ESA21

Environmental Science Activities for the 21st Century



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## Photosynthesis and Respiration: Introduction

You are by now quite familiar with photosynthesis. It is the process by which plants and some other organisms convert solar energy to chemical energy in the form of sugars. In this reaction, the energy from sunlight is harnessed and utilized to form sugar molecules from carbon dioxide and water, forming oxygen gas as a byproduct.

**Photosynthesis:** $6CO_2 + 6H_2O$ + sunlight ---> $C_6H_{12}O_6 + 6O_2$

While photosynthesis creates sugar with the sun's energy, cellular respiration utilizes the chemical energy in sugar to meet the energetic needs of organisms. During respiration, sugar is combined with oxygen, resulting in energy and carbon dioxide. Note that the equation for respiration is the opposite of photosynthesis, indicating the products of photosynthesis become reactants in respiration, and vice-versa.

**Respiration:** $6O_2 + C_6H_{12}O_6$ -----> energy + $6CO_2 + 6H_2O$

While only plants and select other organisms are capable of photosynthesis, all organisms (plants included) carry out respiration to convert their food (sugar) to the energy needed to power the wide variety of biochemical reactions that are necessary to sustain life. After all, plants are not creating sugar from carbon dioxide and sunlight for you, they're making it for themselves, and you're simply taking advantage of the process by consuming the biomass the plant produces through photosynthesis. Many students incorrectly uniquely associate photosynthesis with plants, and respiration with animals. It is important to realize that plants carry out both respiration and photosynthesis, as this will be useful during your lab analysis.

If you think about the gases inhaled and exhaled by humans, the process of respiration should be easy to remember. We breathe in oxygen and exhale carbon dioxide because we are constantly carrying out cellular respiration. In our lungs, oxygen from the air enters your blood and is carried to cells throughout your body where it is used for cellular respiration. The waste product of respiration, carbon dioxide, is carried back to your lungs by your blood, and then exhaled into the environment.

**Observing the Processes**
So let's take a minute and recap. You know that plants carry out photosynthesis to create sugar, and that all organisms use sugar to fuel cellular biochemical reactions through the process of cellular respiration. Not all of the sugar created by the plant is used up in respiration though, as some is used to create new plant biomass like roots, leaves, stems, wood, and bark. The carbon in plant biomass is only stored temporarily, as it will return to the atmosphere when the biomass decomposes, burns, or is eaten and metabolized.

Up to now you have read about the abstract concepts of photosynthesis and cellular respiration and, being the trusting souls that you are, accepted these ideas without ever likely having observed them. In this activity you will complete exercises that will show you both of the processes in action, and in under an hour's time. These exercises will help to make an abstract concept more concrete, and aid you in understanding the role of plants and other organisms in the cycling of carbon.

**Carbon dioxide and pH**
In the first exercise, you will investigate photosynthesis with *Elodea*, an aquatic plant. In the second exercise, you will examine cellular respiration with seeds of the mung bean (*Phaseolus aureus*). In each of these cases, we will follow the movements of carbon dioxide between a plant or seed and the water that surrounds it. Just as terrestrial plants exchange gases with the surrounding environment through the air, aquatic organisms exchange gases through the water. Gases from the atmosphere, like oxygen and carbon dioxide, readily dissolve in water and are utilized by aquatic plants and animals in the same manner as terrestrial organisms. Aquatic plants therefore take up carbon dioxide from the surrounding water during photosynthesis, and introduce carbon dioxide into the water when respiring. Hence, to observe the processes in action we need to have some way of observing changes in carbon dioxide concentrations in water. One way to do this would be to put radioactive carbon into the water, add the plants/seeds, allow them to interact with water for 45 minutes or so, and then compare the amount of radioactivity in the water and in the plants/seeds. While this is the method used by scientists to study photosynthesis, the potential lawsuit implications are staggering, and this won't be mentioned again. Another way would be to use sensors or processes to directly measure carbon dioxide concentrations in the water, but this is too costly and/or complicated for our purposes.

**pH and Gas Exchange**
Luckily, there is another option available – pH. The pH scale ranges from 1 (very acidic) to 14 (very basic), with neutral substances having a pH of 7. Substances with a pH below 7 are said to be acidic, those above 7 are basic, and those that are exactly 7 are neutral. When carbon dioxide is introduced into water, it forms a carbonic acid, a weak acid, and lowers the pH of the solution. Conversely, when carbon dioxide is removed from a solution, the solution becomes less acidic and the pH rises. We can use this relationship to observe photosynthesis and respiration, as the two processes affect the amount of carbon dioxide in a sample of water.

If we place a plant in water containing dissolved gases, the plant will remove carbon dioxide from the water as it photosynthesizes, reducing carbon dioxide concentrations in the water, and raising the pH of the solution. If we place a plant or seed in the water and it undergoes respiration, it will release carbon dioxide into the water, and lower the pH of the solution. So by monitoring the changes in the pH of a solution, you can determine if the plant or seed in the solution is photosynthesizing (pH goes up) or respiring (pH goes down). This relationship between pH and photosynthesis/respiration is key to today's exercise, so be sure you understand it completely.

An illustration may help.  Imagine a meter stick with the word "pH" written on one end and "carbon dioxide concentrations" written on the opposite end (Figure 2).


**Figure 2: Carbon dioxide and pH**
**[ Animate ]**

Note that if you raise the concentration of carbon dioxide in the water (by raising that end of the meter stick), pH declines. If you decrease the amount of carbon dioxide in the water, pH increases. As carbon dioxide uptake is one way to measure photosynthesis rates, and changes in carbon dioxide concentrations cause changes in pH, we can use pH changes as an indirect measure of photosynthesis rates.  To view this as an animation, click the *Animate* link above.

By now, you see that we will be observing the processes of photosynthesis and respiration by observing changes in the pH of solutions containing aquatic plants or seeds. So how do we measure pH? There are a variety of methods available, but we will be using a method commonly used in laboratory exercises like this one - bromothymol blue. Bromothymol blue is a pH indicator solution that is blue when its pH is basic (and carbon dioxide concentrations are low) and yellow when its pH is acidic (and carbon dioxide concentrations are high). Figure 3 shows these color changes as a function of solution pH. Note that the solution is blue when basic, greenish when neutral, and yellow when acidic.

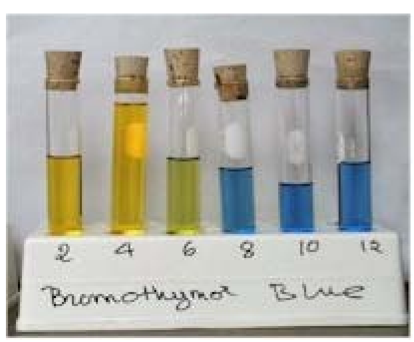



**Figure 3: Bromothymol blue color change with pH**

In today's activity you will be examining changes in solution pH to indirectly measure carbon dioxide concentrations in solutions containing *Elodea* plants and mung bean seeds. By looking at changes in carbon dioxide concentrations over time, you will be able to observe firsthand the processes of photosynthesis and respiration.

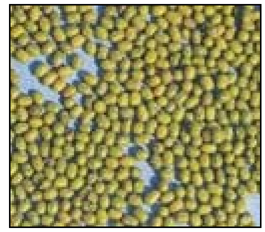
**Activity: Procedures - Photosynthesis**

In the first exercise, you will examine the processes of respiration and photosynthesis with the aquatic plant, *Elodea*. *Elodea* is commonly found in freshwater lakes and ponds, where it floats in the water column. Because it does not require a root system to survive, *Elodea* is commonly used in freshwater aquaria and can be purchased at pet stores. When exposed to sunlight, *Elodea* will begin photosynthesizing and will remove carbon dioxide from the solution. The plant will respire constantly regardless of light conditions, as its cells always need energy.

| **Photosynthesis Exercise:** | |
|---|---|
| (1.) | Place about 75 ml of bromothymol blue into a 125 ml Erlenmeyer flask (the triangular glass containers at your work bench) and return to your workstation. |
| (2.) | Observe the color of the solution. The next step is to introduce carbon dioxide into the solution. We could do this with a carbon dioxide tank like those used for soda dispensers, but that would be overkill. Luckily, there is a ready source of cost-free carbon dioxide within you right now - your lungs. Use a straw from Station 1 to **slowly** blow $CO_2$ into the solution until it **just** turns yellow. |
| (3.) | Compare the color of the solution to the printout showing bromothymol blue at various pHs. Find the color on the printout that best matches the color of your solution. If your color is between those shown, use the pH value that is intermediate between them. Record the color of the solution after you've introduced $CO_2$ (Initial color) and estimated pH (Initial pH) for each of the tubes in Table 1. When comparing or describing colors, be sure to hold the tubes in front of a white background and be as detailed as possible when describing the color (e.g., use terms like "greenish-blue" or "yellow-green"). |
| (4.) | Pour the solution into three screw cap tubes, dividing it evenly between them. Obtain two 2-inch pieces of *Elodea* from the open dish at the *Elodea* Station ("Light *Elodea*"), place them in one of the tubes, and cap it. Obtain two 2-inch pieces of *Elodea* from the covered dish, place them in a second tube covered with aluminum foil (to prevent the entry of light), and cap it. In both tubes, make sure the plant is completely submerged in the solution. Cap the remaining tube – it will serve as your control. Place the tubes upright on the lab bench approximately 8-10 inches from the lamp. Ensure the light hits all three tubes equally and from the side, not from the top. Turn on the lamp. While you allow the experiment to run, set up the respiration experiment described on the next page. |
| (5.) | Allow the plants to sit undisturbed for 50 minutes, and then carefully remove the *Elodea* plants from the tubes. Determine the color of the solution against a white background, record them in Table 1, and compare the colors to the bromothymol blue printout to determine pH. After all measurements have been completed, return the *Elodea* to Station 1, putting it in the dish marked "Used Light *Elodea*" or "Used Dark *Elodea*" depending on its use. Rinse out your glassware and throw away your used straw. |

**Activity: Procedures - Respiration**

In the second exercise, you will examine the process of respiration with seeds of the mung bean (*Phaseolus aureus*). One problem with studying respiration in plants is that they will begin photosynthesizing when in the presence of sunlight, and this will counteract the increase in carbon dioxide concentrations we are attempting to measure.



**Mung Beans**
http://www.evergreenseeds.com/

As you saw in the first exercise, one way to measure respiration is by placing a plant in the dark. In this exercise, we'll use a slightly different approach. Seeds are immature plants that cannot yet photosynthesize, but are capable of respiring. By using seeds we can look at respiration in this group of organisms and avoid conflicts with photosynthesis when interpreting our results.

| **Respiration Exercise:** | |
|---|---|
| (1.) | From Station 2, obtain two jars and two jar covers. One of the jars should be partially filled with germinating seeds and the other should be empty. |
| (2.) | Rinse out both jars thoroughly (without pouring out the seeds) to ensure that each has a fresh supply of air then fill each jar with equal amounts of bromothymol blue to just above the top of the seeds. Record the initial color and estimated pH of the solutions in Table 2. |
| (3.) | Cover the jars and set them asid, making sure that the two jars are in similar conditions. Allow the jars to sit undisturbed for 45 minutes. |
| (4.) | Filter the seeds out of the jars by pouring the solution through the provided strainer into a separate container. To control all your variables, do the same for the solution with no seeds (even though there is nothing to filter out). Compare the color of the solution in each of the jars against a white background. Record the final color and estimated pH of the solutions in Table 2. |
| (5.) | Return the seeds to Station 2. |

**Case Study: Deforestation**

As you wait for your experiments to proceed, let's use this time to investigate the intricate relationship between vegetation and climate change through an online case study.

You've seen that vegetation can have a profound influence on the cycling of carbon, and thereby on the regulation of global climate. The current increases in atmospheric carbon dioxide concentrations are thought to be caused by the combustion of fossil fuels and by the rapid rates of deforestation currently occurring in tropical forests. By adding carbon dioxide to the atmosphere and destroying the ability to remove it through photosynthesis, this combination of fossil fuel combustion and deforestation may be drastically impacting the systems that affect planetary climate.

**Slash and burn agriculture**

So why are tropical forests declining? These forests are often cleared with a technique called "slash and burn agriculture" in which peasant farmers cut all of the vegetation on a plot of land, then burn it to clear the vegetation and fertilize the soil. This process not only removes vegetation that could reduce atmospheric carbon dioxide levels through photosynthesis, but also adds carbon dioxide to the atmosphere when the vegetation is burned.

Land area occupied by tropical forests has been declining since 1800 (Figure 4), and deforestation rates have accelerated in recent decades. In this section, you will examine a case study on tropical deforestation that illustrates the complex nature of this issue. Deforestation is influenced by a variety of factors, particularly the elevated rates of poverty in the developing world, and the case study will help you to understand the process.

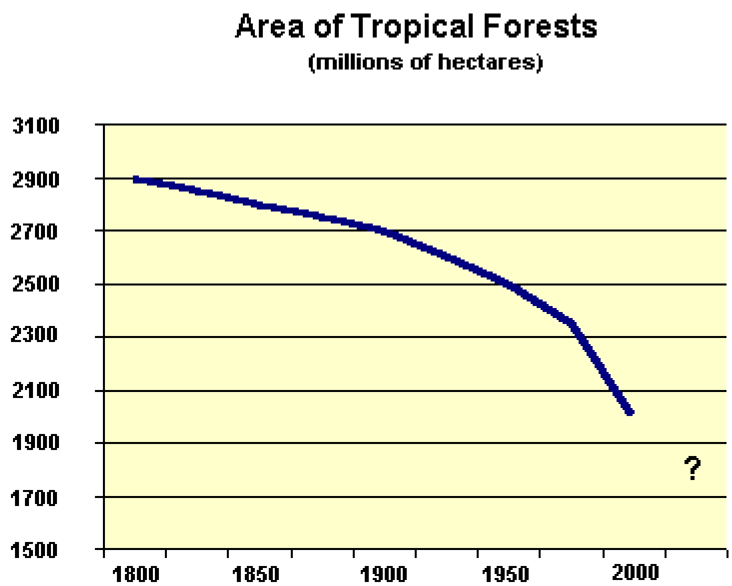



**Figure 4: Tropical Forest Land Area since 1800**

**The Deforestation of the Amazon**

*Phil Camill – Carleton University (MN)*

National Center for Case Study Teaching in Science
https://www.nsta.org/ncss-case-study/deforestation-amazon

**READ ONLY SECTIONS I AND II**

# ESA 21: Environmental Science Activities

Name:

Lecture Professor:

**Photosynthesis:**
***Hypothesis:***
Write a null hypothesis for this experiment, remembering that you are investigating the effects of light (presence or absence) on pH change in solutions with *Elodea*.

$H_o$:

***Data Presentation:***
Table 1:

| Tube | Initial color | Initial pH | Final color | Final pH |
|---|---|---|---|---|
| *Elodea* - light | | | | |
| *Elodea* - dark | | | | |
| No *Elodea* | | | | |

**Conclusion:**
Evaluate your $H_o$, citing data as appropriate. Be sure to explain the results for each of the three tubes, and relate them to $CO_2$ exchanges between the plants and the solution.

**Cellular Respiration:**
Table 2:

| Container | Initial color | Initial pH | Final color | Final pH |
|---|---|---|---|---|
| With seeds | | | | |
| No seeds | | | | |

**Conclusion:**
Explain the results of this experiment in your own words. Be sure to describe the results for each container and relate them to $CO_2$ exchanges between the seeds and the solution.

**Online Case Study:**
Answer the questions below completely and thoughtfully, citing information from the case study for each. Brief, incomplete answers are not acceptable, so state your opinions and their justifications fully.

(a.) Is it hypocritical for developed countries like the United States to criticize the exploitation of natural resources in third world countries when our country did exactly the same thing (westward expansion, Oklahoma land rush) to fuel our country's economic growth in years past?

(b.) Some economists have argued that given the current poor financial status of many third world countries, the only way to protect tropical forests is for developed countries to pay countries like Brazil **not** to destroy their forests. The U.S. government does a similar thing in our country by paying farmers not to cultivate some of their fields? Given the global environmental benefits provided by these ecosystems, would you support the U.S. government paying countries to preserve their forests? Given that these funds would come from tax dollars, how much would **you** be willing to pay on an annual basis to conserve tropical forests? Ask this question of five family members, friends, or acquaintances. What were their answers? Were you surprised by their answers?