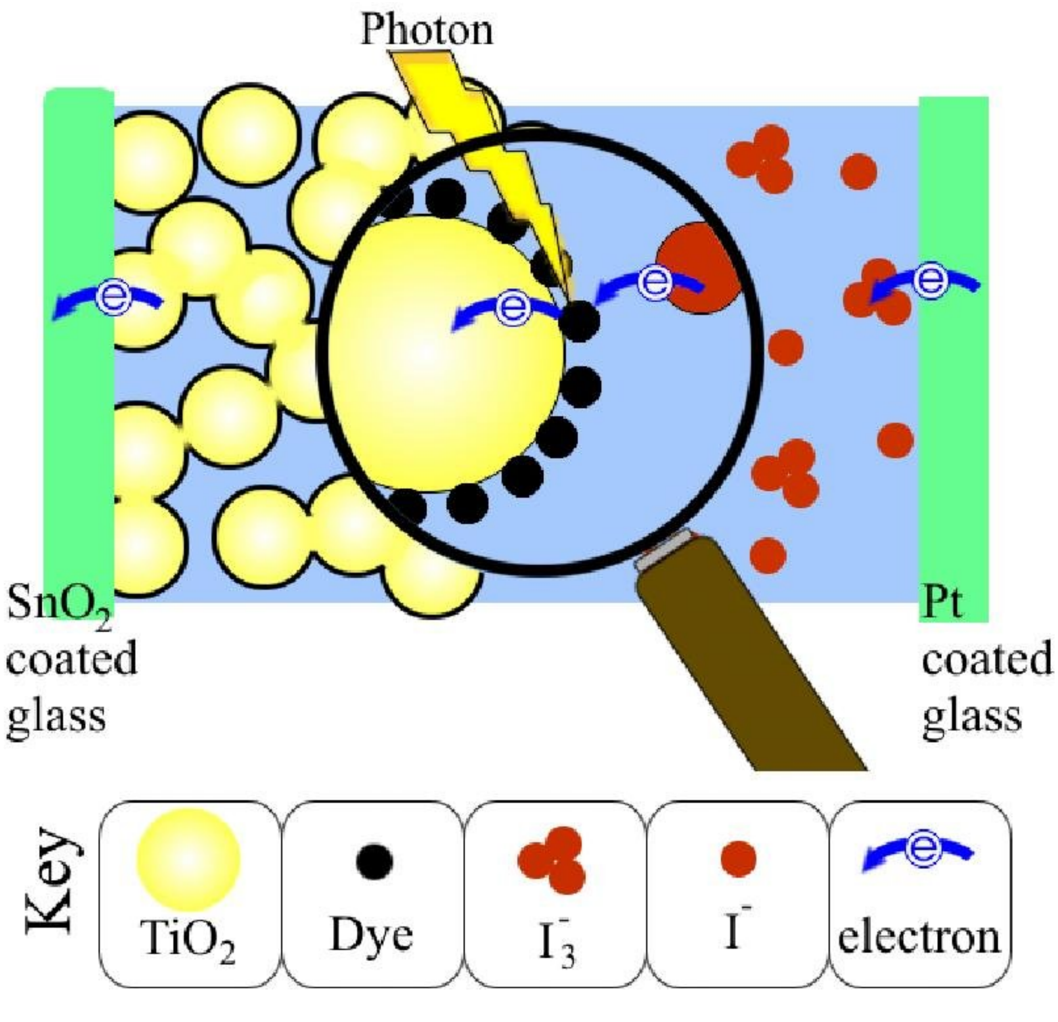
Dye-Sensitized Solar Cells

Using organic dyes to generate electricity from light



Michael Cass, University of Bath (Image used with permission)

Dye-Sensitized Solar Cell Module

Using organic dyes to generate electricity from light

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This material is based upon work supported by the National Science Foundation/EPSCoR Grant #EPS-0554609 and by the State of South Dakota.

Preface

South Dakota EPSCoR interns working at the Center for the Advancement for Math and Science Education (CAMSE) at Black Hills State University developed this classroom module highlighting nanocrystalline dye-sensitized solar cell (DSSC) technology as a simple way to share frontier science and engineering with middle and high school audiences.

DSSCs use an organic dye extracted from plants to imitate the manner in which plants and certain algae convert sunlight into energy. Though these solar cells are still in relatively early stages of development, they show great promise as an inexpensive alternative to costly silicon solar cells and an attractive candidate for a new renewable energy source.

Research into dye-sensitized solar cells, also supported by South Dakota's EPSCoR RII award, is currently taking place at South Dakota State University's department of chemistry and biochemistry. Professor Brian Logue and his colleagues are experimenting with known dyes, as well as searching for innovative new dyes that may increase the efficiency of the cells. The ultimate goal of researchers is to bring the cost of solar cells in line with fossil fuels, thereby decreasing our dependence on those fuels.

This DSSC module is an exciting way for classroom teachers to connect students to this cutting edge science in a variety of content areas. There a few opportunities to incorporate energy education into traditional science classes. The dye-sensitized solar cell module provides an interdisciplinary, real-world context for students learning the basic principles of biological extraction, chemistry, physics, environmental science and electron transfer, as well as an introduction to photochemical technology.

Although the solar cell that students create lasts only a short time, it can provide an avenue for students to join the ongoing discussion about the increasing need for clean, alternative energies.

**This module is based in part on the following article:
Smestad, GP, Gratzel, M. (1998) Demonstrating electron transfer and nanotechnology: A natural dye-sensitized nanochrystalline energy converter. *Journal of Chemical Education*, 75 (6), 752-756.

Table of Contents

Past, Present, and Future of Dye-sensitized solar cells (aka. Grätzel cells)

Michael Grätzel and Brian O'Regan invented "Dye-sensitized solar cells", also called "Grätzel cells", in 1991. The first cells were only capable of using light at the Ultraviolet and Blue end of the spectrum. By the turn of the century, advances in technology were able to broaden the frequencies in which these cells were able to respond. The most efficient of the dyes were simply known as "Black dyes" due to their very dark colors.

Although the silicon based solar cells are currently more efficient, the dye-sensitized solar cells are considerably cheaper to manufacture. The overall efficiency of solar cells has for awhile been unable to get past what was the current peak efficiency of around 11 percent for cells using titanium dioxide. Recently researchers at University of Washington have come up with a new technique that has been dubbed the popcorn ball method. When light hits the surface of the cells some the light is reflected. The idea behind the popcorn ball effect is that by making a very large number of very tiny cells, the efficiency output of the solar cells can be doublde. It would take about 3500 of these microscopic cells to make up the width of a single piece of hair.

Image: DeviceDaily.com (used with permission)

In testing this new popcorn ball method the researchers were astounded to find they had managed to double their efficiency using zinc oxide from 2.9 % to over 6%. This increase in efficiency moves dye-sensitized solar cells even closer to reaching the point where they will be able to become a viable option in the area of energy production.

In the future expect to see further gains in the efficiency of dye-sensitized solar cells. When these cells become efficient enough to use in the real world producing electricity people will be able to have skylights and windows with a layer of dye-sensitized solar cells, enabling the windows to actually produce energy while being aesthetically pleasing.

When looking for alternative sources for electricity in the future, be sure to examine the possibilities of using dye-sensitized solar cells. They aren't quite as efficient yet, but they are significantly cheaper than their silicon counterparts. When the efficiency of the dye-sensitized solar cells is increased they will most likely replace the high priced solar cells on the market today.

Image credit: National Institute of Advanced Industrial Science and Technology (AIST)

The Dye-Sensitized Solar Cell module uses organic dyes to generate electricity from light. We recommend using a lab pro with voltage probe and Logger pro software to detect and display this data. However, a multi-meter capable of measuring volts and ohms may also be used. The concepts explored in this module provide an interdisciplinary context for students learning basic principles in chemistry, biology, physics, as well as environmental science.

This module contains the basic materials to build 15 reusable solar cells. Teacher provided materials and supplies are necessary to complete the lessons. See below for a full list of materials and supplies required to carry out the activities.

Dye-Sensitized Solar Cell Module Inventory:

The following items are included in the module.

- CD w/ instructional power point, manual, and diagrams
- Titanium Dioxide Powder (TiO_2) (1 – 20g container included)
- Conductive (tin dioxide coated) transparent glass (30 pieces included)
- 1ml pipette (1 piece included)
- Acrylic stirring rod (1 piece included)
- Soft Graphite pencils (no.2) (15 pencils included)
- Petri dishes (15 pieces included)
- Plastic cups (15 pieces included)
- Plastic forks (15 pieces included)
- Coffee filters (15 pieces included)
- Plastic spoon (1 piece included)
- Transparent tape (1 roll included)
- Small binder clips (30 pieces included)
- Alligator clips (15 included)
- Squirt bottles for isopropyl alcohol (5 pieces included)
- Squirt bottles for water (5 pieces included)
- Iodine electrolyte solution (0.5 M Potassium iodide mixed with 0.05 M iodine in water-free ethylene glycol) (8 bottles included)

*The following items are teacher supplied:

(Local teachers may inquire about the availability of a toolkit for this module available from CAMSE.)

Chemicals:

- 91% Isopropyl Alcohol
- Ethyl alcohol
- Nitric or acetic acid solution (10 mL, pH 3–4 in deionized water) or 0.2 mL acetyl acetone (used per TiO2 suspension batch)

Consumables:

- Organic dye-- Prepared from blackberries, raspberries, pomegranate seeds, Bing cherries, or green citrus leaves, fresh or frozen 2-3 oz. (for each pair of students)
- Dark construction paper
- Paper towels
- Matches
- Pair of Gloves
- Dust mask

Equipment:

- Safety glasses
- Mortar and pestle
- Alcohol lamp
- Ring stand and ceramic triangle
- Scale
- Light source- we recommend an Overhead projector
- Voltage probe
- Lab pro
- Computer w/ Logger Pro software

DYE-SENSITIZED SOLAR CELLS

Purpose

Students will build a dye-sensitized solar cell to develop an understanding of how these cells convert light into energy.

Objectives

Labs

- Build a dye-sensitized solar cell and explore its photovoltaic properties
- Build dye-sensitized solar cells using different dyes and explore the effect that different dyes have on voltage
- Link dye-sensitized solar cells in series circuits and explore the voltage produced
- Build dye-sensitized solar cells and measure the effects of different light sources on voltage

Lab Summaries

Core Lab
This lab shows students how to build their own dye-sensitized solar cell. Students will measure how much voltage is produced by the cell. Students will learn how solar cells convert light into energy.

Alternate Core Lab
Students will use different dyes to make their own dye-sensitized solar cells. Students will measure how much voltage is produced by the different cells. Students will explore why certain dyes work better than others in converting light into energy.

Extension 1
After the students have built their own dye-sensitized solar cell they can connect multiple cells in a series circuit. Students should observe an increase in voltage when the cells are connected in a series circuit.

Extension 2
After students have built their own dye-sensitized solar cell, they can use different light sources to power the cell. Students will explore the effect that different light sources have on the voltage produced by the cell.

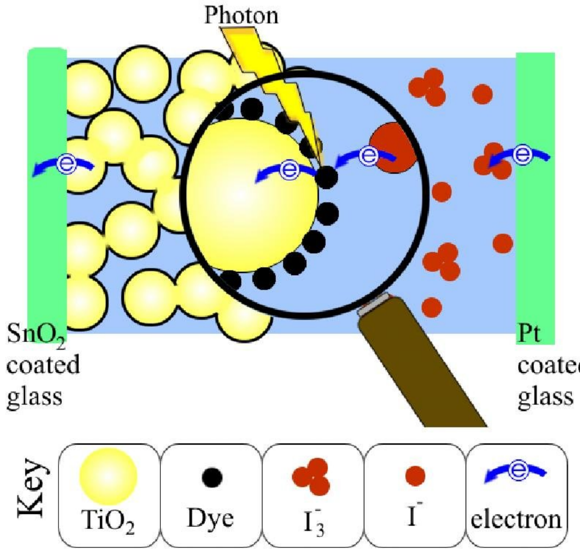
Teacher Information

Solar power makes use of the abundant energy from the sun. Many technologies in our world today use solar energy. Most commonly solar power is used in heating and cooling systems, lighting, and electricity generation. It is also used in common products such as calculators and roadside emergency phones. Solar energy is beneficial because it is less harmful to our environment than other methods of energy production and does not create the waste caused by burning fossil fuels. Since solar power makes use of an inexhaustible and free source of energy, the sun, this technology will lessen our dependence on fossil fuels and protect our natural resources. Currently, solar power is more cost effective than other forms of alternative energy.

Dye-sensitized solar cells are innovative solar cells that mimic photosynthesis in plants. These cells have a lot of potential because they can be made and manufactured with low-cost materials. Unlike traditional solar cells, dye-sensitized cells can work effectively in low light conditions and are less susceptible to losing energy to heat.

A dye-sensitized solar cell consists of two conducting glass electrodes in a sandwich arrangement. (See Diagram 1) Each layer has a specific function in the cell. The glass electrodes are transparent which allows the light to pass through the cell. The tin dioxide coating is a transparent, conductive layer. The titanium dioxide serves as a holding place for the dye. The dye molecules collect light and produce excited electrons which cause a current in the cell. The iodide electrolyte layer acts as a source for electron replacement. The bottom conductive layer is coated with graphite so that light does not pass through the bottom layer.

Dye-sensitized solar cells produce electricity through electron transfer. Sunlight passes through the conductive glass electrode. (See Diagram 2) The dye absorbs the photons of light and one of the electrons in the dye goes from a ground state to an excited state. This is referred to as photoexcitation. The excited electron jumps to the titanium dioxide layer and diffuses across the film. The electron then reaches the conductive electrode, travels through the wire, and reaches the counter electrode. The dye molecule, having lost an electron to the titanium dioxide, is now oxidized, which means it has one less electron than before. The dye wants to recover its initial state so it must obtain an electron. It obtains this electron from the iodine electrolyte and the dye goes back to ground state. This causes the iodine to become oxidized. When the original lost electron reaches the counter electrode, it gives the electron back to the electrolyte.



Michael Cass, University of Bath (Image used with permission)

Before the lab

1. Decide if you are going to do the Core lab or the Alternate Core Lab. Also decide if you are going to be doing either of the extensions.
2. Prepare the titanium dioxide coated slides. There should be one for each group of students. Follow the directions in the Pre Lab Preparation section.
3. Read over the materials and procedures so that you are familiar with all of the content. It may be beneficial for you to make a cell beforehand so that you can assist students with the construction of their own cell. Read over the follow up information for the labs so you are familiar with the results students should be getting.
4. Have students work in groups of 2 or 3. Set up work stations with all of the needed materials for each group of students. Make a copy of the procedure for each group of students. Make a copy of Diagram 1 and Diagram 2 for each group of students or use the overhead projector to show them the diagrams.
5. Introduce solar cells to the students. Give them background information about solar cells. Explain cell layers and functions (Diagram 1).

During the lab

1. Have students record their results on a piece of paper. Have them write down any questions or ideas about how the cells work, etc.
2. Discuss predictions, observations, and results.

After the lab

1. Read the follow up information for the labs. Have students share their results.
2. Read over the possible questions. Facilitate a discussion and help students understand what the lab is showing them.

Pre-lab Preparation

The electrodes for the solar cells need to be coated with titanium dioxide prior to the lab period.

Materials Needed

Titanium dioxide powder

Scale

Large mortar and pestle

Acetic acid solution (pH 3-4 in deionized water)

Scotch tape

Glass or acrylic stirring rod

Plastic bottle for storage

Ring stand

Alcohol burner

Matches

Gloves

Dust mask

Safety glasses

1ml Pipette

Plastic spoon

Ethyl alcohol

For each group of students prepare 1 slide to be coated with titanium dioxide.

1. ***Wear a dust mask, safety glasses, and gloves while preparing the titanium dioxide suspension***. Measure out 6 g of titanium dioxide powder with the scale. Mix 6 g of the titanium dioxide powder with 9 ml of acetic acid solution. Put the titanium dioxide powder into the mortar and add 1 ml increments of acid solution with the pipette while grinding with a pestle. Make sure it is uniform and lump-free before adding each ml. Use the plastic spoon to scrape off any residue that is stuck to the sides of the mortar and pestle. This is a colloidal suspension and should resemble latex paint.
2. Store the titanium dioxide suspension in a small plastic capped bottle and allow it to equilibrate for at least 15 minutes for the best results.
3. Handle the slides by their edges. The slides should already be marked with a black sharpie line on the non conductive side. If neither side is marked, use an ohm meter to test for conductivity. Mark the non conductive side of the slide. Be careful not to touch the conductive side. Clean the slides with ethyl alcohol before coating the slide with the titanium dioxide suspension, but make sure not to wipe off the marking on the non-conductive side.

4. Apply four pieces of scotch tape to the conductive side of the glass slide. The scotch tape pieces should mask a 1-2 mm strip on three sides and should mask a 4-5 mm strip on the fourth side. This will create a well for the titanium dioxide. The 4-5 mm will be the exposed side for the connecting wires when the cell is assembled.
5. Three drops of the titanium dioxide mixture should be placed in the well and distributed uniformly by sliding a glass stirring rod horizontally over the slide in a rapid motion. The film should be uniformly distributed in the well. Allow this film to air dry. After one minute, or when the film is dry, carefully remove the tape. Be sure not to touch the titanium dioxide on the slide.
6. Set the slide on a wire screen and place it on a ring stand with the film side of the slide pointed up. Light an alcohol burner and place it beneath the slide, so the slide is positioned at the tip of the flame. Allow the slide to heat for ten minutes, remove the alcohol burner, and allow the slide to cool to room temperature on the wire screen.

Use multiple ring stands and alcohol burners and heat multiple slides at the same time to speed up the process. Alternate one alcohol burner between two ring stands with wire screens to allow slides to cool on the same screen they were heated. If you try to remove the slides from the wire screen while they are still hot, the slides are more likely to break. Make one titanium dioxide coated slide for each group of students. Prepared slides can be stored for later use.

Materials for Core Lab

For each group of students

One glass slide coated with tin dioxide

One glass slide with tin dioxide and titanium dioxide

Two binder clips

Graphite pencil

Paper towels

Plastic cup

Plastic fork

2-3oz. raspberries

Coffee filter

Petri dish

Safety glasses

Gloves

Dark piece of construction paper

Charts and diagrams (if included)

<u>For the class</u>

Multiple dropper bottles with iodine electrolyte solution

Overhead projectors

Squirt bottles with isopropyl

Squirt bottles with water

Empty plastic cups for rinsing with squirt bottles

Voltage probe

Lab Pro

Computer

Ethyl alcohol

<u>Procedure for Core lab</u>- Building a dye-sensitized solar cell (40-50 minutes)

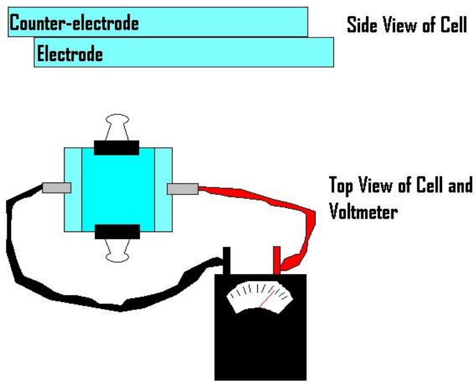
Dye must be extracted from the raspberries.

1. Portion 2-3oz of fresh (or frozen/thawed raspberries) and add 1-2 ml of water.
2. Crush the berries in a plastic cup using a fork until the mixture is soupy.
3. Pour the crushed berries into a coffee filter over the Petri dish. Gently squeeze the filter so that the liquid dye flows into the Petri dish. Use care to prevent tearing the filter.

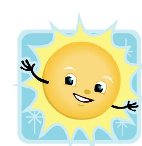
Building the cell

1. Each group should have two slides, each coated with conductive tin dioxide. One of these slides has been coated with titanium dioxide. This can be identified by the white rectangle of titanium dioxide film. Be careful not to touch the coated sides of the glass. Handle the slides by their edges.
2. Place the titanium dioxide coated slide face down in the raspberry dye leave it for approximately ten minutes. The titanium dioxide film should absorb the dye. If white titanium dioxide can still be seen on either side of the slide after the initial soak place it back in the dye for five more minutes. While your slide is "soaking", prepare the counter electrode slide.
3. To prepare the counter electrode, identify which side is conductive. The nonconductive side is marked with a black line. Take the graphite pencil and apply a heavy film to the entire conductive side of the slide. Be careful not to miss any spots.
4. Next, remove the titanium dioxide coated slide from the dye. Rinse the slide with the squirt bottle containing water. Then rinse the slide with the squirt bottle containing isopropyl. The isopropyl pulls any excess water trapped in the dyed titanium dioxide. Blot the slide dry with a paper towel but make sure not to damage the titanium dioxide layer.
5. Place the dye stained electrode on the counter with the titanium dioxide side face up. Place the graphite coated counter electrode, face down, on top of the stained electrode so that the conductive sides are facing each other.

6. Offset the glass slides so that all of the titanium dioxide is covered by the counter electrode and the 4-5mm strip (not coated by titanium dioxide) is exposed. The offset edges will become the contact points for the negative and positive electrodes so that electricity from the test cell can be measured.



7. Place the two binder clips where the slides overlap to hold the cell together.
8. Add one to two drops of electrolyte solution to one edge of the slides. Alternately open and close the binder clips so the solution is drawn into the cell by capillary action. Make sure that all of the dyed titanium dioxide is covered by the electrolyte. Wipe excess electrolyte off the edges with a paper towel.
9. Connect the lab pro to your computer and insert the voltage probe into channel 1. To test the voltage produced by the cell, connect the cell to a voltage probe.(or volt meter) Place the negative electrode on the titanium dioxide coated slide and the positive electrode on the counter electrode slide. (The black wire is the negative electrode and the red wire is the positive electrode)



10. Place the cell in the direct light of an overhead projector and press “Collect”. Use the dark piece of construction paper to block the light reaching the cell. Block and unblock the cell multiple times. Auto-scale your graph and observe the difference in voltage when the cell is covered and uncovered. Record what happens when the cell is covered and uncovered.

Note: **Do not disassemble the cell if you are going to continue with the extensions.**

11. Disassemble the cells. Be sure to keep track of which was the electrode and which was the counter electrode. Clean both slides with a tissue dampened with ethyl alcohol. Be careful not to scratch the tin dioxide coated side of the slide. Place electrode and counter electrode slides in designated containers.

Alternate Core Lab- **Using multiple dyes (50-60 minutes)**

Students will use different dye sources to make the dye-sensitized solar cell and compare the different electrical outputs.

Materials

For each group of students

One glass slide coated with tin dioxide

One glass slide with tin dioxide and titanium dioxide

Two binder clips

Graphite pencil

Paper towels

Plastic cup

Plastic fork

Spinach leaves, raspberries, blackberries, and grape juice concentrate (each group of students will only need 2-3oz. of one of these choices) Hibiscus tea is also a good choice, be creative.

Coffee filter

Petri dish

Safety glasses

Gloves

Charts and diagrams (if included)

For the class

Multiple dropper bottles with iodine electrolyte solution

Overhead projectors

Squirt bottles with isopropyl

Squirt bottles with water

Empty plastic cups for rinsing with squirt bottles

Voltage probe

Lab Pro

Computer

Ethyl alcohol

Pre-Lab Preparation

Same as pre-lab preparation for the core lab

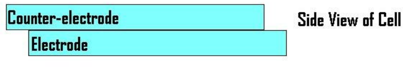
<u>Alternate Core Lab Procedure</u>

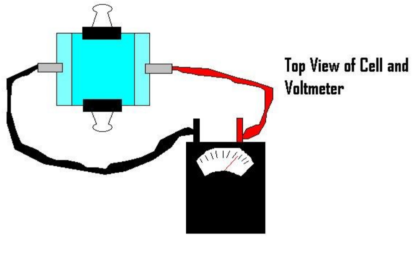
The dye sources need to be processed into useable dye.

1. Portion 2-3oz of your given dye source. Add 1-2 ml of water to raspberries and blackberries and add 5-6 ml of water to spinach leaves.
2. Crush the berries or spinach leaves in the plastic cup using a fork until the mixture is soupy. (those testing grape juice do not need to do steps 2 and 3)
3. Pour the crushed berries, etc. into a coffee filter over the Petri dish. Gently squeeze out the liquid dye into the Petri dish. Take care not to tear the filter.

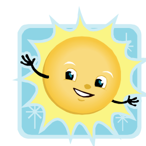
Building the cell

1. Each group should have two slides, each coated with conductive tin dioxide. One of these slides has been coated with titanium dioxide. This can be identified by the white rectangle of titanium dioxide film. Be careful not to touch the coated sides of the glass. Handle the slides by their edges.
2. Place the titanium dioxide coated slide face down in the raspberry dye leave it for approximately ten minutes. The titanium dioxide film should absorb the dye. If white titanium dioxide can still be seen on either side of the slide after the initial soak place it back in the dye for five more minutes. While your slide is “soaking”, prepare the counter electrode slide.
3. To prepare the counter electrode, identify which side is conductive. The nonconductive side is marked with a black line. Take the graphite pencil and apply a heavy film to the entire conductive side of the slide. Be careful not to miss any spots.
4. Next, remove the titanium dioxide coated slide from the dye. Rinse the slide with the squirt bottle containing water. Then rinse the slide with the squirt bottle containing isopropyl. The isopropyl pulls any excess water trapped in the dyed titanium dioxide. Blot the slide dry with a paper towel but make sure not to damage the titanium dioxide layer.
5. Place the dye stained electrode on the counter with the titanium dioxide side face up. Place the graphite coated counter electrode, face down, on top of the stained electrode so that the conductive sides are facing each other.
6. Offset the glass slides so that all of the titanium dioxide is covered by the counter electrode and the 4-5mm strip (not coated by titanium dioxide) is exposed. The offset edges will become the contact points for the negative and positive electrodes so that electricity from the test cell can be measured.





7. Place the two binder clips where the slides overlap to hold the cell together.
8. Add one to two drops of electrolyte solution to one edge of the slides. Alternately open and close the binder clips so the solution is drawn into the cell by capillary action. Make sure that all of the dyed titanium dioxide is covered by the electrolyte. Wipe excess electrolyte off the edges with a paper towel.
9. Connect the lab pro to your computer and insert the voltage probe into channel 1. To test the voltage produced by the cell, connect the cell to a voltage probe.(or volt meter) Place the negative electrode on the titanium dioxide coated slide and the positive electrode on the counter electrode slide. (The black wire is the negative electrode and the red wire is the positive electrode)



10. Form larger groups at a computer with at least one pair of students with a raspberry cell, a blackberry cell, a grape juice cell, and a spinach cell. Connect one cell at a time to the voltage probe. Place the cell in the direct light of an overhead projector and press “Collect”. Once you have collected data, select “Experiment” and “store latest run” for each cell. After you have collected data for each of the four cells, auto-scale your graph and observe the difference in voltage for each different cell. Maker certain to keep written results for your cells.
11. Select a new graph and connect each cell to the voltage probe one at a time. Place the cell in the direct light of the projector and begin collecting data. Use the dark piece of construction paper to block the light reaching the cell. Block and unblock the cell multiple times. Auto-scale your graph and observe the difference in voltage when the cell is covered and uncovered. Do this for each of the four cells. Record what happens when the cell is covered and uncovered.

Note: **Do not disassemble the cell if you are going to continue with the other extensions.**

12. Disassemble the cells. Be sure to keep track of which was the electrode and which was the counter electrode. Clean both slides with a tissue dampened with ethyl alcohol. Be careful not to scratch the tin dioxide coated side of the slide. Place electrode and counter electrode slides in designated containers.

Extensions

These are possible extensions to the lab depending on allotted time.

Extension 1- Linking cells in series (10-15 minutes)

Students will link their dye-sensitized solar cells in a series circuit to see the effects of a multiple cell system.

Materials

Cells already prepared in the core lab

Connecting wires

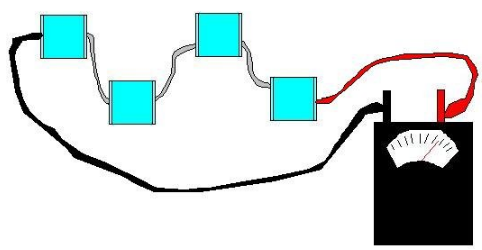
Voltage probes

Overhead projector

Lab Pros

Computers

Extension 1 Procedure



1. Once the students have built their dye-sensitized solar cells, have them connect their cells together in series using the wires provided. Remember to place the negative electrode on the titanium dioxide coated slide and the positive electrode on the counter electrode slide.

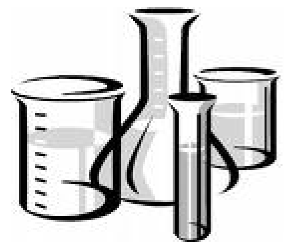
(The black wire is the negative electrode and the red wire is the positive electrode) Start out by connecting four cells together to insure that all of them will fit under the overhead projector light. If time allows more cells can be connected.

2. Have students make a hypothesis about the effect of connecting their cells in a series circuit.
3. Place the series on the overhead projector. Make sure all of the cells are getting direct light from the overhead projector.
4. Connect the circuit to the voltage probe and collect data. Compare this data to your single cell data.
5. Experiment with other factors; are all cells in series same dye? What if I flip over certain cells? Be creative and record your results.
6. Disassemble the cells. Be sure to keep track of which was the electrode and which was the counter electrode. Clean both slides with a tissue dampened with ethyl alcohol. Be careful not to scratch the tin dioxide coated side of the slide. Place electrode and counter electrode slides in designated containers.

Extension 2- Using different light sources (10-15 minutes)
Students will use multiple light sources and compare which light source causes the cell to produce more voltage.

Materials

Cells already prepared in core lab
Fluorescent light source
Overhead projector
Spectroscope tubes
Voltage probes
Lab Pros
Computers



Extension 2 Procedure

1. Once the students have built their dye-sensitized solar cells, have them connect their cell to the voltage probe. Repeat the procedure for testing with both a fluorescent light and the over head projector. Make sure the cell is at the same distance from each light source. Collect voltage data for each different light source. Store each separate run, auto-scale the graph after collecting data from each light source, and observe the differences in voltage between the two.
2. Using a spectroscope tube, look at each of the light sources separately. This will work best if all other lights are turned off. Observe the different spectrums for the two light sources.
3. Disassemble the cells. Be sure to keep track of which was the electrode and which was the counter electrode. Clean both slides with a tissue dampened with ethyl alcohol. Be careful not to scratch the tin dioxide coated side of the slide. Place electrode and counter electrode slides in designated containers.

Wrap up

Core Lab

Have students report the voltage created by their solar cell. The voltage for the cells should be between 0.4 V and 0.5 V when it was in direct light of the overhead projector. When the students cover the cells with the paper, the voltage should drop because the light that is converted into energy in the cell is being blocked. Have students share their hypotheses about how their solar cell works. Explain the process of electron transfer through the cell.

Possible Questions

1. What is voltage?
   Voltage is the measure of the difference in electrical potential energy between the two electrodes. The dye molecule releasing an electron is what creates the difference in electrical potential.

2. How does the solar cell work?
   The electron transfer is what creates the energy output from the cell. See explanation and picture from Diagram 2.

Alternate Core Lab

Have the students report the voltages created by the cells with different dyes. The cells with raspberry and blackberry dyes should have a higher voltage than the cells with spinach leaves and grape juice. Discuss possible reasons for differences. Explain why certain dyes work better than others. Have students report what happened when they covered and uncovered the cell with paper. The voltage should have dropped when the cell was covered with paper because the light that is converted into energy in the cell is being blocked. Have students make a hypothesis about how the cell works. Explain electron transfer in cells.

Possible Questions

1. What is voltage?
   Voltage is the measure of the difference in electrical potential energy between the two electrodes. The dye molecule releasing an electron is what creates the difference in electrical potential.
2. How do these solar cells work?
   The electron transfer is what creates the energy output from the cell. See explanation and picture from Diagram 2.
3. Why do certain dyes work in solar cells?
   The dyes used in these cells have to contain pigments with the right chemical groups. These chemical groups allow the dye to attach to the titanium dioxide. The dyes also need to have certain energy levels to absorb light and transfer electrons.

Extension 1

Have students share their results from connecting their cells in series. When the cells are connected in series, the voltage should be higher. Discuss with students how solar cells on a larger scale can power larger things. Discuss how a series circuit works.

Possible Questions

1. What is the effect of connecting cells in series?

   Cells connected in series produce a higher voltage than single cells. Individual cells produce such a small voltage that it is necessary to have many cells to produce a useable voltage. Using these solar cells on a larger scale has the potential of powering many things.

2. How does a series circuit work?

   When cells are connected in series, the voltage of each individual cell is added to all of the other cells to produce a higher voltage. The voltage increases as more cells are connected to the circuit.

Extension 2

Have students share their results using different light sources. The overhead projector should produce a higher voltage than the fluorescent light. Discuss some possible reasons for different voltages from different lights. Explain why certain lights cause more energy output than others. When the students looked at the different lights through the spectroscope tubes, they should have observed that the overhead projector had all of the colors of the spectrum blended together while the fluorescent light had a few bright bands of the spectrum.

Possible Questions

1. Why do different light sources affect the voltage?

   The overhead projector has a significantly higher wattage than the fluorescent light. This means that there are many more light photons coming from the overhead projector allowing more photoemission which creates a higher voltage. Photoemission is the release of an electron from the dye molecule when the energy of the light strikes the molecule. Also, the overhead projector has a very broad spectrum of light while the fluorescent light has a limited spectrum. The fluorescent light emits fewer frequencies of light which creates less energy in the cell. The overhead projectors spectrum is much closer to the spectrum of the sun than the fluorescent light.

Trouble Shooting

1. Charcoal pencils can be used in place of the graphite pencils
2. If you do not have access to acetic acid solution (for mixing the titanium dioxide), use white vinegar diluted with distilled water. Using a pH probe, add distilled water to a little bit of vinegar until the pH is between 3 and 4. Using vinegar will give similar results as the acetic acid solution, but the vinegar solution does not store well so only use this if necessary.
3. The cell works sporadically. Make certain that the cells and contacts are clean and that electrolyte solution has not seeped from the cell. Wipe any excess with paper towel.
4. If the cell does not work, check leads and make sure voltage probes are secure. You may need to add more electrolyte.

****This module is based in part on the following article:**

Smestad, GP, Gratzel, M. (1998) Demonstrating electron transfer and nanotechnology: A natural dye-sensitized nanochrystalline energy converter. *Journal of Chemical Education*, 75 (6), 752-756.

Materials

Nanocrystalline Solar Cell Kit from the Institute for Chemical Education (ICE)
At the University of Wisconsin – Madison
Department of Chemistry
http://ice.chem.wisc.edu/

"This material is based upon work supported by the National Science Foundation/EPSCoR Grant #EPS-0554609 and by the State of South Dakota."

Dye-Sensitized Solar Cells (DSSC)

This DSSC module can provide an interdisciplinary context for students learning the basic principles of biological extraction, chemistry, physics, environmental science and electron transfer. It is based on nanocrystalline dye-sensitized solar cells that mimic photosynthesis in plants by using an organic dye (extracted from fruit and plants) to absorb incoming light and produce excited electrons. Although the solar cell that students create lasts only a short time, it can provide an avenue for students to join the ongoing discussion about the increasing need for clean, alternative energies.

Correlations to SD Science Content Standards:

Middle School- Grade 6

6.N.2.1. Students are able to pose questions that can be explored through scientific investigations.

6.P.1.1. Students are able to identify the subatomic particles that make up atoms.

6.P.3.1. Students are able to identify types of energy transformations.

6.S.1.1. Students are able to describe how science and technology have helped society to solve problems.

6.S.2.1. Students are able, given a scenario, to identify the problem(s) of human activity on the local, regional, or global environment.

Middle School- Grade 7

7.N.2.1. Students are able to conduct scientific investigations using given procedures.

7.S.1.1. Students are able to describe how science and technology are used to solve problems in different professions and businesses

7.S.2.1. Students are able, given a scenario, to predict the consequence(s) of human activity on the local, regional, or global environment.

Middle School- Grade 8

8.N.2.1. Students are able to design a replicable scientific investigation.

8.S.1.1. Students are able to describe how science and technology have been influenced by social needs, attitudes, and values.

8.S.2.1. Students are able, given a scenario, to offer solutions to problems created by human activity on the local, regional, or global environment.

High School- Grades 9-12:

Nature of Science:

9-12.N.1.1. Students are able to evaluate a scientific discovery to determine and describe how societal, cultural, and personal beliefs influence scientific investigations and interpretations.

9-12.N.1.2. Students are able to describe the role of observation and evidence in the development and modification of hypotheses, theories, and laws.

9-12.N.2.1. Students are able to apply science process skills to design and conduct student investigations.

9-12.N.2.2. Students are able to practice safe and effective laboratory techniques.

9-12.N.2.1A. Students are able to manipulate multiple variables with repeated trials.

Science, Technology, Environment, and Society

9-12.S.1.2. Students are able to evaluate and describe the impact of scientific discoveries on historical events and social, economic, and ethical issues.

9-12.S.2.1. Students are able to describe immediate and long-term consequences of potential solutions for technological issues.

9-12.S.2.2. Students are able to analyze factors that could limit technological design.

9-12.S.2.3. Students are able to analyze and describe the benefits, limitations, cost, and

Physical Sciences:

9-12.P.3.1. Students are able to describe the relationships among potential energy, kinetic energy, and work as applied to the Law of Conservation of Energy.

9-12.P.3.2. Students are able to describe how characteristics of waves are related to one another.

9-12.P.3.3. Students are able to describe electrical effects in terms of motion and concentrations of charged particles.

9-12.P.1.5A. Students are able to examine energy transfer as matter changes.

9-12.P.3.2A. Students are able to describe the relationship between charged particles, static electricity, and electric fields.

Life Science:

9-12.L.1.1. Students are able to relate cellular functions and processes to specialized structures within cells.

9-12.L.1.1A. Students are able to explain the physical and chemical processes of photosynthesis and cell respiration and their importance to plant and animal life.

2005 SOUTH DAKOTA SCIENCE STANDARDS 6, 7, 8 and 9-12
(http://doe.sd.gov/contentstandards/science/newstandards.asp)

References

Bailey, M., Park, J., Dhirani, A. (2002) Natural Dye-Sensitized Nanocrystalline Solar Cell. Department of Chemistry,University of Toronto. (http://www.chem.utoronto.ca/staff/DHIRANI/solar%20cell.pdf)

Grätzel, M. (2001). Photoelectrochemical Cells. *Nature*, 414 (15), 338-44.

How to build your own solar cell (http://www.solideas.com/solrcell/english.html), A nanocrystalline dye-sensitized solar cell DIY.

O'Regan, B & Grätzel, M. (1991) A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO2 films. *Nature*, 353 (6346), 737-740.

Shariff, J. (2008).Photochemical solar cells. In, 50 Green Projects for the Evil Genius (pp105-111) McGraw Hill Companies, Inc.

Smestad, GP & Grätzel, M. (1998). Demonstrating electron transfer and nanotechnology: A natural dye-sensitized nanochrystalline energy converter. *Journal of Chemical Education*, 75 (6), 752-756.

SOUTH DAKOTA SCIENCE STANDARDS 6, 7, 8 and 9-12 (http://doe.sd.gov/contentstandards/science/newstandards.asp)

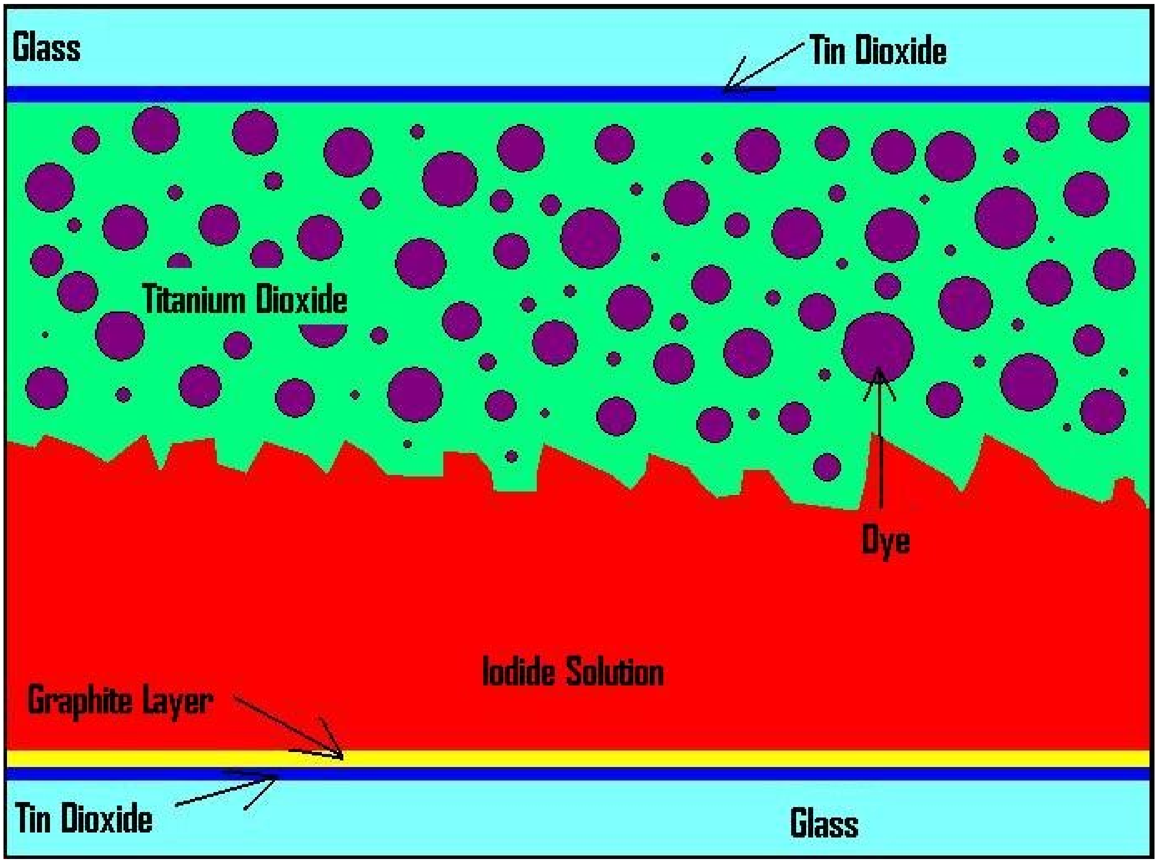
Takechi, K., Muszynski, R., Kamat, PV. Fabrication procedure of dye-sensitized solar cells (http://www.nd.edu/~pkamat/pdf/solarcell.pdf)

Image Links

Cover
http://people.bath.ac.uk/pysabw/research/scell/dssc.htm

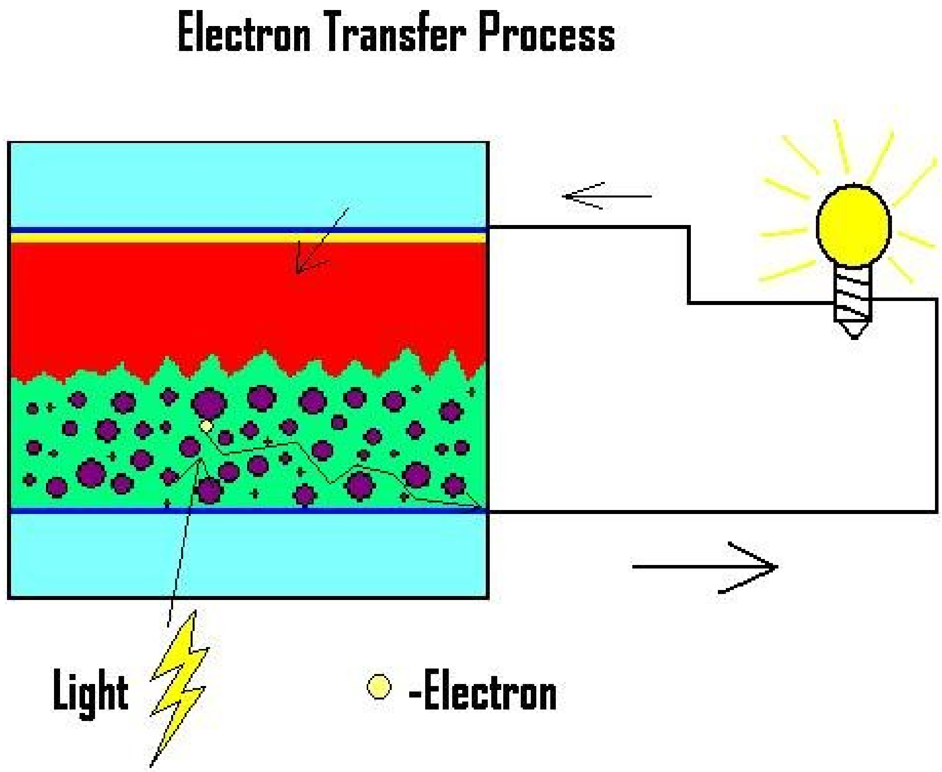
Past, Present, and Future
http://www.devicedaily.com/tag/photovoltaic-cells
http://unit.aist.go.jp/energy/groups/img/slecg_photocell.jpg

DIAGRAM 1 – Dye-sensitized solar cell



Glass- Transparent layer
Tin dioxide- Conductive layer
Titanium dioxide- Holds dye in place
Dye- Collects light and produces excited electrons to cause a current in the cell
Iodide electrolyte- Source for electron replacement
Graphite layer- Facilitates electron donation to the electrolyte

DIAGRAM 2



Electron Transfer in Dye-Sensitized Solar Cells

Dye-sensitized solar cells produce electricity through electron transfer. Light passes through the conductive glass electrode. The dye absorbs the photons of light and one of the electrons in the dye goes from a ground state to an excited state. This is referred to as photoexcitation. The excited electron jumps to the titanium dioxide layer and diffuses across this layer. The electron then reaches the conductive electrode, travels through the wire and reaches the counter electrode. The dye molecule, having lost an electron to the titanium dioxide, is now oxidized, which means it has one less electron than before. The dye wants to recover its initial state so it must obtain an electron. It obtains this electron from the iodide electrolyte and the dye goes back to ground state. This causes the iodide to become oxidized. When the original lost electron reaches the counter electrode, it gives the electron back to the electrolyte.