Artificial Photosynthesis: Mimicking Plants to Produce the Fuel of the Future

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This curriculum unit is recommended for:
Honors Biology
Biology

Keywords: Energy, photosynthesis, artificial photosynthesis, biomass, carbon emissions, fossil fuel, geothermal, hydropower, nuclear power, solar energy, wind energy, thylakoid, stroma, chloroplast, and chlorophyll.

Teaching Standards: See Objective section and Appendix 1 for teaching standards addressed in this unit.

Synopsis: Photosynthesis is a topic in science curricula that students have a difficult time conceptualizing due to the fact that it occurs inside a tiny organelle, the chloroplast. This curriculum unit addresses this obstacle by providing students with background information on photosynthesis, and then several hands-on labs in which they are required the measure the amount of photosynthetic activity occurring. This unit will also include strategies for relating photosynthesis to other energy production techniques we use to provide energy and electricity for everyday use. Students will conduct research into various methods of energy production and will discover how scientists today are attempting to mimic the process of photosynthesis through artificial photosynthesis, in order to create a new environmentally friendly and sustainable form of energy production.

I plan to teach this unit during the coming year to 90 students in Honors Biology.

Artificial Photosynthesis: Mimicking Plants to Produce the Fuel of the Future

Trista L. Hartman

Introduction

I teach at Providence High School in the Charlotte-Mecklenburg School (CMS) system. There are around 2100 students in grades 9-12, and every year I teach about 150 of them. Providence is a racially diverse school with 8.1% African-American, 77.2% White, 4.4% Hispanic, 8.1% Asian and 2.1% other students. Providence has been designated as an Honor School of Excellence due to the fact that about 90% of students enrolled have met their Annual Measurable Objectives set forth by the No Child Left Behind Act.

I teach on a 4x4 schedule, which means that I teach a modified version of the same lesson three times a day to three different classes each semester. This also means that the entire Biology curriculum is covered in just about 20 weeks. My classes include heterogeneous groups of students with varying levels and abilities. I teach every level of student abilities ranging from one section of Greenhouse Biology, an inclusion and foundations class, to one section of regular Biology, and four sections of Honors Biology. I diversify and differentiate my lessons and activities in order to meet the diverse educational needs of all my students. My Greenhouse Biology students learn the basics of biology during the fall semester and when they come back during the spring semester and take Biology, the content they learn builds upon the knowledge gained during the fall semester.

My Biology curriculum is based on the 2009 North Carolina Essential Standard, which includes teaching students about the structure and function of living organisms, ecosystems, evolution and genetics, and molecular biology while still "engaging students in inquiry-based instruction [a]s a critical way of developing conceptually understanding of the science content that is vital for success in the twenty-first century."[i] I pace each semester based on the CMS pacing guide and choose activities that will create inquiry-based science experiences for my students. Most of my lessons and units are broken down into teacher instruction, guided practice, independent investigations and group inquiry activities.

When my students enter my class for the first time, they come with prior knowledge of life science from middle school science classes as well as most recently ninth grade Earth and Environmental Science. Since Biology is a course that requires students to take a READY End-of-Course Assessment, all semester long my students are constantly preparing for success on that exam. Their performance on this exam is used in measuring their growth and progress toward the school's goals as well as the Annual Measurable

Objectives, not to mention also measuring my effectiveness as a teacher in the new teacher evaluation. Due to the time restraints in teaching the entire curriculum in only 20 weeks, as well as preparing for the End-of-Course test, there is very little time left to explore new and exciting topics in Biology that I know my students have a lot of interest in.

Rationale

At Providence High School, many of my colleagues have participated and completed curriculum units for the Charlotte Teachers Institute (CTI). Last spring several of them began talking about the CTI program with me and thought that this would be a great experience for me, especially since I am planning on pursuing my National Board certification next Fall. Of the courses available, the one that stuck out the most for me was "The Nature of Energy: How We Use and Store It to Power Our Everyday Lives"; this course also presented my first challenge, coming up with a good unit that would incorporate energy into my curriculum. Traditionally, when you think of energy you might first think of physics, much like I did. Then while glancing over the biology curriculum I remembered that there are at least three or four times that I am required to teach about chemical energy during the course of the semester (i.e. food webs, photosynthesis and respiration). Those are also the units my students are most familiar with and the ones they complain about already having learned before in previous science classes. With that realization, how could I not find a way to improve any one of those units? I did not want to simply teach my students about the process of creating chemical energy from the sun's energy and how this new form of energy is transferred between trophic levels until it becomes used by the organisms in order to sustain daily functions. My purpose in creating this curriculum unit was to expand my photosynthesis unit to incorporate artificial photosynthesis in order make real-world connections and heighten student learning and interest without repeating material learned either in middle school or in Earth and Environmental Science class.

Every semester when the units involving photosynthesis, food webs, and cells come up, students of mine say, "we've learned this before, why are we learning it again?" When I hear this, my first reaction is sadness because I want them to be excited about our upcoming unit, not dreading it. My second reaction and usual response is, "well you haven't learned it like this before!" That usually gets them excited again, but I am constantly trying to evaluate their prior knowledge and reassess my units in order to make them as engaging and exciting as possible. I want each and every unit of mine to be as exciting as it is when we cover biotechnology (i.e. cloning, stem cells, transgenic organisms, etc.). I want my students to be amazed at the awesomeness of biology. I want them to ask questions and find the answers to those questions. And I want them to thirst for more knowledge about what they learn about while still adhering and achieving the goals set forth by the Essential Standards and Common Core.

My students learn the basics of photosynthesis in their middle school science classes. By the time they get to my class they know the purpose of photosynthesis, which organisms use it, and the role of this process in the carbon cycle. However, they do not have a thorough understanding of how important this process is to the survival of all heterotrophic organisms and specifically how the sun's energy is converted into chemical potential energy, which is then converted into other forms of energy necessary for organisms to sustain life. I am also certain that very few of my students are aware of the experiments and technologies current biologists, physicists, engineers, and mathematicians are currently designing in order to mimic the process of photosynthesis in order to create a new form of "green", sustainable energy. Based on these reflections I have decided to revamp my photosynthesis unit in order to increase rigor and student understanding of this biological process, as well as expose my students to real-world, cutting edge research in the biological community.

I plan for this unit to last approximately 2 weeks on a 4x4 schedule. During this unit my students will participate in directed instruction, research groups, as well as hands-on activities and labs. My students will begin the unit by recalling what they already know about photosynthesis which will then be followed by completing in-depth notes and creating a concept map of the photosynthetic process. After they have completed these activities they will also conduct two labs; one lab will require them to explore the chloroplasts inside an aquatic plant by using a microscope, and during the other lab they will measure a plant's photosynthetic productivity by measuring how high the plant floats in a beaker of water when exposed to various amounts of light. These labs will be followed by an activity where students will determine the necessity of everyday items and the amount of energy used to create those items. Then they will research various methods of energy production and create a presentation about the benefits and consequences of using these different methods of energy production and will participate in a class discussion. Lastly my students will learn about artificial photosynthesis and conduct a lab in which they will use a similar process to artificial photosynthesis in order to generate power for a miniature car.

I intend to incorporate several literacy strategies and resources into my new unit. Also, I will be incorporating the National Common Core Standards for Math and Language Arts. This unit will utilize the Reading and Writing Standards of the Language Arts Common Core to expose my students to a variety of nonfiction sources, such as *Popular Science*, *How It Works*. The use of literature in this unit will provide students with a solid base of understanding throughout duration of this unit and will also be used to demonstrate to my students the importance and relevance of what we are learning in the classroom to experiments scientists are currently running in their laboratories.

Objectives

This curriculum unit will be designed around the 2009 North Carolina Biology Essential Standards that CMS has adopted. Through the use of these objectives I will incorporate lessons, activities, and labs that are aligned with these standards in order to create a rigorous and holistic understanding of relationships between biochemical processes, renewable energy, and alternative fuel sources.

North Carolina Essential Standard Goal Bio.1.1 states: The learner will build an understanding of the relationships between the structures and functions of cells and their organelles.

Objective Bio.1.1.1
Students will summarize the structure and function of organelles in eukaryotic cells (including the nucleus, plasma membrane, cell wall, mitochondria, vacuole, chloroplasts, and ribosomes) and ways that these organelles interact with each other to perform the function of the cell.

Students will identify and understand the function of the chloroplast. Students will examine *elodea* for the presence of chloroplasts under the microscope. Students will also work in paired groups to conduct a lab where they measure the amount of photosynthesis being done in a leaf cutting by how high the leaf is floating in the test tube. Lastly, they will design an experiment to see how various environments affect the leaf's ability to undergo photosynthesis. These labs, procedure and materials lists needed to complete these activities are described during the classroom activities section and the lab report is included at the end of this unit.

North Carolina Essential Standards Goal Bio.2.2 states: Understand the impact of human activities on the environment (one generation affects the next).

Objective Bio.2.2.1
Students will infer how human activities (including population growth, pollution, global warming, burning of fossil fuels, habitat destruction and introduction of nonnative species) may impact the environment.

Students will analyze how human activities have impacted the environment. This unit will contain two activities that will adhere to this goal. The first activity will include students examine a bag of "garbage" to determine if items are a luxury or necessity, and discuss why those items had been discarded. The second activity will require students to analyze and evaluate the environmental impacts and sustainability of production and distribution methods and practices used to create and deliver these products to global consumers. These activities, procedures, and materials list needed to complete these activities are described during the classroom activities section.

Objective Bio.2.2.2
Students will explain how the use, protection and conservation of natural resources by humans impact the environment from one generation to the next.

Students work in groups to research the benefits and consequences of using various methods of energy production. From their research they will create a presentation about their source of energy and will participate in a class discussion. They will then use what they have learned about sustainable practices and photosynthesis and apply it to artificial photosynthesis. Students will use the process of artificial photosynthesis to turn water in to hydrogen and oxygen gas, which is then used to generate fuel for a miniature-motorized car. The activities, procedures, and materials list needed to complete these activities are described during the classroom activities section.

Scientific Content for Teachers

Vocabulary

For this unit, students will need to know several vocabulary terms. Below are the vocabulary terms my students will need to know.

Artificial Photosynthesis: a sustainable practice which requires the use of sunlight, water and carbon dioxide to produce carbon-neutral fuel sources such as hydrogen, which can be used as a replacement for traditional fossil fuels, solar energy, wind energy, or hydropower.

Biomass Energy: the process used to burn dead organic materials such as dead plants and animals in order to produce heat or steam, which can be used to heat homes or produce electricity.

Carbon Emissions: the release of carbon, in the form of the gas carbon dioxide (CO_2), into the atmosphere; these emissions are caused by an increase in deforestation and burning of fossil fuel, which ultimately magnifies the Earth's greenhouse effect, raising average temperatures on Earth

Electrolysis: the process by which energy is used to break water into hydrogen and oxygen gas.

Fossil Fuel: "a fuel such as coal, oil, or natural gas which is formed in the earth from dead plants or animals."[ii]These resources are found deep within the Earth and are extracted in order to produce heat, electricity, and power.

Geothermal Energy: is a sustainable practice, which requires utilizing the heat energy radiating from within the Earth and turning it into power used to heat houses or provide electricity.

Hydropower: a form of renewable energy that is used to produce energy by running high volumes of water over a turbine to produce electricity.

Nuclear Power: also known as nuclear fission and is achieved when the nucleus of atoms are split apart and release the energy stored in their bonds.

Photosynthesis: the biological process that takes place in the chloroplast of a leaf cell where sunlight, carbon dioxide, and water react to make the sugar glucose.

Solar Energy: the sun provides the source for all energy on earth. The sun's energy can be captured and converted into other forms of energy to fuel our everyday lives from heating our homes to producing electricity.

Wind Energy: wind is produced when the sun heats up air, which then rises because when molecules heat up they spread out, move faster, and rise above colder, slower molecules. Since there is a void where the hot air previously was, cooler air flows into the open space creating wind. Wind can be used to create electricity when used to move a turbine.

Photosynthesis

Photosynthesis is a two part biological process. The first part is called Photosystem II or Light Reaction because it requires sunlight to break apart water into hydrogen ions and oxygen gas. During this part of the chemical reaction the plant will transport water from its roots to its leaves. The water will then be delivered to the chloroplasts within each cell, but more specifically to a thylakoid (a small membrane bound sac found in the chloroplast which contains the green pigment chlorophyll) where it will react with the energy from the sunlight and be split apart into H^+ ions and oxygen (O_2). The oxygen is then released as a waste product through the stomata of the leaf back into the atmosphere. The H^+ ions will then be used during the next part of the chemical reaction called Photosystem I also called the Calvin Cycle or the Dark Reaction because it does not require the energy from sunlight to power this reaction. During this reaction the CO_2 brought into the plant through the stomata on the underside of the leaf is transported to the stroma (the gelatinous matrix surrounding the thylakoids in the chloroplast) and will react with the H^+ ions and turn into the sugar glucose, which the plant and other animals that consume the plant, will use as to produce cellular energy, adenosine triphosphate (ATP) during cellular respiration.

Artificial Photosynthesis

Artificial Photosynthesis is the process by which scientists are attempting to copy the biological process of photosynthesis. During this reaction scientists mimicking the process of how a plant converts sunlight into chemical energy in the form of glucose, however, instead of creating glucose they are trying to produce liquid hydrogen or possibly methanol, which could be stored and later used to directly fuel a car, produce heat, or provide electricity for our houses. Scientists have found three types of catalysts or substances, which are able to react with the sunlight to initiate the reactions of splitting apart water molecules. These catalysts include: manganese, dye-sensitized titanium dioxide and cobalt dioxide. The use of artificial photosynthesis as a method of fuel production has many more possibilities than photovoltaic (solar) cells because unlike the weather-dependent solar cells, the process of artificial photosynthesis can produce a fuel that is storable as well as potentially various types of fuel. This process also will not produce as much or any harmful waste when compared to the burning of fossil fuels or production of solar cells.

Benefits and Shortcomings of Current Methods of Energy Production

Current methods of fuel include fossil fuels (coal, oil, and natural gas), nuclear power, geothermal energy, hydropower, wind energy, biomass energy and solar energy. Each of these practices has their own benefits and drawbacks. These methods of energy production are broken down and include a brief description of their benefits and deficits for each since a long-term solution to global energy needs may include a variety of energy sources.

Biomass Energy

Biomass is generated from all organic materials (i.e. plants, animals, bacteria, protists, etc…). These materials are considered organic because they contain carbon-based molecules, which are ideal for easily generating energy. Examples of materials used to generate biomass energy include wood, manure, and garbage. The use of biomass as a form of energy has many benefits and deficits. A benefit to using biomass as a form of energy is that it is a renewable energy source; we can plant more trees, produce more manure, and create more garbage. Waste products can be burned to produce energy thereby reducing the volume of waste and the amount of space it is taking up. Simultaneously, the process of burning these materials also produces large quantities of greenhouse gases. Landfills are often used as a deposit site for waste products, and landfill produce large quantities of methane. Methane is a considered one of the greenhouse gases, which is not good. However, methane can be captured and burned to create power, thereby reducing its impact on global warming. For additional information on this form of energy, see the bibliography for the link to the website *Energy Kids*.

Fossil Fuels

Fossil fuels are considered a nonrenewable energy source since they come from ancient organisms that lived and died, and have been buried underground for a long time. The organic deposits are high in carbon, which is what makes them so good at creating heat, electricity, and power. Currently fossil fuels make up approximately 83% of the United States' energy consumption. One drawback of using fossil fuels is that once all the oil, natural gas, and coal are used up there is no more. Besides being a nonrenewable energy source, fossil fuels produce large amounts of carbon dioxide, which magnifies the greenhouse effect. One benefit of fossil fuels using coal is that it is actually very abundant, easy to find, and [iii]"relatively inexpensive to produce and convert to useful energy". Due to the many negative side effects of using the government is imposing stricter guidelines for companies and individuals obtaining and using fossil fuels. For additional information on this form of energy, see the bibliography for the link to the website *Energy Kids*.

Geothermal Energy

"Temperatures hotter than the sun's surface are continuously produced inside the Earth by the slow decay of radioactive particles."[iv]A benefit to using geothermal energy is that is essentially a "free" source of energy, which can be used to generate heat for homes as well as electricity. A drawback is that most geothermal resources are located near plate boundaries; if you do not have easy access to these locations, this source of energy may not be ideal. For additional information on this form of energy, see the bibliography for the link to the website *Energy Kids*.

Hydropower

Hydropower is made by harnessing the flow of water to produce power or electricity. A benefit to using hydropower is that it is generates "clean electricity" meaning that the process of making this energy does not directly produce greenhouse gases.[v]However, the building of dams does have environmental impacts including obstructing the migration of fish, changing the natural flow of water, as well as possible relocation of people due to flooding. For additional information on this form of energy, see the bibliography for the link to the website *Energy Kids*.

Nuclear Power

Splitting atoms apart by breaking the bonds found within the atom creates nuclear power. This process does not directly produce carbon dioxide or other greenhouse gases, which is a benefit to using this type of energy. However, the process of finding, cleaning the uranium and making the nuclear reactor does require a large amount of energy. Also, nuclear power produces radioactive waste, which is dangerous to human health. For

additional information on this form of energy, see the bibliography for the link to the website *Energy Kids*.

Solar Power

Solar power uses the sun's energy to produce heat and electricity. A major benefit to using this as a form of energy is that there is no harmful product directly made that might increase greenhouse gases or pollute nearby water. However, there are drawbacks to using solar energy because the process of making the photovoltaic or solar cell does produce some nasty, harmful products. Also, when areas are used for solar farms there is an increase of temperature around the cells because of the concentration of light coming from the sun as well as the light being reflected. This can alter the natural habitat around the solar farm, and as such the land cannot be used for any other purpose besides being a solar farm. For additional information on this form of energy, see the bibliography for the link to the website *Energy Kids*.

Wind Energy

Wind energy is converted into heat or electricity when wind turbine is moved. The process of converting wind energy into electricity does not produce any harmful products that could add to global warming or pollution, which is a good thing. Unlike solar farms, the land designated for a wind farm can be used for other things like a pasture for cattle since the windmills are so tall. However, in order to have wind farms, areas will need to be cleared of trees in order to make room for the large windmills. Also, they are very loud and have been known to harm birds that fly through those areas. For additional information on this form of energy, see the bibliography for the link to the website *Energy Kids*.

Teaching Strategies & Classroom Activities for Teachers

Introductory Activity

Photosynthesis Carousel Activity

The introduction for this unit will include reviewing the process of photosynthesis with my students. I plan to have students complete a "carousel" activity where they will circulate around my classroom to pieces of paper on the walls that contain several prompts. At each of these stations students will be given a 2-3 minutes to think with the other individuals in their group to come up with as much information as they can about the prompt in front of them. When signaled at the end of the 3 minutes, each group will rotate to the next station. Student groups will continue to rotate until they begin having struggle with coming up with new ideas to add to the prompts. At that point they will be asked to evaluate the most important piece of information written on the prompt, which

they will then share with the rest of the class. This is a great tool to use to get all students to share their ideas without the fear of embarrassment in front of the entire class. Also, it is a great to that I use to assess student information prior to the start of a new unit. Below is a list of materials needed to complete this activity and well as suggested prompts for each station.

Materials: 6 large pieces of paper, tape, markers, and timer.

Suggested Prompts:
What is the source of energy that powers your daily activities?
What role do pigments have in the process of photosynthesis?
What factors affect photosynthesis?
Where do plants get the molecules necessary for photosynthesis?
How are forests and lungs related?
What characteristics make something a necessity?

Photosynthesis Notes: Appendix 1

After this activity, we will go through the notes on photosynthesis. At the end of these notes students will understand and explain what organisms use the process of photosynthesis, where it occurs in the cell, what happens during the two photosystem, as well as the balanced equation? Using these notes, students will generate a concept map diagramming out the process of photosynthesis.

Elodea Lab: Appendix Two

In this activity students will use the aquatic plant *elodea* in order to examine the chloroplasts found in plant cells by viewing the leaves under a microscope. The *elodea* is a simple aquatic plant and has basic plant cell structures, which make them excellent specimen for this lab. Students will work in groups of two for this lab. They will use the microscope to examine the *elodea* under low and high power. At each magnification they will diagram what they see in their field of view as well as label the parts of the chloroplast they can see.

Materials: Microscopes, slides, slide covers, water, droppers, *Elodea* sprig

Photosynthesis & the Floating Leaf Lab: Appendix Three

During the next activity, students will complete the Floating Leaf Lab. This is an inquiry-based lab that will require students to take their prior knowledge of plants and photosynthesis and apply it in order to design and test how to make a leaf cutting float the highest in a test tube. The ability of the leaf to float is determined by the amount of photosynthesis being done within the leaf's chloroplasts. The more photosynthesis, then

the more oxygen produced. Since oxygen is a gas, the more there is in the leaf cutting, the more buoyant it become and the higher it floats in the test tube. Students will have options such as changing the temperature of the water, the amount of sunlight, the distance from the light source, the size of the leaf cuttings, etc. to see how these factors impact photosynthesis' productivity.

Materials: sodium bicarbonate, liquid soap, 20 mL syringe, spinach leafs, single-hole punch, timer, light source, stirring rods, plastic cups, beakers, tin foil.

Garbology & On the Road to Retail Activities

At this point in unit I would like to review and compare the process of photosynthesis to the processes of energy production and use by humans (i.e. electricity). These activities come from the two-week unit, *Buy, Use, Toss? A Closer Look at the Things We Buy*, by *Facing the Future*. In the first activity, *Garbology*, students will work in groups of four and will be given bags that contain various materials. As a group, they will have to sort through those materials and determine which are necessities and which are luxuries. Then, they will break up into groups of 2 to complete the *On the Road to Retail* activity where they determine how much energy is require to create, transport, and purchase those items. I will then have my students come up with the different methods of energy production that are currently available and used to produce or transport those items, as well as energy that is necessary power their homes, vehicles, etc. (solar power, wind power, hydropower, geothermal, nuclear, etc…)

Materials for Garbology: Reused plastic/paper bags, assortment of "trash" materials, handout.

Materials for On the Road to Retail: handouts, which can be printed from the unit.

Energy Research & Presentation Activity

Students will then be broken up into groups and will research the various methods of energy production (biomass, fossil fuel, geothermal, hydropower, nuclear, solar, and wind). Through their research, each group will acquire facts about the benefits and consequences of using the various types of energy production. The information gathered throughout their research will be used to create a 5-7 minute presentation on the benefits and drawbacks to each type of energy. At the end of these presentations, the class as a whole will participate in a discussion about how to reduce our carbon footprint.

Artificial Photosynthesis: H_2GO Lab: Appendix Four

After the presentation and class discussion about energy I will introduce my students to artificial photosynthesis. They will compare this process to the other methods of energy

production and as well as photosynthesis. In order to demonstrate the process of artificial photosynthesis, my students will participate in a lab where they will use sunlight to split water molecules into usable energy (H_2 and O_2) to fuel a motorized car.

Materials: distilled water, fuel cell car, timer, meter stick, syringe, and light source.

Appendix One

Implementing Common Core Standards

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CCSS.ELA-Literacy.RST.9-10.2 *Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.*

Students will conduct research into various forms of energy production. Using their research, students will create a presentation for the class about that form of energy production.

CCSS.ELA-Literacy.RST.9-10.3 *Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.*

Students will follow the procedure for several labs, obtain data and record observations.

CCSS.ELA-Literacy.RST.9-10.7 *Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.*

Students will generate graphs depicting the data obtained during the labs.

Appendix Two

Name: _____
Period: _____ Date: _____

Photosynthesis Notes

- What is photosynthesis? The conversion of **light** energy into the chemical energy of **carbohydrates (sugars/glucose)**

- What organisms undergo photosynthesis? **Plants/autotrophs**

- What is the chemical equation? **$6H_2O + 6CO_2$ + Sunlight → $C_6H_{12}O_6 + 6O_2$**

LIGHT REACTION
(Photosystem II)

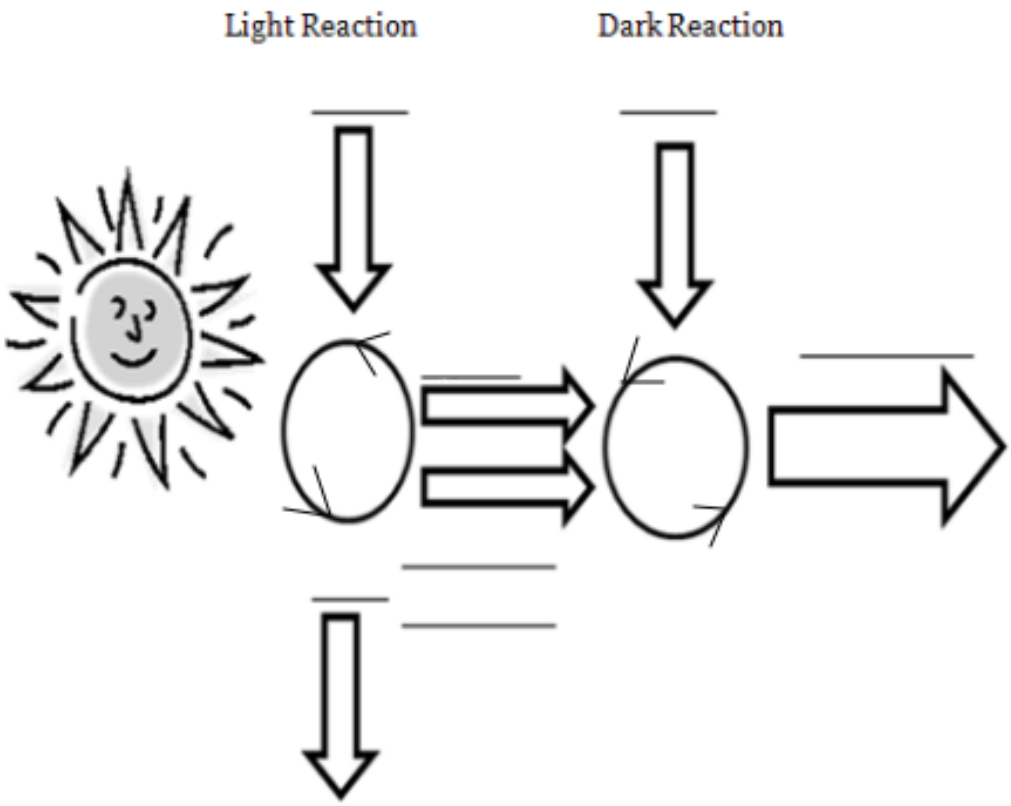
- Occurs in the **thylakoid** of the **chloroplast**

- **Chlorophyll** traps **light energy** and splits **water** into **oxygen** and **hydrogen**

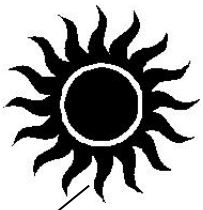
DARK REACTION
(Photosystem I)

- Occurs in the **stroma** of the **chloroplast** and takes place in **dark** or light

- **Hydrogen** from the light reaction combines with **CO_2** to produce **glucose.**



Light Reaction

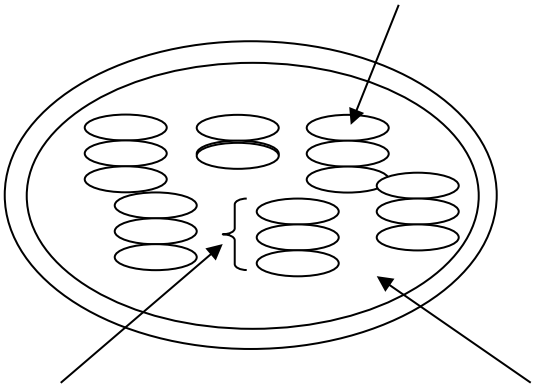


Sun provides **light** energy, which gets converted into **chemical** energy by the **chlorophyll** molecule.

- This energy is used to **split** the **water** molecule into **hydrogen** and **oxygen**

Dark Reaction
(Aka Calvin Cycle)

When the **hydrogen** from the light reaction combines with **carbon dioxide,** the light energy is stored as **chemical** energy in the bonds in the **glucose** molecule.



Appendix Three

Name: _____
Period: _____ Date: _____

Elodea Lab

Objective: Students will observe the chloroplasts within plant cells using a microscope.

Background: Plants are considered autotrophs because they are capable of converting their own form of energy from sunlight. This process is known as photosynthesis. *Elodea* is a common water plant that shows the chloroplast well. Photosynthesis occurs within the chloroplast of a plant cell due to the concentration of light capturing pigments known as chlorophyll. By capturing light energy, plants are able to convert it into high-energy sugars that the plant itself as well as other animals are then able to use to fuel their everyday lives.

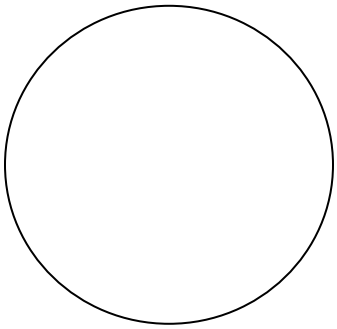
Materials:

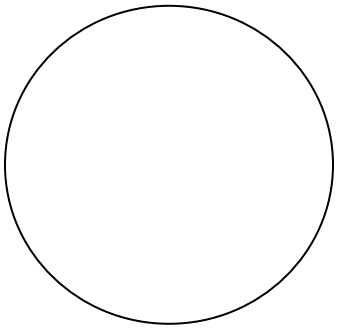
Microscope	Slide Covers	Dropper
Slides	Water	*Elodea* leaf

Procedure:

1. Bring a microscope back to your desk, making sure to carry it with both hands.
2. Take one *elodea* leaf from the sprig.
3. Prepare a wet mount of the *elodea* leaf.
    a. Add a drop of water to your slide.
    b. Place the *elodea* leaf on top of the water droplet.
    c. At a 45° angle, slowly lower the slide cover onto the slide.
4. Using low power of your microscope, position your slide so you are looking near the edge of the leaflet. Locate green, oblong cells.
5. Draw and color what you see under low power.
6. Change your microscope to medium power and focus before examining these cells under high power.
7. Once focused under high power, draw and color what you see.
    a. Note the small green organelles inside each cell. These are chloroplasts. Movement of the chloroplasts within the cell often can be observed. This is called “cytoplasmic streaming”.
8. Be sure to label the *cell wall, chloroplast, and cell membrane* of one *elodea* cell.

Observations:





Low Power: _____ High Power: _____

Analysis Questions:

1. Describe the overall shape of an *Elodea* cell. _____
    a. Is *elodea* a plant or animal? _____
    b. Is a cell wall present? _____
2. Look at the chloroplast:
    a. Describe the color. _____
    b. Describe the shape: _____
3. Can you see the 3 parts of the chloroplast? _____ Why or why not? _____
    _____
4. Within what cell part do chloroplasts lie? _____
5. What is the function of the chloroplast? _____
6. Are chloroplasts usually present in animal cells? _____Explain. _____
    _____
7. Why does each plant cells contain multiple chloroplasts? _____
    _____

Appendix Four

Name: _____
Period: _____ Date: _____

Photosynthesis and the Floating Leaf Lab

Objective: Students will be able to observe and measure the effect of various environmental conditions on the amount of photosynthesis occurring inside plant cells.

Background: Photosynthesis is the process by which plants convert water and carbon dioxide into high-energy sugars (glucose) through the use of sunlight. Plants are able to absorb and convert the sun's energy into glucose through the use of pigments found inside each plant cell. In this lab, you will be using leaf disks to measure the relative amount of photosynthesis occurring under various environmental conditions. Leaf disks normally float, however when the open spaces inside the disks become concentrated with carbon dioxide, the density of the disk increases and will cause the disk to sink. Sodium bicarbonate will be added to the water in order to provide the carbon needed for photosynthesis. As the leaf discs begin to undergo photosynthesis, oxygen gas will be produced, which will increase the disks buoyancy and cause the disk to rise.

Materials:

Sodium Bicarbonate	Spinach Leaf	Light Source	Beakers
Liquid Soap	Hole Punch	Stir Rods	Tin Foil
20 mL Syringe	Timer	3 Plastic Cups	

Procedure:

1. Label 3 plastic cups as following: light, ambient light, dark.
2. Mix a small scoop (1/8 teaspoon) of sodium bicarbonate and 300 mL of water in a beaker.
3. Add one drop of soap to the solution.
4. Using the hole punch, create 30 uniform leaf disks from the spinach leaves. Avoid major leaf veins.
5. Remove the plunger of the syringe and place 10 leaf disks inside.
6. Carefully, replace the plunger making sure not to crush the disks.
7. Push the plunger until only a small amount of air remains in the barrel.
8. Draw up 5 mL of sodium bicarbonate into the syringe.
9. Invert the syringe and gently tap the side to make the disks float in the liquid.
10. Slowly and gently push the plunger so that as much air as possible can be removed.
11. Create a vacuum by placing your finger over the opening in the syringe and carefully drawing the plunger back. Hold this for 10 seconds while gently

swirling the syringe to make sure the disk are becoming dispersed throughout the solution.

12. Slowly let go of the plunger in order to release the vacuum.
13. Repeat step 11 two-three more times until all disks sink. If the disks do not sink, add more soap to the solution.
14. Pour the disks and solution into the first cup.
15. Add the bicarbonate solution until the cup is ½ full.
16. Place the cup under the corresponding light conditions and begin timing.
    a. For the dark trial, wrap a beaker with tinfoil and cover the plastic cup when not taking observations.
    b. For light trial, place the cup directly under the lamp.
17. Record the number of floating disks at the end of each minute in the tables below.
18. Gently swirl the disk with a stir rod to get them unstuck from each other and the cup.
19. Repeat steps 5-18 for the remaining light conditions.

Prediction:

- How will the different light conditions affect the number of floating leaf disks?

_____

_____

Tables

Light	
Time (min)	# of disks floating
1	
5	
10	
15	
20	
25	
30	
35	

Ambient Light	
Time (min)	# of disks floating
1	
5	
10	
15	
20	
25	
30	
35	

Dark	
Time (min)	# of disks floating
1	
5	
10	
15	
20	
25	
30	
35	

Analysis & Questions:

1. Graph your results for all three trials on a piece of graph paper. Make sure to label your axes and provide a key for each trial.

2. Which trial worked best? Explain. _____

_____

_____

3. How does light intensity affect the rate of photosynthesis? Explain. _____
   _____
   _____

4. If you were to boil the leaf or use ice water, what kind of results would you expect? Explain. _____
   _____
   _____

Appendix Five

Name: _____
Period: _____ Date: _____

Artificial Photosynthesis Lab: H_2GO

Objective: Students will mimic the process of artificial photosynthesis in order to produce energy to fuel a car.

Background: During photosynthesis, sunlight is used to split water into hydrogen ions and oxygen gas; this is called electrolysis. The hydrogen ions will later be used to create glucose. During artificial photosynthesis, sunlight is used to split water into hydrogen ions and oxygen gas as well. These products will then be stored and when recombined will create the energy (fuel) necessary to power the motorized car by creating a current.

Materials:

100 mL Distilled Water	Timer	Syringe
Fuel Cell Car	Meter Stick	Light Source

Procedure:

1. Pour distilled water up to the "0" line of each cylinder.
2. Place the dome inside each of the container. Make sure there is no trapped air and make sure water is still at the "0" line or carefully remove excess water using a syringe.
3. Connect the tubing to the tops of each dome.
4. Connect the tubes from the domes to the appropriate side of the fuel cell.
5. Connect the black and red cables to the solar panel and fuel cell and place it under direct light for 5 minutes.
    a. Electrolysis should begin happening. Bubbles will start to form in each cylinder, and the water levels may rise.
6. After 5 minutes of charging fuel cell, disconnect from the red and black cables from the solar panel and plug them into the motor.
7. Time how long the car runs and how far it travels and record in table.
8. Repeat steps 4-7, but with various amounts of time letting the fuel cell charge.

Table:

Time Charged (min)	Time Car Ran (min)	Distance Traveled (m)
5		

Analysis & Questions:

1. Graph your results for the four trials on a separate sheet of graph paper. Make sure to include a key for the different trials.
2. What was the effect of the amount of time the fuel cell was "charged" and the amount of time the car ran? Explain. _____
   _____
   _____
3. What do you think would happen if the solar cell was not placed directly under the lamp? Explain. _____
   _____
   _____
4. What possibilities does artificial photosynthesis have as a new energy/fuel source? Explain. _____
   _____
   _____
5. What drawbacks might there be to using artificial photosynthesis? _____
   _____
   _____

[i] (NCDPI 2013)
[ii] (Merriam-Webster 2013)
[iii] (EIA Energy Kids: Coal 2013)
[iv] (EIA Energy Kids: Geothermal 2013)
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