Student Lab:
Make Your Own Solar Cell

Materials and Equipment

Nanocrystalline titanium dioxide (TiO₂) powder
Iodide electrolyte solution
Conductive glass slides 2.5 cm x 2.5 cm (2)
Blackberries, raspberries, pomegranate seeds, or Bing cherries, defrosted if frozen
Ethanol or isopropanol
Wash bottle
Distilled white vinegar
Distilled water
Clear dishwashing detergent
Absorbent tissues
Cotton swabs
Small shallow dish (e.g. Petri dish)
Scotch tape
Aluminum foil
Mortar and pestle
Glass stirring rod
Plastic tweezers
Metal tongs
Dropper bottle
Small funnel
Tea candle and matches
Small binder clips (6)
Alligator clip leads (2)
Copper tape
Potentiometer
Multimeters (2) with leads
Bread board
Hot air paint stripping gun
  - or -
Alcohol burner with ring stand
Safety Note:

Be sure to wear protective gloves and safety goggles while doing this lab. Take care to avoid inhaling TiO$_2$ during the grinding process, and remember that the hot air gun becomes extremely hot during the annealing process.

Part 1: Preparing the TiO$_2$ Suspension

1. Start with 6 g of TiO$_2$ powder in a mortar and pestle. Under a ventilated fume hood, slowly add vinegar in 1-mL increments to the solution, grinding well each time. The process should take around 30 minutes and will result in a very white, milky paint-like solution.

2. Add a drop of clear dishwashing liquid to the solution, but do not grind (otherwise it will get foamy and bubbly.) The dishwashing liquid will act as a surfactant, which reduces the surface tension of the solution and thus helps it coat the glass plates more evenly.

3. Use a funnel to pour the solution into the small dropper bottle. Leave the solution alone to equilibrate for at least 15 minutes.

Surfactant:
A molecule with a hydrophilic (water-loving) and a hydrophobic (water-fearing) part. Surfactants reduce the surface tension of a solution. An example is soap.
Part 2: Coating Slides With TiO₂ Suspension

1. Clean two conductive glass slides by rinsing them with a washbottle filled with ethanol. Gently dry them with a soft tissue.

2. Use a multimeter set to resistance (ohms) to check which side of the glass slide is conductive. The slide should conduct 10 to 30 ohms on the conductive side, and nothing on the non-conductive side. There should be a slight visible difference between the conductive and non-conductive sides as well. The conductive side will appear bluish and cloudy, while the non-conductive side will appear clear and yellowish.

3. Use the transparent tape to tape one glass slide down to the table on all four edges. The tape should cover roughly 1 mm of the slide on three of the edges, and about 4 mm of the slide on the remaining edge. This tape has a controlled thickness and will form a 40 - 50 micron deep channel into which the TiO₂ suspension can flow.

4. Use ethanol on a tissue to wipe off any fingerprints or oils on the slide.

5. Put a drop or two of the TiO₂ solution on the slide and quickly spread the solution as evenly as possible over the slide using a clean glass stirring rod.

6. Wait for the slide to dry for a few minutes before carefully removing the tape.
Part 3: Annealing the Coated Slides

1. Anneal the TiO\textsubscript{2} film on the glass slide in a fume hood or well-ventilated area. Use one of the following methods:
   i. Make a simple tube furnace from a hot air gun. Start by removing the outer plastic casing at the base of the nozzle to prevent it from melting, then wrap aluminum foil around the nozzle to form an enclosed oven. The slides will lie flat inside this oven for the annealing process. Be sure to leave a small opening in the foil so that you can watch the slides for color change (see below) as they anneal. Turn the hot air gun on high, or to 450°C. Let heat for 30 minutes.
   ii. Place a ring stand over an alcohol burner. Anneal the slides one by one by resting them on the ring stand at the tip of the flame for 10 minutes.

2. Watch the slides as they anneal. The TiO\textsubscript{2} coated section should turn purplish-brown, then back to white, as the heat burns off the surfactant.

3. Store the slides for later use.

Part 4: Staining the TiO\textsubscript{2} with Anthocyanin Dye

1. Use a clean mortar and pestle to crush 3 - 4 berries. Transfer the crushed berries to a Petri dish.

2. Add about a tablespoon (15 mL) of distilled water to the crushed berries and stir with a clean glass rod.

3. Place the slide face down into the berry mixture so that the TiO\textsubscript{2} coated section is submerged in berry juice.

Anthocyanin: The pigment responsible for the red or blue coloring in flowers and other parts of many plants.
4. Let the slide soak in the juice for 10 minutes. The film should be bright purple. If you can see any white TiO₂ remaining on either side of the glass after 10 minutes, put the slide back into the dye for another 5 minutes. Now is a good time to start on Step 4: Carbon Coating the Counter Electrode.

5. Lift the slide out of the juice using a pair of plastic tweezers. Rinse the slide first in distilled water to remove any fibrous debris from the berries, and then in ethanol to remove excess water from the porous TiO₂ coated section. Blot the slide dry with a tissue.

6. You have now made a TiO₂ dye-sensitized electrode. If the slide is not going to be used right away, store it submerged in distilled white vinegar in a closed, dark-colored bottle.

Note: Not all plants containing anthocyanins work for this experiment. Some plants, like strawberries or grapes, contain anthocyanin dye structures that are not always capable of chelating (complexing) to the TiO₂ surface. The dye structure must possess several carbonyl (C = O) or hydroxyl (-OH) groups to work successfully.

Part 5: Carbon Coating the Counter Electrode

1. While the TiO₂ electrode is being stained in the berry juice, make the counter electrode from another piece of conductive glass.

2. Determine which side of a clean glass plate is conductive with a multimeter set to resistance (ohms).

3. Light a tea candle with a match. Hold the slide by one edge with the metal tongs. Pass the conductive side through the middle of the flame until the entire side is coated evenly with soot, except for where the metal tongs were.

4. Place the carbon-coated slide face up on the counter. Be careful, the slide will be hot. Allow it to cool. Then, use a tissue and cotton swab to clean any residual soot off of the edge of the slide covered by the metal tongs to clear the carbon off of a 4 mm strip. This edge will be where the alligator clip attaches.

Carbon Catalyst: The carbon coating on this slide serves as a catalyst - a substance that increases the rate of a reaction without being consumed in the reaction. In this solar cell, the carbon serves as the catalyst for converting triiodide to iodide.
4. You have now made a carbon-coated counter electrode. The carbon coating on this slide is very fragile and is easily rubbed off. Be careful not to touch it.

Part 6: Assembling the Solar Cell Device

1. If the stained TiO₂ glass slide has been stored in vinegar, carefully remove it. Rinse the slide with water and then with ethanol. Then gently blot it with a tissue.

2. These two slides, the TiO₂ coated slide and the carbon-coated slide, will be sandwiched together to make a solar cell. Both slides have a 4 mm strip on one edge that is clear of any coating. The slides must be assembled so that the coated areas of the slides are touching each other completely. This means the slides will be offset, and the 4 mm empty strips will be exposed on each side. These two exposed edges will serve as the contact points for the negative and positive electrodes.

3. Place the dried TiO₂ coated slide on a flat surface so that the TiO₂ coated section is face up. Place the carbon-coated slide face down on top of the TiO₂ slide so that the coating completely covers the TiO₂ coating, leaving a 4 mm strip exposed on each slide.

4. Pick up the two slides in this orientation, being careful not to let them move. Clip the edges (the ones that do not have the 4 mm strip exposed) together on both slides with two binder clips.

5. Place one or two drops of the iodide electrolyte solution at one of the edges of the slides.

6. Alternately open and close each side of the solar cell by releasing and returning the binder clips. The liquid is drawn into the space between the electrodes by capillary action. This wets the stained TiO₂ film. Make sure that all of the stained area is contacted by the electrolyte.
7. Wipe off the excess electrolyte solution from the exposed areas of the glass using cotton swabs and tissues dampened with ethanol. The cell will not work well if there is any electrolyte solution left on the exposed areas where the alligator clips attach.

8. Fasten alligator clips to the two exposed sides (or poles) of the solar cell to make electrical contact to the finished device.

Part 7: Measuring the Electrical Output

1. The completed solar cell can be taken outside and measured under sunlight. The cell will last longer if it is protected from the elements by a polycarbonate plastic cover, like a plastic Petri dish. Sun and air will dry out the iodine electrolyte solution inside the cell, which will speed up the deterioration of the dye molecules in the berry juice.

2. For instructions on how to measure the voltage and amperage of the cell, see Experiment 1: Measuring Voltage and Current.

Congratulations!
You just made a solar cell!

An assembled solar cell