

Using Nature to Make a Photovoltaic Cell

Adapted from: *Smestad, G. P; Grätzel, M. J. Chem. Ed., 1998, 75, 753.*

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In this lab, you will construct a photovoltaic cell (PV), or solar cell. Before starting this lab, you should already be familiar with the concepts of absorption, transmission, and the visible spectrum. Rather than using silicon in your cell, you will be using blackberry juice as an absorber. Blackberry juice is full of a class chemical compounds known as anthocyanins (fig. 1). These compounds are what give many fruits and vegetables their distinct colors. This includes blackberries, strawberries, raspberries, and even the deep red and orange colors of autumn leaves.

For a PV cell to function, light must be absorbed and converted to electrons. This feat is accomplished by the anthocyanin, which has a molecular structure that acts like a photon antenna. As light is collected, the molecule enters an excited state whereby it dumps an electron wherever it can to relieve this “excitement”. We will harness that electron by attaching the anthocyanin to a semiconductor, titanium dioxide.

Titanium dioxide, also known as titania, has the molecular structure TiO_2 and is one of the most common oxide compounds on Earth beside silica (sand and glass). The crystal structure is shown in figure 2. Titania is the compound that gives many things their bright white appearance. This includes white paint, sunblock, and toothpaste. As previously mentioned, titania is a semiconductor, but is not a good absorber of light, hence the white color. It does absorb in the UV spectrum and is currently being explored as a photocatalyst for splitting water and cleaning up smog-filled air.

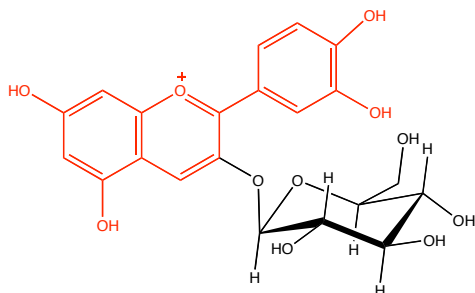


Figure 1. Anthocyanin molecule.

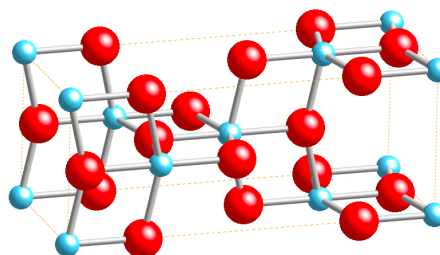


Figure 2. Crystal structure of titania.

Anthocyanins, as well as other inorganic compounds, attach themselves very well to titania due to a number of hydroxyl (-OH) bonds on both the titania and the dye. When electrons are produced by the dye, they conduct themselves through the molecule and into the titania. As long as the titania film is bound to a conductive surface, we can harness those electrons to do useful work, such as power a light bulb. As the adage goes, however, you cannot get something for nothing. The dye molecule cannot produce an endless supply of electrons and they must be regenerated. By using an electron donor, or redox electrolyte, the electrons are supplied *back* to the dye. Of course, this electrolyte does not have an unlimited supply of electrons either. The electrolyte receives its electrons from the return of the dye-generated electrons that were sent through the circuit. This cycle is important- electrons are never “used up” or destroyed, the power is just used to do some amount of work. This whole device: dye, titania, and electron donor complex creates what is known as a dye-sensitized solar cell, or DSSC. This type of cell was “invented” and published by Michael Grätzel in the journal *Nature* in 1991, but nature itself has been performing this same process for millennia in plants by using chlorophyll.

Goals

- Extract natural anthocyanin dyes from blackberries
- Fabricate a dye-sensitized solar cell
- Make comparisons on voltage, current, and efficiency of your cell.

Safety notes

You will be working with sharp glass, acids, heat sources, and staining dyes. Wear gloves during this lab. If your skin comes in contact with any chemicals in lab, wash the exposed areas with copious amounts of water. As always, goggles are required when working in lab.

Materials

Fluorine-doped tin oxide conductive glass
Scotch tape
Titania powder
1 mM nitric acid
Blackberries
Binder clips
Multimeter

Isopropanol
Deionized water
Hotplate
Disposable pipettes
Pencils
Items in lab drawer

Procedure

Preparing the electrode

1. Preheat your hotplate by turning it to the maximum setting (large hotplates set to *half*).
2. Begin by obtaining two pieces of conducting glass. One will be your anode with the titania film and dye, the other the cathode.
3. Switch the multimeter to the resistance setting (Ω) and test the piece of glass for conductivity. Only one side is conductive and this is the side you **must** use as a substrate for the titania film and dye.
4. Prepare the conducting side by wetting a Kimwipe with isopropanol and wiping the piece of glass (like cleaning a window). Follow this with a similar cleaning with deionized water and wipe dry. You may need another Kimwipe.
5. Using Scotch tape, make a 3-sided border with two pieces of tape on each side. Use one piece of tape on the 4th side. Smooth and press the tape by pushing and dragging a glass stir rod across the surface. See Figure 3 as an example.

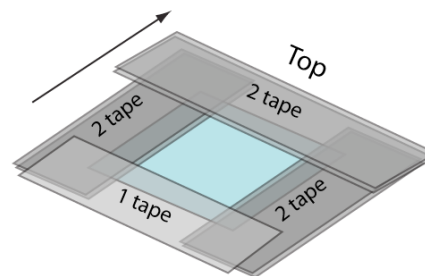


Figure 3. Conductive glass with tape border. Number of pieces of tape are shown.

Making the titania paste

6. Measure out approximately 0.5 g of titania powder on the balance and add to a small beaker.
7. Add diluted nitric acid drop-wise, mixing with a Teflon spatula after every 3-4 drops.
8. Stir mixture thoroughly with the spatulas for approximately 3-4 minutes.

Applying the film

- Using a spatula, apply 2-3 drops of the titania paste to the top border of the square of conducting glass. Using a stirring rod, *quickly* sweep the titania paste from top to bottom, coating the glass square. If the film does not stick, just sweep upwards and back down again.
- Wait approximately two minutes for the film to dry. Carefully remove the Scotch tape border, paying attention to not splatter any of the wet paste.
- Carefully place the piece of glass on top of your preheated hotplate. Keep it there for 20 minutes (goto step 12 while you wait), and then turn off the heat so the film can gradually cool.

Preparing the dye

- While the film is heating/cooling, begin to prepare the dye. Obtain one (1) blackberry and crush it in a beaker using the Teflon spatula. Add 3-4 drops of deionized water and continue to crush the blackberries, obtaining red juice. You can filter this with a Büchner funnel or cheesecloth, but it is not necessary.
- Remove the cooled piece of glass (your anode) and place enough blackberry dye on the titania film to completely cover it. Keep it there for 10 minutes. In the meantime, prepare the counter electrode (Step 15).
- After 10 minutes, gently rinse the blackberry dye from the electrode using deionized water followed by isopropanol (**this is essential**). Gently blot the electrode dry using a Kimwipe.

Preparing the Counter electrode

- Using a pencil, “color in” the conductive side of the second piece of glass. It will take on a slight gray color. The graphite will function as a catalyst for the redox electrolyte. Check that this is done on the conductive side!

Assembling the cell

- Place the titania/dye electrode face up on the lab bench. Place the counter electrode on top of it, offsetting it so that the film is still covered by the counter electrode, but there is about 1/8” of the glass exposed for connections on both electrodes. See figure 4.
- Clamp the two electrodes together using two binder clips. They should be placed on the sides adjacent to the electrodes.
- Add the redox electrolyte by placing 1 drop of the electrolyte solution on one edge of the electrode sandwich. Slowly open and close the binder clips, one at a time, until the brown electrolyte solution is drawn into the sandwich, making the titania film look wet.
- You now have a working PV cell!

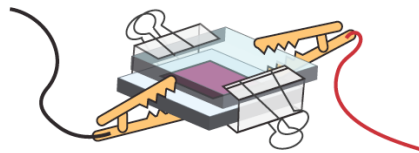


Figure 4. Assembled PV cell with binder clips and electrodes.

Studying the cell

- Use the multimeter (or Vernier) to determine the maximum voltage and current of the cell. Connect the probes to the cell using alligator clips and wire. Use same circuit diagram as the PV lab from Wednesday. Record your data. Depending on the weather, your light source will either be an overhead projector, halogen work light, or sunlight.
- If using a projector, locate the height (location) of the maximum output voltage. Where is it? What does this mean with respect to focus? Must this process be done when using sunlight?
- What happens to the voltage as you change the angle of the cell?
- Does the side that is exposed to the light matter (film/dye side or counter electrode)?

Cleanup

- Place all used fruit in the trash. Wash all glassware and spatulas with soap and water. Finish with a DI water rinse.
- Disassemble your PV cell. Rinse it with isopropanol. You can reassemble and keep it, but be aware that the blackberry juice will begin to fade and turn brown.
- Return all materials to the appropriate locations.
- Place all paper towels, Kimwipes, pipettes, tape and other disposable materials in the trash.

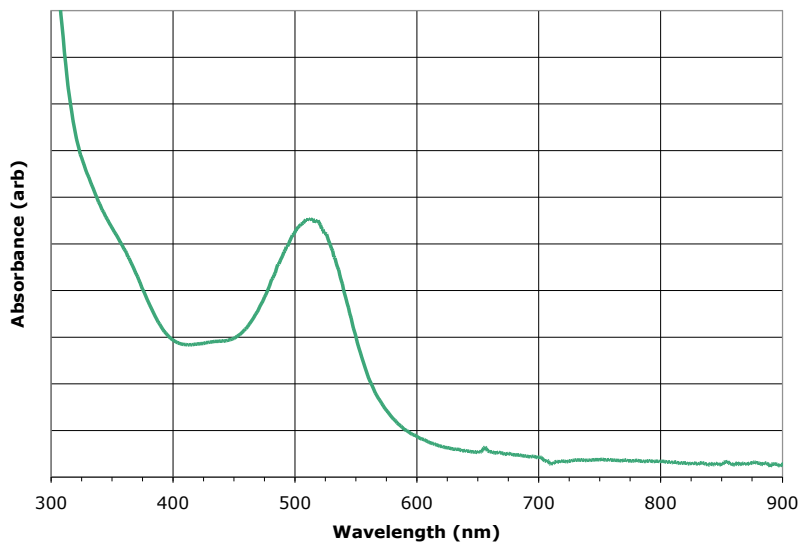


Figure 5. Absorption spectrum of blackberry juice.

Questions for thought...

- 1) Tree leaves are generally green in color. What wavelength of light do they absorb? Is this a smart idea on the plant's part?
- 2) What is one advantage of using titania powder rather than a sheet of titania?
- 3) What color sunlight does the cell most readily absorb (fig. 5)? How might other portions of the spectrum be utilized?