

# SOLAR ENERGY

## Solar Energy, Kit #4: Investigating Photosynthesis

**TOSHIBA**



Washington University in St. Louis  
INSTITUTE FOR SCHOOL PARTNERSHIP



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## Topic Template

Topic	Photosynthesis, Nature's Solar Energy Transformer	
Associated Curriculum	Solar Energy	
Associated Content	Photosynthesis, Chemical Reactions, Redox, Sunlight => Energy, Energy Transfers, Light as EM Waves, Plants	
Materials Needed	<b>KIT MATERIALS</b>	<b>TEACHER TO PROVIDE</b>
	<ul style="list-style-type: none"> <li>• Large test tubes</li> <li>• Light bulb base</li> <li>• Various light bulbs</li> <li>• Stop watch</li> <li>• Test tube rack</li> <li>• Thermometer</li> <li>• Colored filters</li> <li>• Baking soda</li> <li>• Paperclips</li> <li>• Metric ruler</li> </ul>	<ul style="list-style-type: none"> <li>• Meter stick</li> <li>• Dechlorinated water</li> <li>• Scissors</li> <li>• Elodea and other aquatic plants (available at local pet stores)</li> <li>• Ice</li> <li>• Water</li> <li>• Balance</li> <li>• Protractor</li> <li>• *other liquids</li> <li>• *optional materials</li> </ul>
5E Learning Cycle <ul style="list-style-type: none"> <li>• Engagement</li> <li>• Exploration</li> <li>• Explanation</li> <li>• Elaboration</li> <li>• Evaluation</li> </ul>	<ul style="list-style-type: none"> <li>• What color is every plant? Why are plants colored the way they are?</li> <li>• What factors can influence photosynthesis?</li> <li>• Draw a diagram of photosynthesis including sunlight, the plant, water and carbon dioxide.</li> <li>• How do organisms (such as plants and bacteria) get and use the matter and energy they need to live and grow?</li> <li>• Why is photosynthesis necessary for plants to survive?</li> </ul>	
Related NGSS Standards	<p><b>MSPS1-5.</b> Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.</p> <p><b>MSPS4-2.</b> Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.</p> <p><b>MSLS1-6.</b> Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.</p> <p><b>MSLS1-7.</b> Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.</p>	
Background/Why	Covers how photosynthesis is used by plants to capture the sun's energy using chlorophyll. An understanding of this could lead to human's harnessing this power.	
Model 1 (Extension)	Half reactions for Photosynthesis (Using chemistry, specifically redox reactions, to go deeper into how photosynthesis produces glucose)	
Model 1 ALT (Essential)	Photosynthesis is a Chemical Reaction (Balancing the reaction of photosynthesis to show how plants create food through chemistry).	
Model 2 (Essential)	Chlorophyll Absorption in Photosynthetic Organisms (Chlorophyll absorbs very specific wavelengths of light and reflect everything else, mainly green light)	
Model 3 (Extension)	Photosynthetic Antennas (Plants utilize very complex photosynthetic antennas to capture light energy)	

## Photosynthesis, Nature's Solar Energy Transformer

### WHY?

All living organisms need energy. When we look around us, much of what we see, other than stone and water, is either a photosynthetic product or something derived from photosynthetic products. Only green plants can use light energy to split water and reduce carbon dioxide. Green plants do this to make their own carbohydrates; animals obtain carbohydrates by eating plants or other animals. Without photosynthetic organisms, the sun's energy would not be transformed into usable energy for living things. In addition, the oxygen we breathe comes from photosynthesis by plants. If we can understand the process of photosynthesis then we can use this knowledge to improve bioenergy technologies for acquiring energy in a carbon neutral, renewable manner.

### Background:

Nature's most sophisticated and important solar energy storage system is found in photosynthetic organisms, including plants, algae and a variety of types of bacteria. All these organisms utilize sunlight to power cellular processes and ultimately derive most or all of their biomass through chemical reactions driven by light. Photosynthesis begins when light is absorbed by an antenna pigment. This pigment can be a chlorophyll (or bacteriochlorophyll), carotenoid or bilin depending on the type of organism. A wide variety of different antenna complexes are found in different photosynthetic systems. Antennas permit an organism to increase greatly the absorption cross section for light without having to build an entire photochemical reaction center and associated electron transfer system for each pigment, which would be very costly in terms of cellular resources. After the initial electron transfer event, a series of electron transfer reactions takes place in the reaction center that eventually stabilizes the stored energy in forms that can be used by the cell.

### Engage:

*What color is every plant? Why are plants colored the way they are?*

### Explore:

*What factors can influence photosynthesis?*

## Lab Protocol: Investigating Factors Affecting the Rate of Photosynthesis

In this experiment the rate of photosynthesis is measured by quantifying the bubbles of oxygen rising from the cut end of a piece of an aquatic plant.

### Engage:

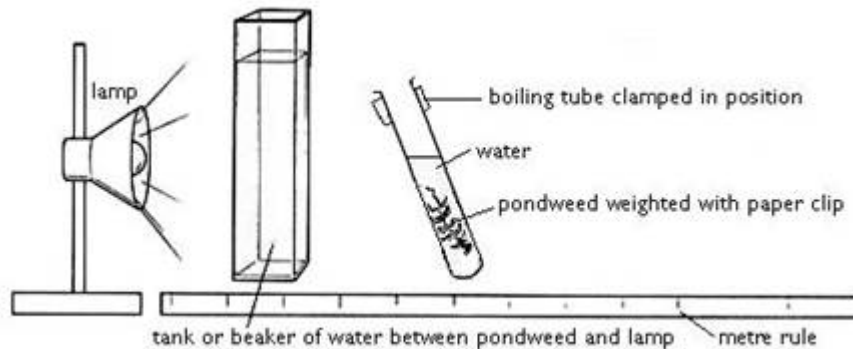
A cut aquatic plant will produce bubbles when placed underwater in a test tube when a light is shined on it.

*What happens when the light is turned off and on?*

*What is happening and why?*

*What questions might you ask related to what you see?*

Diagram of set up:



**\*\*Note:** The beaker of water is there to absorb some of the heat from the light. However, it is not essential. If the beaker is large, it can cast a shadow on the plant and inhibit photosynthesis.

### Materials:

Metric ruler

Test tube

Beaker

Dechlorinated water

*Elodea* or *Cabomba* (oxygenating pond plant)

Scissors or razor

Forceps

Electric halogen lamp

Clamp stand with boss and clamp or Test tube rack  
Stop watch

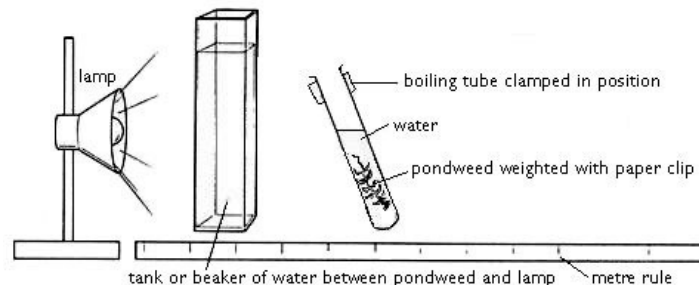
**Materials for Variable Testing:**

Hot water  
Ice  
Thermometer  
Colored filters or light bulbs  
Balance  
Baking soda

**Procedure:**

**Part A: Set Up\***

1. Obtain a sprig (~10 cm) of *Elodea* or *Cabomba*
2. Cut 2-3 mm off the end that will face upward
3. Weigh down the other end by putting a paper clip on it
4. Fill the test tube with water and put the pond plant in it
5. Set up the apparatus as shown below with the test tube 5 cm from the light source



**Part B: Establishing Mean Rate and Investigating Impact of Light Intensity**

1. Look for a stream of bubbles coming from the pond weed
2. Count the number of bubbles produced in 1 minute
3. Repeat twice to determine the mean rate of bubble production
4. Move the test tube so that it is 15 cm from the light source
5. Count the number of bubbles produced in 1 minute
6. Repeat twice to determine the mean rate of bubble production
7. Move the test tube so that it is 25 cm from the light source
8. Count the number of bubbles produced in 1 minute
9. Repeat twice to determine the mean rate of bubble production

*Write a reasonable hypothesis for the experiment:*

*What is the independent variable in this experiment?*

What is the dependent variable in this experiment?

Explain why you should conduct three trials:

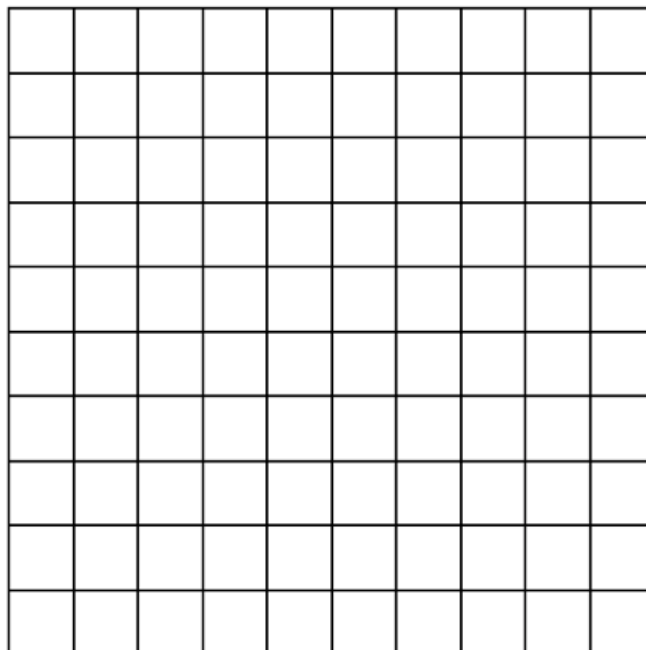
**Table 1. Effect of Light Intensity on Rate of Photosynthesis**

	<b>Trial 1</b>	<b>Trial 2</b>	<b>Trial 3</b>	<b>Average</b>
<b>Number of Bubbles (5 cm)</b>				
<b>Rate (5 cm) (bubbles/minute)</b>				
<b>Number of Bubbles (15 cm)</b>				
<b>Rate (15 cm)</b>				
<b>Number of Bubbles (25 cm)</b>				
<b>Rate (25 cm)</b>				

Use the data from the data table to construct a graph on the grid below.

Be sure to provide:

- An appropriate title
- Labeled axes with appropriate units
- Appropriate number scales
- Correctly plotted data



### **Part C: Testing Other Variables**

1. Choose another factor to vary that might affect the rate of photosynthesis  
**NOTE:** Be sure to keep all other factors the SAME
2. Create a ***testable question*** and ***hypothesis***
3. Leave for 2 minutes
4. Count the number of bubbles produced in 1 minute, three times, as done above
5. Record data in a data table and calculate the mean
6. Change the factor being varied
7. Create a ***testable question*** and ***hypothesis***
8. Leave the apparatus for 2 minutes
9. Count the number of bubbles produced in 1 minute, three times, as done above
10. Record data in a data table and calculate the mean
11. Plot data on a line graph  
**NOTE:** The independent variable should be on the x-axis and the mean bubble rate, in bubbles/minute should be on the y-axis

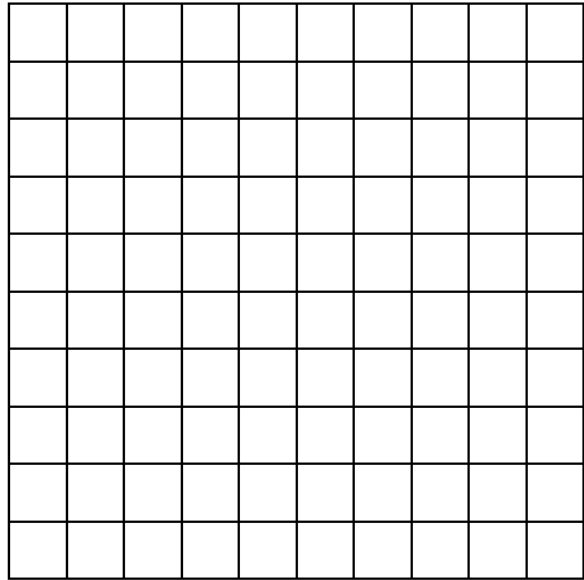
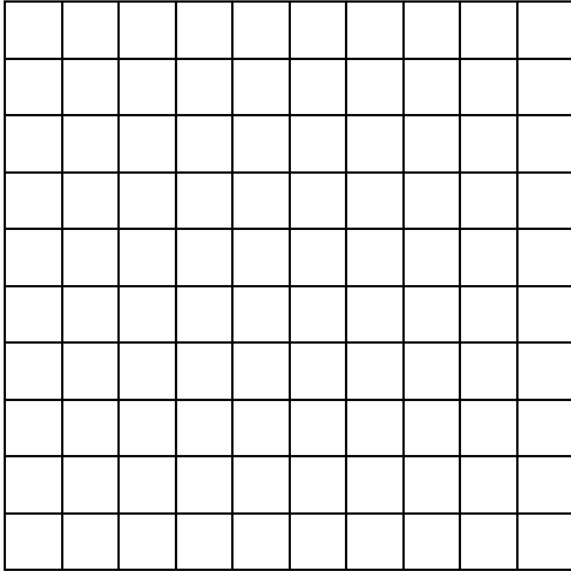
**Testable Questions for Other Variables Investigated:**

**Hypotheses for Other Variables Investigated:**

**Data Tables for Other Variables Investigated:**



**Graphs for Other Variables Investigated:**



*Write a conclusion for your investigation of factors that affect photosynthesis. Be sure to include specific data from your investigations.*

## \*Lab Teaching Notes

### Pond Plants

*Elodea* can be stored in a fish tank on the windowsill in the laboratory or classroom. It is probably a good idea to replace it every so often with a fresh supply. You might want to cut the 10 cm lengths of *Elodea* and set up the test tubes on the day of the experiment, leaving them by a high intensity light to ensure they are bubbling. Sometimes cutting 2-3 mm off the end will induce bubbling or change the size of the bubbles. *Cabomba* (usually available from pet shops as a oxygenator in tropical fish tanks) can be used as an alternative. Some people find it produces more bubbles although it tends to break apart quickly.

This experiment is based on the assumption that gas bubbles being counted are of oxygen, only. Therefore, the production of oxygen is assumed to be proportional to the rate of photosynthesis. For more accurate measurements, dissolved oxygen meters with the LabQuest may be used (see Protocol on Investigating Light Quality).

### Variable Investigation

Students can be allocated to investigate a particular factor, they can choose from a teacher-created list or they can develop their own ideas.

Examples:

- Light intensity or distance of plant from the lamp (light intensity is proportional to  $1/\text{distance}^2$ )
- Temperature of the water
- Carbon dioxide concentration – add 0.05 g of baking soda at a time. The available mass of  $\text{CO}_2$  will increase with each addition.
- Acidity
- Color of light

### Concepts learned should include:

1. Photosynthesis increases as the plants are closer to the light.
2. Photosynthesis increases when the light is overhead. This is demonstrated in real life in a pond. During the middle of the day, the plants in the pond photosynthesize the most which puts the most  $\text{O}_2$  into the water. As the day begins or ends the photosynthesis slows down which decrease the  $\text{O}_2$  in the water. Whereas, in a lake the  $\text{O}_2$  throughout the day is more constant as it is not as dependent on the plant life.
3. Different plants photosynthesize at different rates.

4. Baking soda added to the water will increase the rate of photosynthesis because it adds CO<sub>2</sub> to the water which the plants need to use in the process.

## Explain it with Science

### MODEL 1: Photosynthesis is a Chemical Reaction

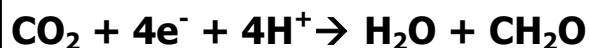
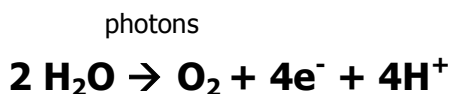


*What two molecules does photosynthesis require? What else does it require?*

*What two products are made during the photosynthesis reaction?*

*This equation is out of balance because there are 1 Carbon, 3 Oxygen, and 2 Hydrogen on the left side and 6 Carbon, 12 Hydrogen, and 8 Oxygen on the right side. Can you put numbers in the boxes that will balance the numbers on both sides? Remember, when you put a number in front of a molecule, it multiplies the number of atoms. (For example, if I put a 2 in front of CO<sub>2</sub>, I will have 2 Carbon and 4 Oxygen. If I put a 2 in front of H<sub>2</sub>O I will have 4 Hydrogen and 2 Oxygen).*

### MODEL 1A (Optional): Half Reactions for Photosynthesis



*What is the overall reaction of photosynthesis?*

*What two products are made during the photosynthesis reaction?*

What two inorganic molecules are used to make glucose?

Which half reaction represents oxidation? Which represents reduction?

## MODEL 2: Chlorophyll Absorption in Photosynthetic Organisms

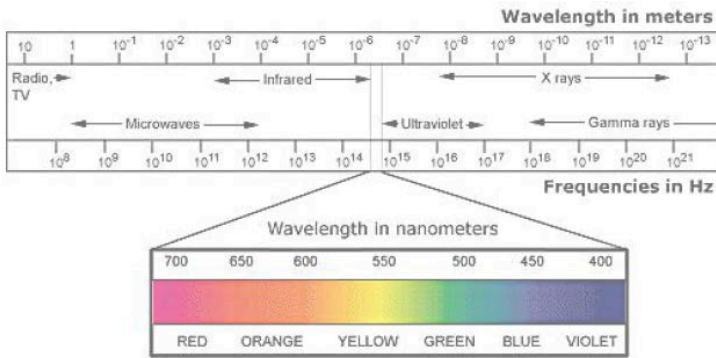


Figure 1: Electromagnetic Spectrum

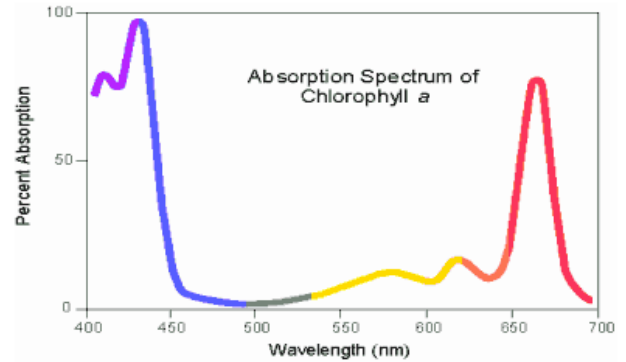


Figure 2: Absorption Spectrum of Chlorophyll A

What color of light has a wavelength of 700 nm?

According to Figure 2, at what two wavelengths does chlorophyll a absorb light the best?

What two colors of light do those wavelengths correspond to?

What color light does chlorophyll a use the least amount of?

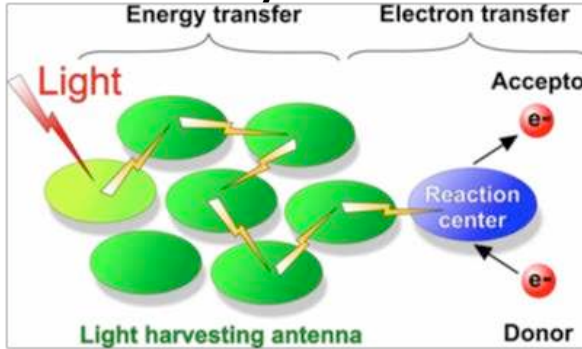
In what organelle would you find chlorophyll?

Based on your knowledge of science and Model 2, why do plants appear to be green?

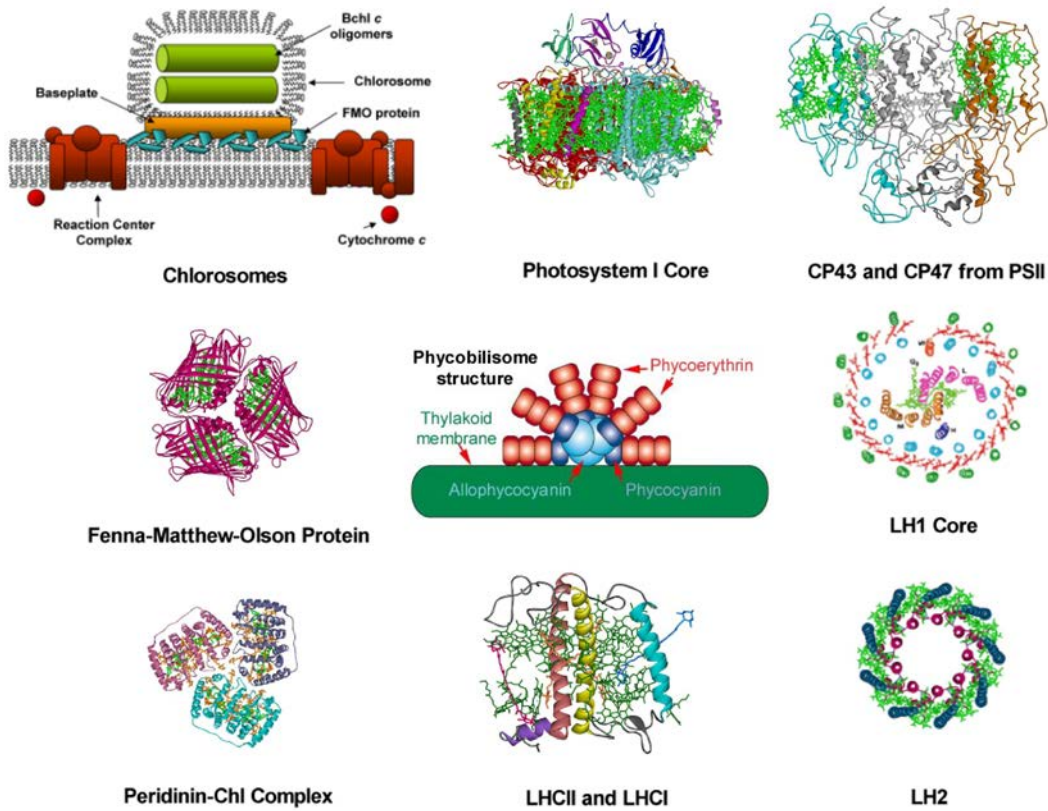
Pigments are defined as substances that interact with light to absorb only certain wavelengths. Explain why chlorophyll a might be considered a pigment.

Summarize the purpose of chlorophyll and the role of light energy in photosynthesis.

**Model 3: Photosynthetic Antennas**



**Figure 1. Photosynthetic energy collection and storage**



**Figure 2. Gallery of different types of natural photosynthetic antenna complexes**

The depictions and associated research are supported as part of Washington University's Photosynthetic Antenna Research Center (PARC), an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science. For more information, please visit <http://parc.wustl.edu> <<http://parc.wustl.edu>> .

Provide a caption to explain what is happening in Figure 1 in the box above.

*Figure 2 demonstrates the diversity of antenna systems used for photosynthetic energy conversion. Why might different organisms have evolved to have such different antenna structures?*

### **Key Questions:**

*List the things that go into a plant for photosynthesis:*

*List the things that come out of a plant as waste from photosynthesis:*

*What is the equation for photosynthesis?*

*Why does counting bubbles tell us about the rate of photosynthesis?*

*How do the results of your experiment relate to this equation?*

*How would a pond change throughout the day based on what you learned from this investigation?*

*How do photosynthetic organisms get and use the matter and energy they need to live and grow?*

*Why is photosynthesis necessary for plants to survive?*

*If you could do the investigation again, what would you change?*

*What other questions do you still have?*

## **Claim, Evidence and Reasoning**

### **Prompt:**

Photosynthesis is a process that takes place in plants and other photosynthetic organisms like algae. Photosynthesis involves chemical reactions with water and carbon dioxide to produce food for a plant. In this process, complex molecules containing carbon react with water to produce oxygen and glucose. In this lab, you completed an experiment to test how the different environmental factors influence the rate of photosynthesis.

Using the data collected during the experiment and your knowledge of science, construct an argument to answer the following question: ***In renewable energy research, algae is used to produce fuel that can be used in cars, trucks, and planes. To produce the fuel, algae must undergo the process of photosynthesis. The director of the plant wants to increase the rate of fuel production. How could she do this?***

### **Directions:**

*Step One: CLAIM*

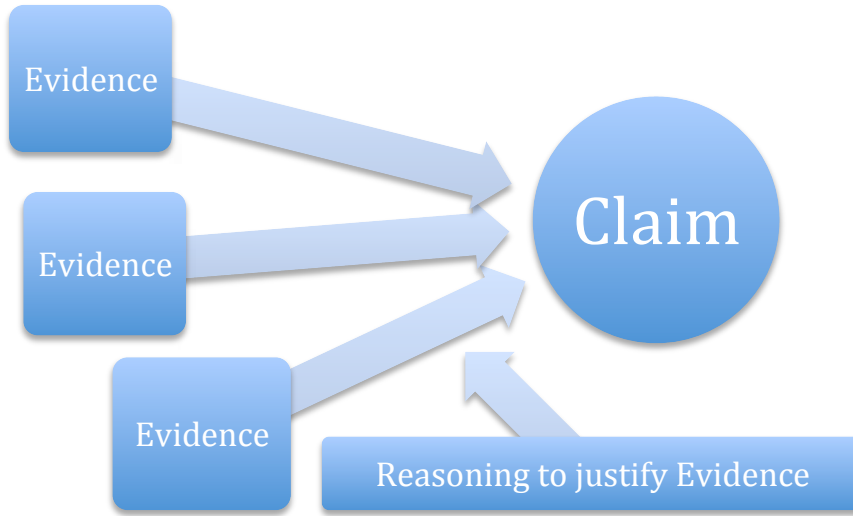
Answer the question clearly and concisely.

*Step Two: EVIDENCE*

Provide scientific evidence that supports your claim. Make sure the scientific facts and/or data you include are both appropriate and sufficient to support your claim. See the attached rubric for a detailed description of evidence.

*Step Three: REASONING*

A justification that shows WHY your evidence supports your claim and includes appropriate scientific principles.



**Template: Use this template to plan your CER argument. When complete, assemble your thoughts into a complete paragraph.**

Question:	Claim:
Evidence	
Reasoning	



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	A	B	C
Claim	Claim is clearly stated, focused and strongly maintained. Claim is introduced and communicated clearly within the context.	Claim is clear, though some loosely related material might be present.	Claim on the issue may be somewhat unclear and unfocused.
Evidence	Scientific data supports the claim. Data is detailed and clearly described. Data is appropriate. Data is sufficient. Use of evidence from sources is smoothly integrated, comprehensive, relevant and concrete.	Scientific data supports the claim, but is somewhat less detailed. Data is appropriate. Data is sufficient. Some evidence from sources is integrated, though citations may be general or imprecise.	Data is incomplete or not scientific. Data is not sufficient to support the claim. Evidence from sources is weakly integrated, and citations, if present, are uneven.
Reasoning	A justification for why the evidence supports the claim using scientific principles. Each piece of evidence may have a different justification for why it supports the claim.	A justification for why the evidence supports the claim is not clear, or not based on scientific principles.	A justification for why the evidence supports the claim is not included or is unclear.

## Evaluate: Performance Task

### Directions to the Student

Today you will be taking a performance task that assesses:

- knowledge of experimental design (the ability to analyze and interpret given data, draw conclusion, and make prediction based on the given data)
- knowledge of photosynthesis

Your work will be graded according to the rubric below. You will have the entire class period to complete this performance task.

Things to remember:

1. Work INDEPENDENTLY! This is NOT a collaborative assignment.
2. Read the **performance event** (part 1) and the excerpt from an **article** (part 2) carefully and think about how to answer the questions.
3. Show all of the work that you did to answer the question with a number 2 pencil. If a box is provided, make sure that all of your work is in the box. If a line is provided to write your answer on, be sure your answer is on the line.
4. If you do not know the answer to a question, skip it and go on. You may return to it later if you have time.
5. If you finish the task early, you may check over your work.

## **Part 1 – The Effect of Light on Photosynthesis**

### **Tiny Bubbles**

Two students were doing an investigation in which they studied the effect of light intensity on the rate of photosynthesis of elodea, an aquatic plant. To determine the rate of photosynthesis, they counted the number of bubbles of oxygen (O<sub>2</sub>) produced in the water. The results of their experiment are shown in the data table.

**Data Table 1**

<b>Light Intensity (Candelas*)</b>	<b>Rate of Photosynthesis (Bubbles per Min)</b>
0	0
400	1
800	2
1200	3
1600	4
2000	6
2400	6
2800	6
3200	6
3600	6
4000	6

\*Candelas: The SI base unit of light (luminous) intensity.

1. What is a testable question or problem that is the basis for this investigation?

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2. Write an appropriate hypothesis for this investigation.

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3. Identify the independent and dependent variables for this investigation.

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4. Identify TWO variables, other than the one investigated, that could have an effect on the rate of photosynthesis.

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5. Identify TWO factors that should be held constant for this investigation.

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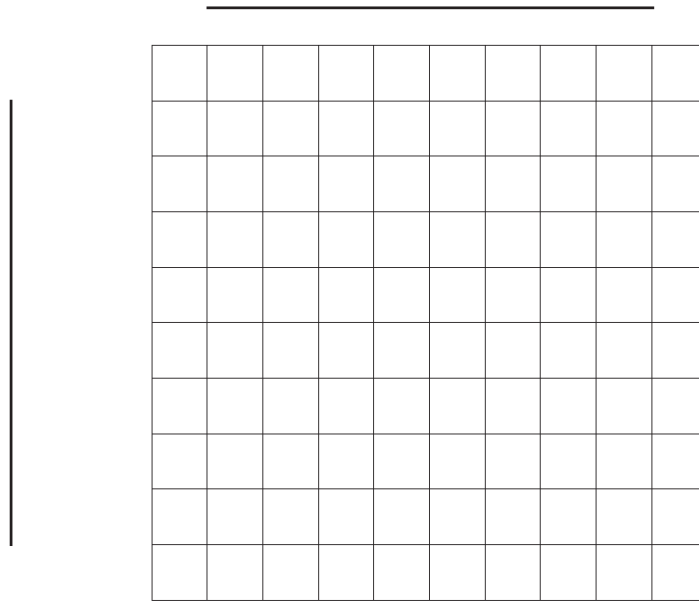
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6. Explain why it is important to hold some conditions constant during an investigation.

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7. Use the data from Data Table 1 to construct a line graph on the grid below. NOTE: Be sure to provide: an appropriate title, labeled axes with appropriate units, appropriate number scales, and correctly plotted data.



8. Describe three essential features of an experimental apparatus that could be used to measure oxygen production by a plant. Explain why each of these features is necessary.

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9. Based on the data in the table, predict what the rate of photosynthesis would be at 4400 candelas.

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## Part 2 – Why Care About Photosynthesis?

### Novel Methods Store Sunshine as Fuel<sup>1</sup>

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<sup>1</sup> This excerpt is taken and modified from the article “Novel Methods Store Sunshine as Fuels” published on the Scientific American website: <http://www.scientificamerican.com/article/novel-methods-store-sunshine-as-fuel/>

The sun is the most abundant power source on Earth, but new designs soon hitting the market could keep its energy flowing even after sunset.

Researchers are exploring various strategies to put sunshine on tap, converting the sun's energy into fuels that can be stored, transported and used as needed.



One storage method is **hydrogen** from a **thin, flat solar leaf** (*ClimateWire*, March 29).

"The [leaf] absorbs that light and **generates electrons**," said Tom Jarvi, chief technology officer at Sun Catalytix, the company bringing the technology to the market. He said the free electrons on the leaf's surface then interact with water, **catalyzing its split into oxygen on the leaf's light side and hydrogen on the dark side**. The mechanism **mimics how plants convert sunlight into energy**, hence "leaf."

"This particular result is a combination of several things that have not been pulled together in the past," said Jarvi. In the paper, the leaf was **wireless**, with **no external inputs or electrodes**, and was **made with low-cost materials like silicon and cobalt**. In addition, the device yielded 2.5 percent efficiency in converting light to hydrogen.

The goal now is to reduce costs even further while increasing the system's efficiency.

"Our real, sincere focus at this point is springboarding off this leaf result and working on the nanoscale," said Jarvi. Mike Decelle, president and CEO of Sun Catalytix, said the current strategy is to create nanoparticles that can produce hydrogen from water. "The way to visualize this is that instead of a large-scale solar cell, you have billions of solar cells," said Decelle. "That will deliver the **lowest-cost hydrogen** we're striving for."

1. Based on the excerpt above, how does an artificial leaf mimic the action of a real leaf?

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2. Although apparently not yet being mass produced, these artificial leaves are promising in terms of production costs. Identify at least TWO cost-effective features of these artificial leaves from the article.

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3. Knowing what you know about the mechanism – and the components involved – in photosynthesis, propose a possible area of research that aims at increasing efficiency in solar technologies. Justify your response.

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**Rubric**

NOTE: Notes to grader is highlighted.

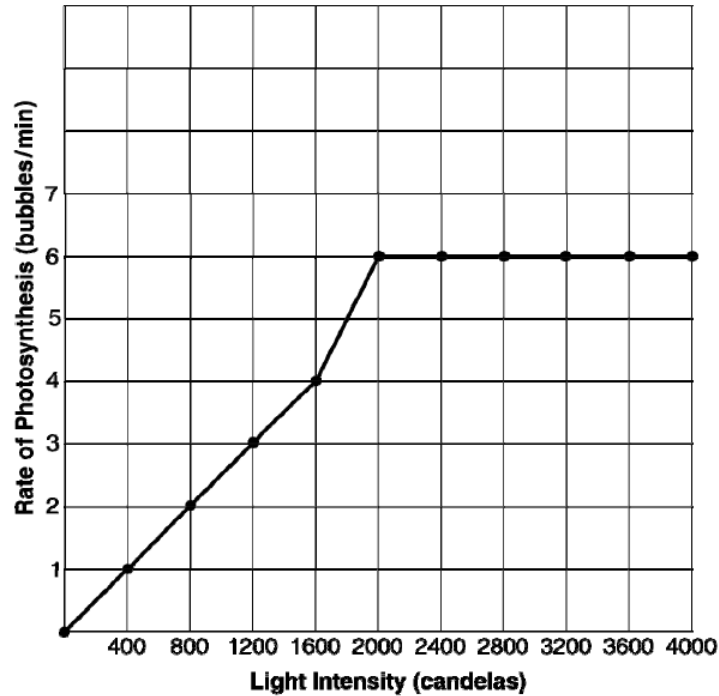
**Part 1 – The Effect of Light on Photosynthesis**

1. **1 point** – any reasonable testable question or statement

2. **1 point** – any reasonable hypothesis based on the testable question or statement of a problem that predicts an effect, or the lack of effect, of the independent variable on the dependent variable
3. **1 point** – correct identification of variables. NOTE: No point is awarded if variables are switched. Independent variable: light; Dependent variable: rate of photosynthesis/rate of production of oxygen
4. **1 point for each variable, 2 points maximum** – accept any two of the following: length of elodea sprig, number of leaves on sprig, age of elodea, amount of dissolved carbon dioxide, color of light/wavelength, pH
5. **1 point for each variable, 2 points maximum** – accept any two of the following:
  - length of elodea sprig
  - amount of water in reaction chambers
  - same size of reaction chambers
  - amount of dissolved carbon dioxide (baking soda)
  - type of light
  - pH
6. **1 point** – ensure any observed effect is due to/correlated with the independent variable
7. **3 points possible** – correct orientation of x (independent) and y (dependent) axes (1 point); correct scale and label axes with title (1 point); curves plotted (1 point)



**Light Intensity and Rate of Photosynthesis**



8. **3 points maximum** – identify and explain three essential elements of the experiment. **Accept** any of the following:
- method to collect released  $O_2$  (funnel, test tube, counting bubbles)
  - closed system
  - equal numbers of organisms in experimental and control (cut plants to equal length)
  - timer
9. **1 point** – correct prediction and explanation. **NOTE:** No point is awarded if no explanation is offered. **Six (6) bubbles**

### Part 2 – Why Care About Photosynthesis?

1. **1 point, 1 point for elaboration** – correctly identify that the artificial leaf harvests the energy in sunlight to generate electrons that can do work. One elaboration point can be earned for stating that the “high energy” electrons then split water into oxygen and hydrogen which then can be stored to generate energy.
2. **1 point** – correctly identify that the artificial leaves require no external electrodes and made with low-cost materials like silicon and cobalt.
3. **2 points** – identify a reasonable area of research that is connected to understanding of mechanism and/or components of photosynthesis. **Accept any of the following:**

- examine photosynthetic pigment structures and produce similar synthetic “pigments” to more efficiently capture solar energy (mimicry)
- design more efficient ways to transfer the energy captured as the current low efficiency of solar technologies is directly related to inefficient energy transport
- identify the earth-abundant elements that can be used as cost-effective alternates to the rare/expensive elements in current photovoltaic devices

# Solar Energy Kit #4: Investigating Photosynthesis

