Plant Growth: Photosynthesis

SC Academic Standards: 4.L.5B; 6.L.4A; 6.L.4B; 7.L.3A; 7.L.3B; H.B.2B; H.B.2C

NGSS DCI: 4-LS1.C; 5-LS2.B; MS-LS1-A; MS-PS3.D; HS-LS1.A

Science and Engineering Practices: S.1A.1; S.1A.2; S.1A.3; S.1A.4; S.1A.5; S.1A.6; S.1A.7

Crosscutting Concepts: Cause and Effect: Mechanism and Explanation; Structure and Function; Scale, Proportion, and Quantity; and Systems Models.

Focus Question(s): What Affects the Rate of Photosynthesis in Plants?

Background: **Photosynthesis** is the process by which plants take carbon dioxide from the atmosphere, add water, and use the energy of sunlight to produce sugar.

Chloroplasts are leaf organelles that contain the pigments (specifically and most importantly **chlorophyll** (among others)). The presence of cholorophyll is what makes plants look green (they reflect green light, but absorb, and use, the reds and blues). The cholorphyll molecules, embedded in the chloroplast membrane, are part of the electron transport chain, which captures light energy, transform it to ATP (just like the mitochondria does in cell respiration in plants and animals), and then uses the ATP to convert inorganic carbon (CO_2) into organic carbon (sugar). Organic forms of carbon are amazing energy storage molecules.

So, basically, photosynthesis occurs in the chloroplast, an organelle in plant leaf cells that contains the molecule chlorophyll. Chlorophyll absorbs the energy of sunlight. That light energy is converted to chemical energy through the steps of photosynthesis.

The reactions of photosynthesis can be divided into two major types: light-dependent reactions and light-independent reactions. The light-dependent reactions convert energy from the sun into ATP / NADPH which the chloroplast can then use to make sugar from carbon dioxide, in the process producing oxygen as a waste product. The light-independent reactions use that energy to make glucose from carbon dioxide and water. The simple equation

$$\text{Light Energy} + 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

describes how plants take carbon dioxide and water and with the sun's energy convert these molecules to sugars, water and oxygen. It does get a little more complicated; water is actually on both sides of the photosynthesis equation, with 12 H_2O being used (reactants) and 6 molecules of H_2O being produced (they cancel out and become just 6 H_2O on the left side of the equation).

Plants (and photosynthetic bacteria (cyanobacteria) and photosynthetic protists (such as some diatoms, dinoflagellates) do photosynthesis during the daytime while it's light, which uses carbon dioxide and produces oxygen. During the day and night plants take in oxygen and release carbon dioxide through cellular respiration (just like animals!) which occurs in the mitochondria.

Cellular respiration is the process where animals (like humans!) and plants break down the sugars created by photosynthesis back into energy (this time ATP). The chemical equation for respiration is basically the opposite of photosynthesis:

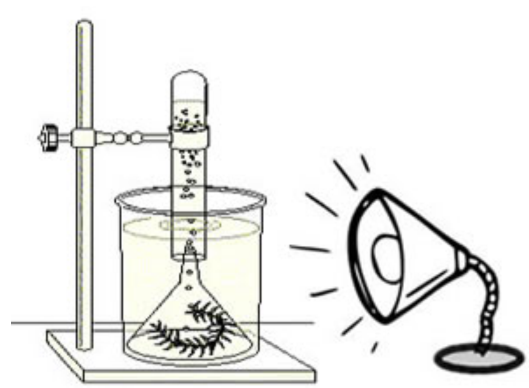
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36\text{-}38 \text{ ATP Energy}$$

Plants carry on respiration in all their living cells except those actively carrying on photosynthesis. If respiration stops in a cell that cell will die. If enough cells can't get food, oxygen, or water, respiration stops and the whole plant can die.

The purpose of this lab exercise is to measure the rate of photosynthesis in an aquatic plant (*Elodea*).

Materials: test tube, clear glass funnel, test tube, *Elodea* cuttings, sodium bicarbonate (baking soda), beaker, lamp, de-chlorinated water (let it sit in a bucket overnight), cm ruler, clamp/test tube stand, light source (I have the most success using 1200 Lumen compact fluorescent bulbs. Incandescent bulbs really don't work well). If available, Gastec pump / CO2 and O2 tubes.

Procedure: (*note - to improve results, add a pinch of baking soda to the water in the test tube (it adds CO_2). Cut *Elodea* stems at an angle, strip away the bottom few leaves, and use your fingers to crush the end of the stem. The water in the beaker is meant to absorb the heat from a light source that produces heat (CFL's don't really). If you do not see bubbles right away, re-cut and crush the stems, experiment with moving the light closer to the apparatus). Your goal is to find a way to consistently measure the rate of photosynthesis – you may modify the design to just simply a test tube, upright, with *Elodea* inside and a light shining on it, and you can still count bubbles).



http://biologycorner.com/worksheets/photosynthesis_rate.html

1. Fill a 500 ml beaker with water (it is best to use water that has been sitting in a bucket overnight, to de-chlorinate). Add a pinch of sodium bicarbonate to the water and mix to dissolve.
2. Cut the bottom of a stem of *Elodea*, remove several leaves from around the bottom, and rub it between your fingers to gently crush stem.
3. Place a sprig of *Elodea* in the bottom of the beaker of water, and place a clear glass funnel completely over it.
4. Position a test tube upside down over the funnel tip (the test tube should be filled with the same water as in the beaker – so hold your thumb over open end and don't release until the open end is submerged in beaker). Clamp the test tube in place.
5. Place your light source close to the beaker (5 cm away), so that the light shines upon the *Elodea*.
6. Wait two minutes to acclimate. Then, count the number of bubbles per minute for 10 minutes. Alternatively, you may measure the height of the air pocket created as water is displaced by the rising oxygen gas into the test tube.

Time (minutes)	# bubbles produced	Cumulative # bubbles produced	Height of air pocket (mm)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Table 1. Number of Oxygen bubbles produced by photosynthesis in 10 minutes

Data Analysis: You will be counting the number of bubbles versus time. Alternatively, you could measure the oxygen gas bubble as it displaces water in the upside down test tube (versus time). Your line graph will be time (minutes) on the X and # bubbles on the Y (or size, in mm, of air pocket). **Rate** is calculated by # bubbles / time.

Extensions: When testing the rate of a reaction, you can look at the rate of reactants being used up as well as the rate of products being produced. Above, we looked at oxygen gas production (counting bubbles). Here, you can test CO_2 reduction, as a reactant. Phenol red is used as an indicator for a base. With excess carbon dioxide, the phenol red will be yellow, as the carbon dioxide is removed, the solution becomes more basic, turning back to red. So -

1. Remove the *Elodea* from your test tube and rinse to remove any sodium bicarbonate from the plant and the test tube.
2. Place dilute phenol red in the test tube.
3. Use a straw to bubble breath into the tube until the solution just turns yellow
4. Place the tube in from of the lamp, observe the tube and note any changes in color.
5. After gathering data on the color change, reset your test tube back to yellow and then cover it in foil. Store this overnight and check the color the next day. (Is photosynthesis happening in the dark? Is cellular respiration, which produced CO_2?)

Try 10 ml of phenol red to 200 ml of water. The yellow water starts to change to pink in about an hour, with the most spectacular results in about 3 hours. If left overnight, the pink will go away and the vial will return to yellow (due to respiration). If time is an issue, you may need to perform this as a demo by setting up the vials beforehand and taking photos. Don't forget a control, a jar with just phenol red (it should color the water yellow) and no *Elodea*.

Another extension is to have the students repeat the oxygen bubble experiment, changing one variable of their choice (Light color - be careful using colored fluorescent bulbs, these do not work, instead try using cellophane or velum to serve as a light filter; Light intensity - provide different sizes of bulbs, or students can experiment with moving the bulbs farther away from the plants; Temperature - ice and warm water baths can be provided).

Reflection Questions:

- **When do plants photosynthesize**? (only in the daytime – they need sunlight. They can't photosynthesize at night - so, plants take in CO_2 only in the day, and respire (put out) CO_2 all the time).

- **When do plants do cellular respiration?** (All the time!! Plants do aerobic cell respiration to break down the sugar (made in photosynthesis) into CO_2, H_2O, and ATP – the ATP is what they need to drive their metabolic reactions, just like humans!)

- **When do animals do cellular respiration?** (all the time ! Plants and animals both do cell respiration in their mitochondria in order to break down the energy rich organic molecule glucose (or other proteins lipids and carbs) into smaller molecules plus ATP, a much more efficient energy source).

- **Compare the reactants and products of photosynthesis and cellular respiration** (the two equations look similar, but opposite. PS uses glucose and oxygen (and water) and sunlight energy and converts it to CO_2 and H_2O; respiration takes CO_2 and H_2O and converts it to glucose and oxygen and ATP energy).

<u>Models and Explanations:</u> In this lab we explored photosynthesis. **A student who demonstrates understanding** of these concepts can justify that the gas being produced is oxygen, and that as photosynthesis occurs, carbon dioxide is used up. **The student can explain** that in the daytime both photosynthesis and cellular respiration are occurring simultaneously, but at night plants will be respiring only. Thus, during the daytime plants are both producing oxygen gas and consuming it - but generally O_2 consumed comes from the roots / dissolved in soul water and isn't taken up from the air. **Further, the student can compare** the photosynthetic and cell respiration equations and show that they are essentially opposite, identifying products and reactants of each reaction. **This student will be able to correctly predict** that at night, in the absence of photosynthesis, the phenol red base (CO_2) indicator will turn from red to yellow, as CO_2 is added to the water by cell respiration, and in the daytime will turn back to red as more CO_2 is removed during photosynthesis.

<u>Bibliography:</u>

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Student Worksheet:

Photosynthesis is the process by which plants take carbon dioxide from the atmosphere, add water, and use the energy of sunlight to produce sugar. Basically, photosynthesis occurs in the chloroplast, an organelle in plant leaf cells that contains the pigment chlorophyll. Chlorophyll absorbs the energy of sunlight. That light energy is converted to chemical energy through the steps of photosynthesis. The reactions of photosynthesis can be divided into two major types: light-dependent reactions and light-independent reactions. The light-dependent reactions utilizes an electron transport chain in the chloroplast membrane to convert energy from the sun into ATP / NADPH which the chloroplast can then use to make sugar from carbon dioxide, in the process producing oxygen as a waste product. The light-independent reactions use that energy to make glucose from carbon dioxide and water in the stroma of the chloroplast. The simple equation

$$\text{Light Energy} + 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

describes how plants take carbon dioxide and water and with the sun's energy convert these molecules to sugars, water and oxygen. Plants (and photosynthetic bacteria (cyanobacteria) and photosynthetic protists (such as some diatoms, dinoflagellates) do photosynthesis during the daytime while it's light, which uses carbon dioxide and produces oxygen. During the day and night plants take in oxygen and release carbon dioxide through cellular respiration (just like animals!) which occurs in the mitochondria. **The purpose of this lab exercise is to measure the rate of photosynthesis in an aquatic plant (*Elodea*).**

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Table 1. Number of Oxygen bubbles produced by photosynthesis in 10 minutes

Rate of Photosynthesis after 10 minutes = distance / time = ___________________

Now- change a variable. Use a different colored lightbulb, or change the water temperature, or light intensity. Your first experiment is the control, and this experiment is the treatment.

Question:

Hypothesis:

Prediction:

Experimental Design:

Data:

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Conclusion:

How did your results differ from the control (comparison group)?

What were your independent, dependent, and controlled variables?