Demonstrating Solar Conversion Using Natural Dye Sensitizers

Subject Area(s)	Science & Technology, Physical Science, Environmental Science, Physics, Biology, and Chemistry
Associated Unit	Renewable Energy
Lesson Title	Dye Sensitized Solar Cell (DSSC)
Grade Level	(11^{th}-12^{th})
Time Required	3 hours / 3 day lab

Summary

Students will analyze the use of solar energy, explore future trends in solar, and demonstrate electron transfer by constructing a dye-sensitized solar cell using vegetable and fruit products. Students will analyze how energy is measured and test power output from their solar cells.

Engineering Connection and Tennessee Careers

An important aspect of building solar technology is the study of the type of materials that conduct electricity and understanding the reason why they conduct electricity. Within the TN-SCORE program Chemical Engineers, Biologist, Physicist, and Chemists are working together to provide innovative ways for sustainable improvements in solar energy technologies. The lab for this lesson is designed so that students apply their scientific discoveries in solar design. Students will explore how designing efficient and cost effective solar panels and fuel cells will respond to the social, political, and economic needs of society today.

Teachers can use the Metropolitan Policy Program Guide “Sizing The Clean Economy: State of Tennessee” for information on Clean Economy Job Growth, TN Clean Economy Profile, and Clean Economy Employers.

www.brookings.edu/metro/clean_economy.aspx

Keywords

Photosynthesis, power, electricity, renewable energy, solar cells, photovoltaic (PV), chlorophyll, dye sensitized solar cells (DSSC)

Next Generation Science Standards

HS.ESS-Climate Change and Human Sustainability
HS.PS-Chemical Reactions, Energy, Forces and Energy, and Nuclear Processes
HS.ETS-Engineering Design
HS.ETS-ETSS- Links Among Engineering, Technology, Science, and Society

Pre-Requisite Knowledge

Vocabulary:

- **Catalyst-** A substance that increases the rate of reaction without being consumed in the reaction.
- **Chemical Formula-**A collection of chemical symbols and subscripts that show the composition of a compound or substance. Examples: TiO_2, H_2O, SnO_2
- **Chlorophyll-** The organic dye used by living plants in photosynthesis to convert light energy into chemical such as carbohydrates and sugars. It is a compound composed of the elements carbon, hydrogen, oxygen, nitrogen and magnesium.
- **Chloroplast-** The subunit with a plant cell where photosynthesis takes place via the action of light energy on chlorophyll
- **Energy-** Ability to do work, it can chemical, electrical, thermal, light, mechanical, and nuclear. It cannot be created or destroyed but saved in various forms. One way to store a form of chemical energy is in a battery. Measured in Joules (watt-seconds)
- **Fossil Fuels-** Oil, coal, natural gas or their byproducts. Fuel that was formed in the earth in prehistoric times from remains of living cell organisms.
- **Global Warming-** Significant increase in the Earth's temperature over a short period of time due to the result of human activity
- **Green House Effect-** the presence of trace atmospheric gases make the earth warmer than would direct sunlight alone. These gases (carbon dioxide [CO2], methane [CH4], nitrous oxide [N2O], tropospheric ozone [O3], and water vapor [H2O]) allow visible light and ultraviolet light (shortwave radiation) to pass through the atmosphere and heat the earth's surface. This heat is reradiated from the earth in form of infrared energy (longwave radiation). The greenhouse gases absorb part of that energy before it escapes into space. This process of trapping the long wave radiation is known as the greenhouse effect. Scientists estimate that without the greenhouse effect, the earth's surface would be roughly 54 degrees Fahrenheit colder than it is today too cold to support life as we know it. It keeps the earth warm when the sun's energy comes into the earth's atmosphere, about 70% of the energy stays on the planet, and the remaining 30% is reflected into space.

- **<u>Oxidation-</u>** A reaction in which an atom, an ion, or a molecule loses an electron that sometimes (but not always) involves its combination with oxygen. Titanium metal is oxidized Into TiO_2
- **<u>Photosynthesis-</u>** The process in which plants use the energy from light to synthesize organic compounds for their growth for carbon dioxide and water. Plants "fix" carbon dioxide into sugars and carbohydrates using photosynthesis. It occurs via a complex chain of reactions taking place within the membrane in the plant cells.
- **<u>Renewable Energy-</u>** Resources that constantly renew themselves or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro and wood. Although particular geothermal formations can be depleted, the natural heat in the earth is a virtually inexhaustible reserve of potential energy. Renewable resources also include some experimental or less developed sources such as tidal power, sea currents and ocean thermal gradients.
- **<u>Thylakoid</u>**- The basic unit of chloroplast in plants. A sac-like structure consisting of stacks of membranes containing chlorophyll and enzymes.
- **<u>Voltage</u>-** A measure of difference in electrical potential between two electrodes or points (in V). The work per unit charge.
- **<u>Watt-</u>** The electrical unit for power representing the amount of work being done per second. The rate of energy use or production

Learning Objectives

- Students will construct a dye-sensitized solar cell using fruit and demonstrate electron transfer
- Students will analyze how energy is measured
- Students will research technological advances in solar energy and predict future trends in solar.

Introduction

1. Photosynthesis is a biological **oxidation-reduction** process.

CO_2= Electron Acceptor

H_2A= Electron donor

$CO_2 + H_2A + \text{light} \rightarrow (CH_2O) + 2A + 2H_2O$

Carbohydrate generated by reduction (CH_2O)

Product by oxidation ($2A$)

Oxygen evolving photosynthesis water is oxidized and the electrons released are energized and ultimately transferred to CO_2, yielding oxygen and carbohydrate. As organic molecules like carbohydrates were broken down and oxidized by plants and animals, the stored solar energy was released and carbon dioxide originally take from the atmosphere was returned to it. Photosynthesis cycle today:

$CO_2 + 2H_2O + \text{energy} \rightarrow (CH_2O) + O_2 + H_2O$

In eukaryotes, photosynthesis occurs in the **chloroplast**

2. Photovoltaic systems are comprised of **photovoltaic cells**, devices that convert light energy directly into electricity, and inverters that convert the direct current from the photovoltaic into alternating current used in homes. Because the source of light is usually the sun, they are often called **solar cells**. The word **photovoltaic** comes from "photo," meaning light, and "voltaic," which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight." Photovoltaics are often referred to as PV. **PV cells** are made of at least two layers of semiconductor material. The semiconductor in a typical solar cell is a single crystal of silicon which performs tow processes simultaneously: absorption of light, and the separation of the electric charges. These charges, electrons and positively charged "holes", are formed when light absorption excites electrons in the crystal to higher energy levels.

3. Nanocrystalline solar cells developed at the Swiss Federal Institute of Technology work to separate the process of light absorption and charge separation making them independent. Light absorption is performed by a single layer of dye attached to the layer of titanium dioxide particles painted on the glass. After being excited by light the colored dye is able to transfer an electron to the semiconducting.

Nanocrystalline dye-sensitized solar cells is a photoelectrochemical cell that resembles natural photosynthesis in two respects: 1. It uses a natural dye like chlorophyll to absorb light and produce a flow of electrons, and 2. It uses multiple layers to enhance both the light absorption and electron collection efficiency. Like photosynthesis, it is a molecular machine. (Smestad 1998).

4. Introduction to Electricity and Ohm's Law - The basic laws for electronics and elementary circuits were developed in the early 1800s by a German physicist, Georg Simon Ohm and are known as Ohm's Law.

If an atom has more protons than electrons, it is considered "positively charged", and an atom that gains electrons is more "negatively charged". Electrons can be made to move between atoms, which will create a current of electricity. **Conductors** (i.e. copper, aluminum, and steel) are materials that allow electrons to be easily moved from their orbits. **Resistance** is used to measure how well something will conduct electricity. **Circuits** provide an environment to collect and move electrons from place to place, and from component to component. When a circuit is turned on it will, the switch acts like a bridge allowing the electricity to move through the circuit.

Ohm's Law is a mathematical equation explaining the relationship between voltage, current, and resistance.

It is expressed in the following equation: **V = I X R**

V = Voltage (Volts)

I = Current (Amps)

R = Resistance (ohms)

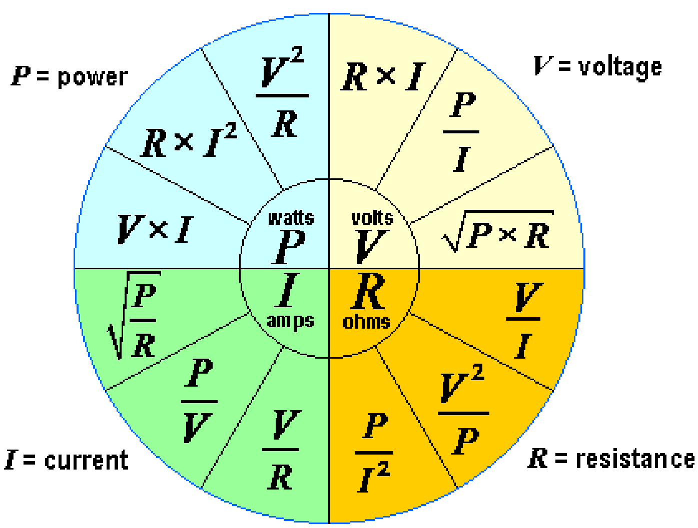
Another measure of electron activity in a circuit is **power**, which is the measure of how much work can be performed in a given amount of time. Power is measured in watts. It can be expressed in the following equation: **P = I^2 X R**

P = Power (Watts)

I = Current (Amps)

R = Resistance (ohms)

Ohm's Law Power Wheel



http://diyaudioprojects.com/Technical/Ohms-Law/

Supply Check List

Day 1:

2 conductive glass slides and
Scotch tape
TiO_2 Powder
Mortar and pestle
Vinegar
Surfactant (dish detergent)
1 non- conductive glass slide
Multimeter

High temperature oven or hot plate
Goggles
Disposable Gloves
Tweezers
Disposable Pipette
Distilled water
Syringe

Day 2:

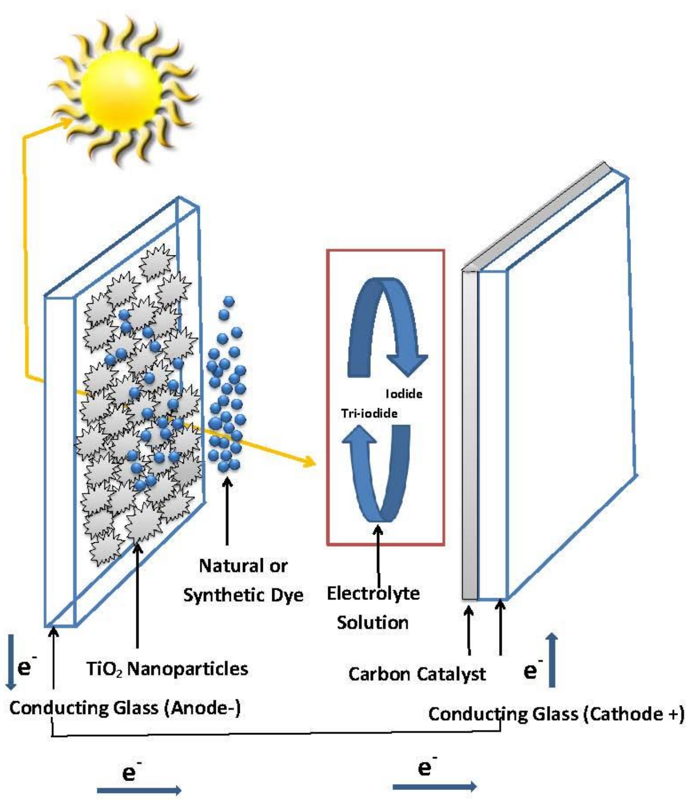
Mortar and pestle
Distilled water
Blackberries, raspberries, or blueberries
Hydrochloric Acid (optional)
pH meter reader (optional)
Goggles
Disposable gloves
Tweezers
Disposable pipette

Day 3:

Distilled Water
Ethanol
Candle or graphite pencil
Tri-iodide Electrolyte solution
Pipette
Binder Clips
Multimeter
Goggles
Disposable Gloves
copper tape (optional)

Lab Procedures for Constructing a Dye Sensitized Solar Cell

Solar Cell Diagram



Day 1: Preparing the TiO_2 on the slide

Conductive Slide- A conductive slide is made of ITO (Idium-Tin-Oxide) coated glass on one side and is 25 X 25 X 1.0 mm, and can be purchased at Solaronix or Institute for Chemical Education (ICE). The resistance of the glass slide should be between 10-30 Ω. **The glass slide should not be handled** so use tweezers or hold the slide by the edges of the glass. Use a voltmeter to check the conductive side of the glass. It should read between 10-30Ω. Use the conductive side to apply the TiO_2.

Preparing the TiO_2:

Teacher Workshop Created TiO_2 Suspension:

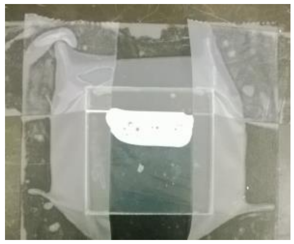
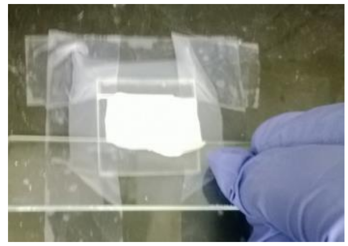
1.0g Anatase (TiO_2 powder)
0.5 g Rutile (TiO_2 powder)
2.5 mL Vinegar
1 drop of surfactant such as clear dish washing detergent added.

Add the TiO_2 powder to the mortar and pestle and while grinding slowly add the vinegar. You will want it to be a uniform lump free consistency of paint. The grinding process should be at least 15 minutes or more. Add the surfactant. Lightly stir trying not to make bubbles. Let the suspension sit for 15 minutes before applying to the slide.

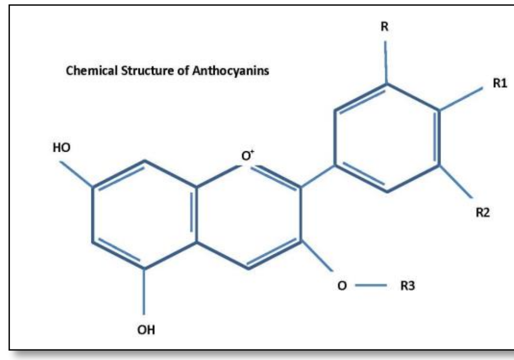
Research Lab Created TiO_2 Suspension:

6.375 g Anatase (TiO_2 powder)
1.125 g Rutile (TiO_2 powder)
12 mL 0.1M Nitric Acid
0.24g Polyethylene Glycol 8,000
0.6ml Triton X100
Add all ingredients to a beaker and place on a stir plate for 2 hours then sonicate for 5 hours (alternate sonication 1 minute; off 2 minutes).

Deposition of The TiO_2 film on the glass slide- TiO_2 (Titanium Dioxide) film application has a porous, sponge-like structure that enhances both the light absorption and electron collection efficiency in a similar way as the thylakoid membrane found in plants. Secure the glass slide, conductive side up, to the table using scotch tape to the edge of the slide on the top and two sides. Double taping can help make sure the mixture does not flow under the tape. Make sure it is secure on the edges of the glass so the TiO2 mixture will not go under the tape when applied. The edges should not have any mixture on them after the tape is removed. Apply the TiO_2 mixture using a pipette to the top of the slide below the tape and use a glass stirring rod or another slide that you do not use for this project to smooth out the mixture evenly down the slide. Once the mixture is smooth and even down the slide, allow it to sit and dry before removing the tape. Once it looks dry carefully remove the tape and bake the slide in a high temperature oven at 450˚ for 45 minutes or on a hot plate for 30 minutes. Allow to sit and cool for 30 minutes. Baking the TiO_2 on the slide is called **Sintering (**a high temperature process for fusing powder together)

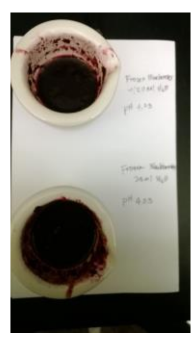
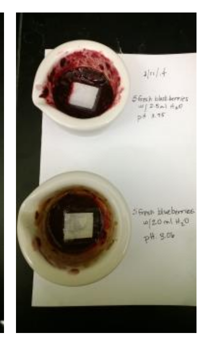

Day 2: Making a natural dye and staining the TiO_2



The Dye is one of the most important components of the DSSC. An efficient sensitizer should absorb light over a broad range from the visible to the near-infrared and, the energy of its electronic excited state should lie energetically above the edge of the TiO_2 (Calegro, et al., 2012). Synthetic dyes such as metal coordination compounds ruthenium and osmium are used as effective sensitizers in DSSCs. The preparation for the metal complex dye is tedious and expensive, which has raised more interest in natural dyes. **Anthocyanin** is a pigment found in many plants that may appear red, purple or blue depending on the pH. Over 500 different types of anthocyanins have been isolated from plants and the main sources of anthocyanins are some fruits and vegetables such as blackberries, raspberries, blueberries, red cabbage, and red radicchio. They show light absorption in the visible regions and are an antioxidant compound that present functional groups (-OH), which help bind better to the TiO_2 nanoparticles. The dye absorbs light and transfers excited electrons to the TiO_2.

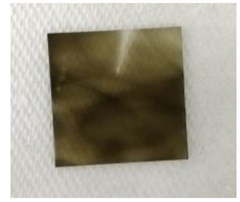
When preparing the dye fresh or frozen (thawed) fruit such as blackberries, raspberries, and blueberries can be used for the dye. A mortar and pestle can be used to crush the berries into to a liquid juice. A small amount of distill water can be added, approximately 2.0 ml per 3-5 berries.

As in the case for many natural dyes, the acid treatment (pH=1) induces a red shift in the absorption of the anthocyanins on the order of tens or nanometers (Calogero 2012). Once the berries have been crushed into a liquid, pH can be tested and altered using hydrochloric acid if the students want to test how pH affects the dye absorption (optional). After the natural dye has been made, soak the TiO_2 coated side of the slide in the juice for at least 15 minutes. If the cell is not going to be assembled until the next day, it can be left in the dye overnight, covered and out of light. After removing the stained film wash with distilled water, and then ethanol. Make sure the dyed glass slide remains out of light and is dry before proceeding with the assembly of the solar cell.

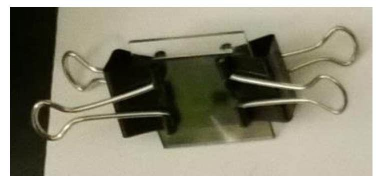
Day 3: Assembling the solar cell and measuring voltage

The **cathode** of a solar cell is usually made with platinum, but **carbon** can be used as well for **catalytic activity**. Though carbon is less efficient than platinum it is easier and cheaper to use. There are 2 ways to make electrodes; one using a graphite pencil and the other is using a candle.

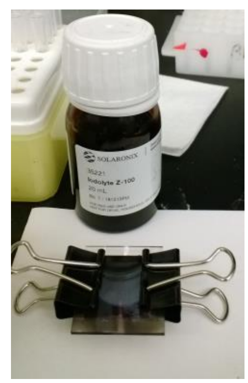


With the second conductive glass slide you can either color the conductive side of the glass using the graphite pencil or you can obtain a carbon electrode by lighting a candle and holding the glass slide, conductive side over the flame depositing the soot from the burning candle. The process is fast and you don't want over burn the slide. You just want enough for a gray to black layer on the conductive side of the glass.

Once the stained TiO_2 electrode is dry and free of water and the carbon electrode is cool from the candle, the solar cell can be assembled. Binder clips are used to hold the electrodes together on the sides. The top of the TiO_2 electrode that does not have any titanium will need to be free for use of testing with the voltmeter. The carbon cathode should be placed on top of the TiO_2 cathode leaving the edges free.



Once the cell has been assembled, the **Iodide/Iodine electrolyte solution** can be added. The iodide solution can also be purchased at Solaronix or ICE. The iodide/triiodide mediator forms a regenerative cycle that accepts the negatively charged electrons that are transferred from the excited dye to the titanium dioxide and the load. This can be applied by adding a couple of drops in between the edges of the plates (Smestad 1998). Clean the iodide solution from the free edges of the slides, and copper tape can be applied to the exposed edges of the positive and negative cell walls. The copper tape will help facilitate electrical contact.



Using the voltmeter to measure the solar cell is done by placing the alligator clips from the voltmeter to each end of the exposed glass or copper tape. The negative electrode is the TiO_2 coated glass, and the black wire should be attached to this side. The red wire to the carbon coated glass slide which is the positive electrode. The solar cell should be under direct sunlight or a lamp to measure the volts and amps. You can then use the Ohm's law power wheel to calculate power.

References

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