

Solar Cells: Juice From Juice

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Subject: Chemistry, Physics

Grade Level: Middle School/High School

Standards: *Next Generation Science Standards* (www.nextgenscience.org)

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

Schedule: One 90-minute class period

CCMR Lending Library Connected Activities:

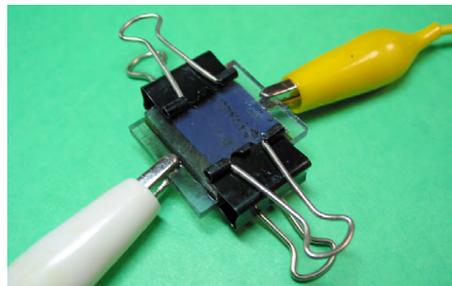


<p><u>Objectives:</u></p> <p>Using materials like iodine, blackberry juice, and a few specialized materials, students will create a working solar cell that mimics the process of photosynthesis.</p>	<p><u>Vocabulary:</u></p> <p>Electron Transfer Photosynthesis Semiconductor Photovoltaic Cell Transfer of Energy 1st Law of Thermodynamics</p>
<p><u>Students Will:</u></p> <ul style="list-style-type: none"> ● Build a working solar cell. ● Measure the voltage of their solar cell. ● Compare the voltage of solar cells created with different dyes. 	<p><u>Materials:</u></p> <p>For Teacher Solar cell presentation for high school and middle school (<i>accessed on internet</i>)</p> <p>For Whole Group or Teacher Distilled white vinegar (<i>in bottle</i>) Scotch tape Nanocrystalline Titanium Dioxide (TiO₂)</p> <p>Per Group (2-4 students) Multimeter Two alligator clip leads Plastic dish (2) Distilled water (<i>in bottle</i>) Ethanol (<i>in bottle</i>) Graphite pencil Small binder clips (<i>2 per cell</i>) 2 conductive glass slides Iodide electrolyte solution</p> <p>Items Teacher Provides Beaker Glass stirring rod Measuring Cylinder Scale Blackberries, raspberry, or blueberries (<i>do not use strawberries</i>) Paper towels</p>
<p style="text-align: center;">Safety</p>	<p>Wear safety goggles at all times during lab. Gloves are also recommended. Take care not to inhale TiO₂ powder. Refer to Material Safety Data Sheets (MSDS) for specific info on individual chemicals.</p>



Introduction

With iodine, blackberry juice, and a few specialized materials, you can create a working solar cell that mimics the process of photosynthesis. This type of cell is called a *Grätzel cell*. Grätzel cells are in commercial operation and cost half as much as silicon solar cells.



Watch the following video for help with the preparation and assembly of the solar cell:
https://www.youtube.com/watch?v=G94_Ec1mY-k&list=PLOj89VmvuWRAzEMo1PpeospYscPOn-UKm&index=2

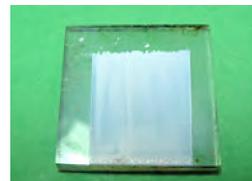
A presentation to go along with the solar cell activity is located at:
https://docs.google.com/presentation/d/1ocDqTU8UeAVYd4aEbSyGCes_as03nIvLZaZXwyQy-HE/edit

Classroom Procedure:

[Note: The TiO_2 coated slides and the Iodide electrolyte solution can be prepared ahead of time.]

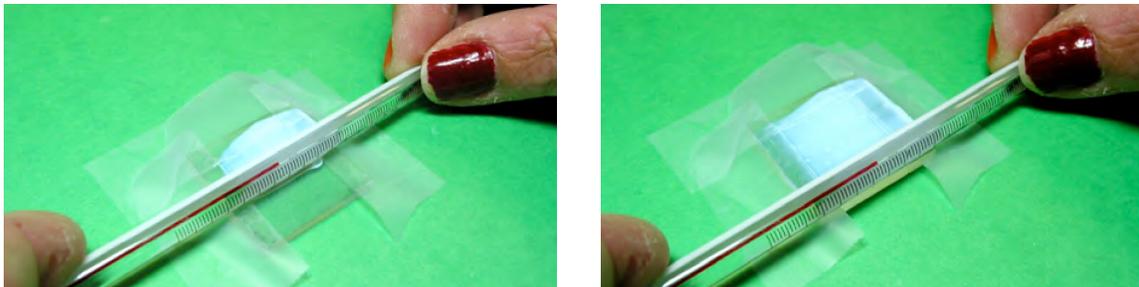
Coat slides with nano Titanium Dioxide

To make the nano Titanium Dioxide (TiO_2) suspension, add 10 mL vinegar (or dilute acetic acid) gradually to 6 g Titanium Dioxide, stirring until smooth and lump-free (about 5 minutes). You should have a smooth solution that looks like White-Out and is just barely thin enough to be taken up into an eyedropper. This mixing helps break up the nanoparticles..



Test one of the glass slides with a multimeter to determine which side is conductive (You can also use your fingernail to compare the sides. The rough side is the conductive one). The side with a resistance reading of 10-30 ohms is the conductive side. Mask about 3 mm on three sides. Extra tape on the sides can help fasten the slide to the table. Drop 3-5 drops of the TiO_2 solution in a row on one side of the slide. Deposit a uniform, thin layer across the





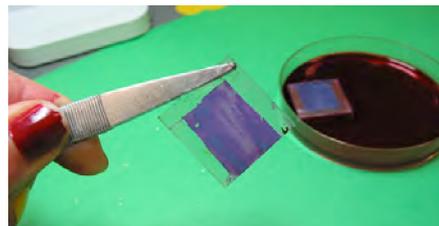
unmasked portion of the slide by drawing a stir-rod (a glass thermometer also works well) along the slide.

Allow the slide to dry for a few minutes before removing the tape. Place the slide directly on the flame of a gas burner for 5-10 minutes, directly on a hot plate for 5-10 minutes or in an oven broiler for about 60 minutes, to sinter the film. Make sure the slides turn yellow and then white again. Let them cool slowly to room temperature. Using an oven is recommended.

The resulting TiO_2 layer is *nanoporous*, meaning that it has pores, like a sponge, which are only a few nanometers (10^{-9} m) wide. The TiO_2 particles themselves are about 20 nm wide. The film is about 7-10 micrometers thick (the thickness of the Scotch tape). The slides can be stored in air for later use.

Stain Titanium Dioxide with Dye

Blackberry: Blend or crush fresh or frozen blackberries in a blender or by hand, adding a tablespoon of water for every 10 blackberries, or simply take the juice from the bottom of frozen berries after they have thawed.



Raspberries: Blend or crush fresh or frozen blackberries or raspberries in a blender or by hand, adding a tablespoon of water for every 10 blackberries, or simply take the juice from the bottom of frozen berries after they have thawed.

Chlorophyll: Take 5 leaves of a citrus tree (lemon, grapefruit) and mash with 10 ml of acetone in a mortar. Pour your sample in amber bottle.

Pour a few mm of the juice dye into a shallow clean dish, and place the TiO_2 coated slide face down in the juice for 5-10 minutes. It should be soaked until it is a deep purple (light green for chlorophyll) with no white TiO_2 showing. Rinse the slides in water, then in isopropanol or ethanol, using a washbottle, and blot dry with a tissue. These films should be used immediately (once dry), or stored in deionized water with acetic acid added (pH 3-4) in a closed, dark colored bottle.

Carbon-coated Counter Electrode

While the films are being stained, prepare the carbon-coated electrode. Use a soft pencil or graphite stick to coat the entire surface of the conductive side of the second slide.

An alternative method which is quicker and gives better coverage is to hold the slide, conductive side down, above a candle flame until it is coated black. The slide should be held directly in the candle frame to deposit soot on the entire surface.



Assembling the Solar Cell

Place the graphite coated slide face down on top of the dry dye soaked TiO_2 coated side of the second slide. The slides should be placed slightly offset to allow enough room on the end to place an alligator clip. Use two binder clips to hold the two slides together. Now with an eyedropper add 1-2 drops of liquid Iodide/Iodine electrolyte solution to the crease between the two slides. The solution will be drawn into the cell by capillary action and will stain the entire inside of the slides. If the electrolyte is not going all the way through add a couple more drops to each side or gently open and close one of the binder clips.



Attach the alligator clips to the two overhanging edges of the slide and attach the clip leads to your multi-meter with the negative terminal attached to the TiO_2 coated slide and the positive terminal attached to the graphite coated slide. Measure

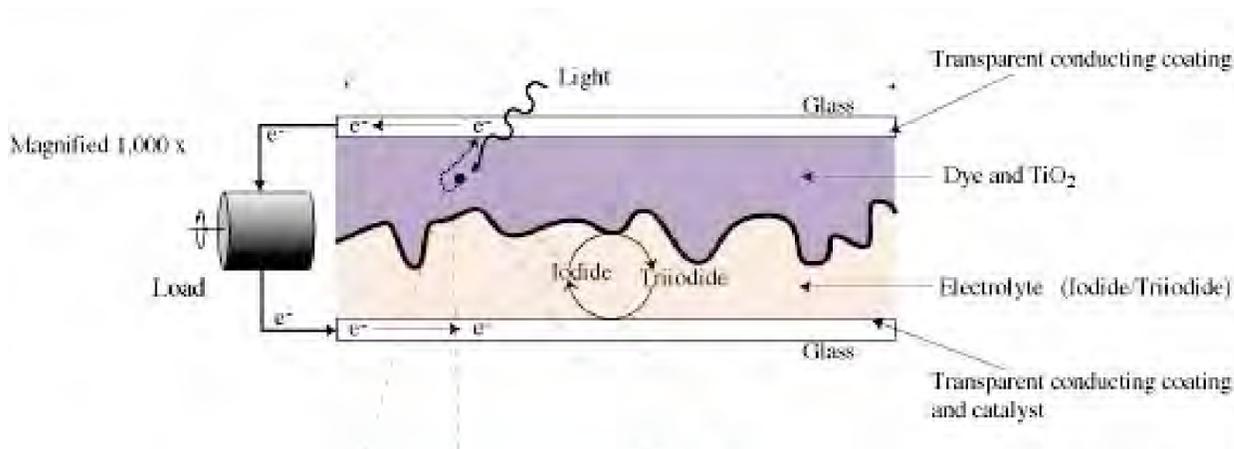
both the current and voltage of the cell in direct sunlight and indoors. The maximum voltage in direct sunlight should be about 0.1 – 0.5 volts. You may also attach several cells in series and parallel, to see which configuration will power a small motor or fan.

Science Content (for HS):

In all solar-powered devices, an incoming photon from sunlight boosts an electron from a semiconductor into a state where it is mobile, and can conduct to produce energy. In a semiconductor (as opposed to a metal), there is an energy gap between the valence electrons (which are tightly bound to the atom and unavailable for conduction) and the conduction electrons (which are mobile). TiO_2 is a wide band gap semiconductor. The gap is so wide that energy from sunlight can't excite electrons enough to make them conduct, but sunlight can excite the electrons in the blackberry dye: $\text{photon} + \text{dye} \rightarrow \text{electron} + \text{dye}^+$. Those excited electrons are transferred from the blackberry dye to the TiO_2 , which transfers it to the electrode, producing electricity. But this leaves the blackberry dye slightly positive (oxidized), and it needs an electron to make it neutral again. That electron is available at the counter electrode (the one coated with graphite).



The dye isn't in physical contact with that electrode, so the Iodide/Iodine electrolyte acts like a ferry, bringing electrons from the counter electrode to reduce the dye. It does that by cycling between Iodide (I^-) and Tri-iodide (I_3^-): $dye^+ + I^- \rightarrow dye + I_3^-$. The Tri-iodide is restored to Iodide by taking the electron from the carbon-coated counter electrode: $I_3^- + electron \rightarrow I^-$. This reaction is catalyzed by the carbon coating (analogous to a docking port for the ferry).



So, the TiO_2 is an electron acceptor, the Iodide is an electron donor, and the dye is a photochemical pump which excites electrons to a mobile (conductive) state. Any porous semiconductor with the right band gap will work, and generally oxides like ZnO , NiO_2 or TiO_2 are used. The dye in blackberries and raspberries is an anthocyanin (called cyanin 3-glycoside and cyanin 3-rutinoside), which makes poppies red. Strawberries and other colored fruits do not work because these dyes do not chelate (bind) to the TiO_2 – only compounds with an $=O$ or $-OH$ group will do. The resulting voltage across the cell is the difference in energy between the redox potential of the electrolyte and the conduction band of the TiO_2 .

This is the same basic process as photosynthesis, in which chlorophyll replaces the blackberry dye and TiO_2 as a light absorber, and the oxidization of water (to produce oxygen, hydrogen, and electrons) replaces the I^-/I_3^- cycle, replenishing the electrons released from chlorophyll. In photosynthesis, the resulting voltage is used to generate ATP and NADPH, instead of an electrical current. Ultimately, carbon dioxide acts as an electron acceptor, resulting in the fixing of carbon dioxide.

Science Content (for MS):

Taken From: Green Student U (<http://www.greenstudentu.com/encyclopedia/energy/solar>)

The first law of thermodynamics states that the total amount of energy in the universe is constant. This means that the amount of energy you begin with has to be the same at the end. Often, the energy that you begin with gets changed into a different form. The different forms of energy are mechanical, nuclear, chemical, electrical, Electromagnetic (light, sound), and thermal.

The sun provides us with the energy to sustain life on Earth. It gives plants the food they need for photosynthesis and controls our climate and weather. And since fossil fuels such as coal and oil are decayed plant and animal matter from millions of years ago, the sun is even a large part of these non-renewable sources. Simply put, the sun is a renewable energy source for all life on Earth.

Electric energy, also known as photovoltaic energy, is energy that is used to make electricity directly from the sun. Electric energy uses solar cells to absorb the sunlight, which in turn transmits an electrical charge through metal wires and circuits. Any extra energy can be stored in a battery and used when there is no sun. Solar electric energy can be used for:

- Calculators
- Watches
- Spacecraft
- Lighting
- Small appliances
- Telephones
- Communication equipment

Many power plants use solar panels to transfer the energy from the sun into electricity. These solar panels trap the sun's light, which is used to heat a fluid. This fluid produces steam, which is converted into mechanical energy and then into electricity by a generator. This is an excellent way to reduce the amount of fossil fuel used by the plants.

Here are some benefits of using solar power:

- Energy from the sun is limitless
- Less greenhouse gas emissions
- Conserves energy
- Doesn't harm natural habitats
- No air pollution
- Cheaper than other energy sources
- Lower power bill
- Less dependence on foreign oil
- It's free



Safety:

Wear safety goggles at all times during lab. Gloves are also recommended. Take care not to inhale TiO_2 powder. Refer to Material Safety Data Sheets (MSDS) for specific info on individual chemicals.

Extension Activities:

Have students plan an experiment to test the effect of a variable on the power output of their solar cell. They would test, collect data, and analyze their results.

Possible variables might be:

Amount of light

Distance of light source

Type of berry juice used

Additional Resources:

Dr. Greg Smestad originally developed this activity, and he has a wealth of information about it on his website at <http://www.solideas.com/solrcell/cellkit.html>

A useful article is Demonstrating electron transfer and nanotechnology: A natural dye-sensitized nanocrystalline energy converter. G. Smestad and M. Gratzel, *J. Chem. Ed.* (75), 1998, pp. 752-756. <http://www.solideas.com/papers/JCE98.pdf>

Lots more detail in this article: Education and solar conversion: Demonstrating electron transfer. G. Smestad, *Solar Energy Materials and Solar Cells* (55), 1998, pp. 157-178.

Specialty Materials:

¹ **Conductive (tin dioxide coated) glass slides**

Precut commercial (2.5 cm x 2.5 cm) TEC 8, TEC 10 or TEC 15 (that's 8, 10 or 15 ohms per square meter) Tin dioxide (SnO_2) coated glass slides can be purchased from:

Hartford Glass Co. Inc.

PO Box 613

Hartford City, IN 47348

Phone: 765-348-1282

Fax: 765-348-5435

Email: hartglass@netusa1.net.

Price: 50 cents each. They prefer orders over \$50 but will do smaller ones for educational use if you ask.



² Nanocrystalline titanium dioxide powder

Aeroxide® P-25 titanium dioxide (TiO₂) powder can be obtained from:

Evonik Degussa Corporation
379 Interpace Parkway
Parsippany, NJ 07054
Phone: 973-541-8106
Price: ~\$5 + S/H for 20g jar

³ Iodide electrolyte solution

To make the Iodide electrolyte solution dissolve 0.127 g of 0.05 M Iodine (I₂) in 10 mL of water-free ethylene glycol, then add 0.83 g of 0.5 M potassium iodide (KI). Stir and store in a dark container.

The materials are also available from the Institute for Chemical Education (ICE) in a pre-assembled kit good for making 5 solar cells for \$45:

ICE, Institute for Chemical Education
University of Wisconsin–Madison
Department of Chemistry
1101 University Avenue
Madison, WI 53706-1322
Phone: 608-262-3033 or 1-888-220-9822 (U.S.)
Fax: 608-265-8094
Email: iceorders@chem.wisc.edu
Web: <http://ice.chem.wisc.edu/Catalog/SciKits.html#Anchor-Nanocrystalline-41703>

ICE also offers the conductive glass slides and titanium dioxide powder for separate purchase

