glass tube cork into the test tube, leaving *no air bubbles*.
4. Put the experimental setup in front of a light source for 30 minutes. What happens?

Procedure

1 Your group is to design a simple experiment that will test whether light is required by the plant during photosynthesis. Be sure to include a control.

2 Check with your instructor when you think you have a good design for the experiment.

3 Now, do it!

4 *Please put the used* Elodea *plants into the special container!* They have some phenol red on them that will contaminate the rest of the *Elodea* and kill it.

? QUESTION

1. If CO_2 is removed from the phenol red solution, then what process is going on in the *Elodea*?

2. Is light required by the plant during photosynthesis?

3. Describe your controls. (There are two.)
   a.
   b.

4. What is the purpose of having a control?

EXERCISE #4

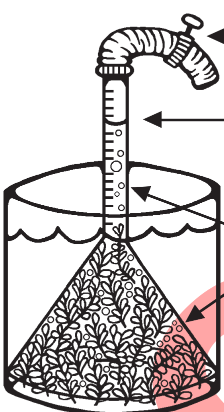
"O_2 Production by Plants"

The photosynthesis equation $H_2O + CO_2 \xrightarrow[\text{(Chlorophyll)}]{\text{(Light Energy)}} C_6H_{12}O_6 + O_2$ says that oxygen is produced. If this is true, then we should be able to observe it.

Experimental Question

How much oxygen is produced by the Elodea plants in one hour?

Experimental Setup



1. You need ten 2" pieces of healthy *Elodea* plants. Trim $\frac{1}{8}$" off each stem. A fresh cut will allow oxygen to bubble out of the plant.
2. You have to suck water up the funnel and up the tube, and then *clamp* the hose at the top to keep the water level from falling.
3. If the experiment is working, the oxygen bubbles will collect at the top of the tube and push the water level down. This drop in water level is what you are to measure during the experiment.
4. Set up a light source shining from the side, but make sure to put a beaker of clear water *between* the light and the *Elodea* container. (The beaker prevents the *Elodea* from overheating. The clear water container will absorb the heat from the light bulb, yet still allows light to pass through to the *Elodea*.)

   Note: If you can take the apparatus outside into the sunlight, your plants will photosynthesize much faster.

Procedure

[1] We will do only one of these experimental setups for the whole class to observe. Select one person in your group to work with the instructor to set up the apparatus.

[2] Have your group's representative record the O_2 production every 15 minutes for one hour.

[3] Record the total milliliters (ml) of oxygen produced during one hour. You will use this production value during Exercise #6.

ml of O_2 produced by the plant in one hour = ____________

EXERCISE #5

"Oxygen Demand for Humans"

Problem

How much oxygen does a human need to survive one hour of biology lab class?

Next week we will actually measure the O_2 consumption of a mouse under different temperature conditions and compare different animals and plants. However, this week we can borrow an estimate of human oxygen demand from experimental research.

The O_2 used by a human in one hour can range from $\frac{1}{4}$ of a liter of O_2 per kg of body weight to as high as 8 liters. (Although that high rate of metabolism could be maintained for only about 2 minutes without total exhaustion.)

A person in biology lab class uses about 0.4 liters of O_2 per kg of body weight in one hour as long as they aren't walking around all the time.

Procedure

1. Assume that the O_2 used by a person during one hour of biology lab is about 0.4 liters (400 ml) per kg of body weight.
2. Assume that the average human weighs 60 kg.

? QUESTION

What is the oxygen demand for an average person during one hour of biology lab?

___________ = ml of O_2 used by a human in one hour

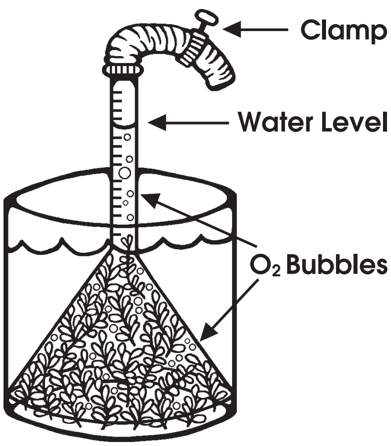
You will use this calculation again in Exercise #6.

EXERCISE #6

"How Big of a Plant Does it Take to Keep You Alive?"

You have an estimate of the amount of O_2 (in ml) produced during one hour by the *Elodea* Plant (see Exercise #4), and you have an estimate of the amount of O_2 used by a human in one hour (see Exercise #5).

Procedure



1. Record the amount of oxygen that the *Elodea* plant produced in *one* hour.

__________ ml of O_2 per hour

2. Measure the cross-sectional area of the *Elodea* plant container. If light is shining from the side, then the cross-sectional area of light on the plants is a triangle shape. (The funnel looks like a triangle when viewed from the side.) Area = $\frac{1}{2}$ Height x Width.

The *cross-sectional area* represents how much light can be captured by the plant. Do the calculations in centimeters and use whatever formula is appropriate for the shape of your experimental setup. What is this value for your experiment?

__________ cm^2 of light-catching surface

? QUESTION

How much oxygen (in ml) is produced by 1 cm^2 of the plant cross-sectional area?

__________ ml of O_2 is produced per cm^2 of plant in one hour

Hint: You would get the correct answer by dividing your answer from procedure #1 above by the answer for procedure #2.

Procedure

1. What was your calculation of the oxygen demand for a human being during one hour of lab class? (Refer to Exercise #5.)

__________ ml of O_2 per hour

2. Use this formula to answer the *? QUESTION* on the next page.

$$\text{Size of Plant Needed to Keep You Alive (in cm}^2\text{)} = \frac{\text{Human Oxygen Demand (in ml)}}{\text{Plant } O_2 \text{ Production (in ml) per cm}^2 \text{ of Plant}}$$

? QUESTION

1. What size of plant is required to keep you alive?

    ___________ cm^2

2. Change this plant size to m^2 by dividing your answer above by 10,000 (there are 10,000 cm^2 in one m^2). What is your answer in m^2?

    Size of plant required = ___________ m^2

3. If you determine the square root of the plant area above, then you will have calculated the *side measurement of a square shape* representing the plant area.

    Side = _________ m

4. In the above calculations, you have determined how big a plant is required to keep you alive during daylight hours, but what will keep you alive at night? **Remember:** Plants don't photosynthesize at night.

5. Does this change your estimate of how big a plant it takes to keep you alive both day and night?

    By how much?

In Conclusion

Go outside and mark off on the ground how big of a plant is required to keep you alive every 24 hours.