# Titanium Dioxide Solar Cell

Adapted by Lauren Cassidy and Thomas. C. Keane, Ph.D.

**Purpose**: The purpose of this lab is to create then test the efficiency of dye sensitized titanium dioxide solar cells. This experiment was originally developed by Greg Smestad of the Institute for Chemical Education, Madison WI.

**Learning Objectives**:

1) Explain in general how solar cells operate
2) Identify real world applications of solar cells

**Introduction**: Solar cell technology is used to convert solar energy into electrical energy which can be used to power electrical devices. Solar cells are already used to supplement or replace dependence on conventional energy sources in few homes and businesses. There is the potential, however, for further development and wider acceptance of solar cell use to be the answer to the growing energy situation.

In coming photons from the sun excite electrons in the $TiO_2$/anthrocyanin dye complex. These electrons are transmitted through the SnO conductive coating to the multimeter. Electrons come from the multimeter back into the conducting SnO coating on the carbon (soot coated) plate which donates electrons to the KI3 electrolyte. This reduces the electrolyte, which donates the extra electrons to the $TiO_2$/dye complex, completing the cycle of electron flow[1].

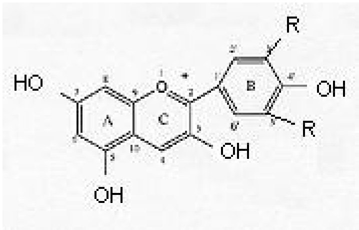
Anthrocyanins are naturally occurring dyes found in plants. They are why raspberries are red and contribute to the autumn color of leaves.[2]

### Anthocyanin Content in mg per 100g fresh weight

| | |
|---|---|
| Cranberry | 60 |
| Black currant | 250 |
| Currant, red | 15 |
| Grape, Merlot fruit | 120 |
| Raspberry, red | 40 |
| Raspberry, black | 300 |
| Blackberries | 200 |

Adapted from a table at http://eng.ege.edu.tr/~otles/ColorScience/anthocyanins.htm

Structure of an anthrocyanin



Where the R groups are nonexistent, OH or OCH3

**Materials**:

20Ω resistance SnO coated glass plates
Nanocrystalline $TiO_2$, Aldrich Batch # 18521HH
Mortar/pestle
99.7% acetic acid Sigma Aldrich batch # 03228LD(or glacial acetic acid)
Distilled water
Titron X-100 surfactant Sigma lot # 06621EH (or clear dish detergent)
Multimeter (with both needle probes and banana clips )
Clear plastic tape
Hot plate
Glass stirring rod
Ethanol
$KI_3$ electrolyte solution
$CH_2Cl_2$
Acetone
Candle/ matches
Paper clamps/Binder clips
Tweezers
Berry Juices
    Bing Cherry, Oregon lot #PCBX3A
    Raspberry, Price Chopper Grade A
    Black Berry, Driscoll's organic

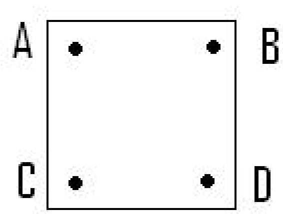
**Procedure**:

1. On a scale in the hood, weigh out 1.5g of nanocrystalline $TiO_2$. Transfer the weighed out $TiO_2$ to a mortar. This should be enough to coat at least 6 SnO glass plates.

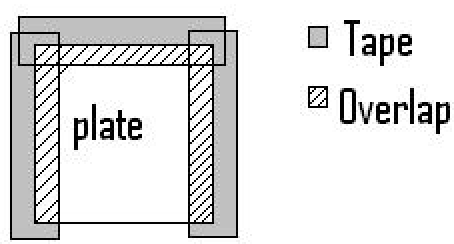
2. Prepare very dilute acetic acid by adding 0.1mL 99.7% acetic acid to 50mL of $dH_2O$ to make a solution of 0.035M acetic acid. This will be more than enough for one person and the volume can either be shared between two people or can be covered with parafilm and set aside for later.

3. To the $TiO_2$ add 4-5 drops of Titron X-100 and 1 pipet full of 0.035M acetic acid. Grind using the pestle. Continue adding more 0.035M acetic acid, drop wise, until the mixture has obtained the consistency of thin toothpaste. It is better to err on the side of slightly more acetic acid added than less acetic acid added since it is undesirable for the mixture to dry out.

4. Using the multimeter with the needle probes attached, determine the conductive side of 6 SnO coated plates. While doing this, check the resistance across the plates by placing the needles at points A,D or B,C. Keep track of any anomalies observed.




5. Apply pieces of tape to three sides of each plate on the conductive side. The tape should overlap the slide ~2mm, with the excess tape being allowed to hang off the side or tucked under itself to prevent it from sticking to the lab bench. Do not tape the bottom side of the slide.




6. Using a glass stirring rod, apply the $TiO_2$ mixture to the plate, spreading it out such that a thin, consistent coating of $TiO_2$ is spread. At this point, more 0.035M acetic acid can be added if clumping/flaking occurs, but this should be avoided because it could cause the $TiO_2$ coating to be too thin.

7. Carefully remove the tape from the plates and set them on a hot plate in the hood to dry. The hot plate should be left on high for at least 30 minutes. During this time the $TiO_2$ coating will turn brown as the organic solvent is evaporated off. When the $TiO_2$ becomes white again, the plates are done and they should be allowed to cool by turning off the hot plate.

8. Store the finished plates in a clean, dry location, preferably in a glass dish with an evaporating dish for a lid. It is imperative to keep the finished plates free of moisture and to make sure the $TiO_2$ coating is not scratched.

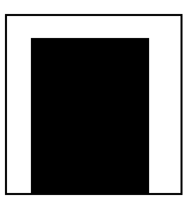
9. Isolate the anthrocyanin dyes from the berries by mashing them, separately, in the presence of acetone. About 3-5 berries of any type are needed to extract the required quantity of anthrocyanin. This can be done by placing the berries in a small beaker with 5mL of acetone (exact volume not important) and mashing with a glass stirring rod till the berry has de-colored and the liquid above the berry is highly colored.

10. Place the $TiO_2$ coated plates coated side down in berry extract and let sit for a minute. A color change should be observed as the $TiO_2$ takes up the anthrocyanin dye. Rinse the plates with a small amount of ethanol to remove excess dye and berry pieces which may still be present in the extract.

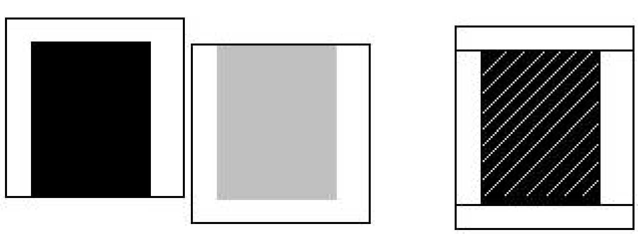
11. While the plates are drying, determine the conducting side of SnO plates, equal in number to those which were coated. Again use the same convention for determining resistance and note any large variations.

12. Set up a candle such that it can stand independently in some holder. Light the candle and, using tweezers, soot the plates by moving them, conducting side down, through the flame.

13. Using a Kimwipe, remove about 2mm of soot from three edges of the plate.



14. Using two paper clamps, clamp the sooted plate to the dyed $TiO_2$ such that the uncoated sides stick out from either end. Be careful not to scratch or unduly rub the plates together.



15. Add 2-3 drops of the $KI_3$ solution to an open end of the clamped plates and allow it to filter through by capillary action.

16. After the $KI_3$ has spread through to the other end of the clamped cell, attach the red alligator clip of the multi meter to the sooted side and the black end to the $TiO_2$ dyed side. Record the current, resistance and voltage* of each cell in the sun. Also note the day's weather conditions (cloudy, partly cloudy, full sun), and the time of day.

***NOTE**: You will not be able to read the resistance of an assembled cell directly. To determine the resistance use the equation form physics class V=IR (voltage= current/resistance). Be sure to watch your units.

Part II

1. Prepare the solar cell components as in part I, but instead of using just $KI_3$ solution mix approximately 5mL of $KI_3$ solution with 5mL of $CH_2Cl_2$ in the hood.

2. Apply this mixture to the cell as one would the $KI_3$ in Part I, being careful to observe the fact that this mixture will have a fairly high vapor pressure.

3. Test the voltage, current and resistance of this cell relative to the KI3 only cell

4. To take this further, combine different amounts of $KI_3$ and $CH_2Cl_2$ to see which yields the best current.

Part III

1. Prepare the solar cell components as in part I, but instead of using berry juices, use toluene suspended quantum dots.

2. Either submerge the $TiO_2$ in quantum dot/toluene mixture, or carefully drip the dot/toluene suspension onto the $TiO_2$ surface.

3. Allow the plates to dry. In this instance it won't hurt the dye if the plates are warm. Between drips or after submersion, gently warm the plates to drive off toluene.

4. Test the voltage, current and resistance of this cell relative to the best performing berry cell.

Questions:

1) What is the oxidation number of the titanium in Titanium dioxide?
2) What is a problem with these solar cells, and what could be done to improve them?
3) What is the function of the $KI_3$ electrolyte?
4) Would one expect a greater current to register on a clear sunny day or a partly cloudy day? Why?

5) Given the relative concentrations of anthrocyanins in the various berries, which would you suspect to produce the highest current? Why? What did you observe?
6) If one were to prepare two cells the same way (using the same materials) what would contribute to differences in current/ voltage/ resistance? Was any difference noticed?

Pt II

7) What is noticed about the $KI_3/CH_2Cl_2$mixture?
8) What do you observe that is different when the $KI_3/CH_2Cl_2$ is added to the solar cell versus when straight $KI_3$ is added?
9) What is a simple experimental technique which could be applied to prevent the $KI_3/CH_2Cl_2$ mixture from dripping out of a pasture pipette?

PTIII

10) Would a dot perform the same as the anthrocyanin?
11) What color does the $TiO_2$/dot coated surface turn when the $KI_3$ is added?
12) What are two benefits and two concerns one would have from using dots over anthrocyanins?

Answers:

1) The oxidation # of O is (1-) so two O would mean a charge of (2-) so to be neutral, the TI must be (2+)
2) Some problems could be that the $KI_3$ electrolyte is liquid and can dry out, one would need a lot of raspberries to do this and raspberries are expensive. It is difficult to consistently coat the plates with TiO2. Solutions would be replace the electrolyte with something which won't dry out or seal the sides very well, use anthrocyanin dye from a less expensive source, use/ develop a spin coating technique. Any well thought out problem / solution pair.
3) The $KI_3$ electrolyte donates electrons to the $TiO_2$/dye matrix and accepts electrons from the carbon coated plate. It serves as a bridge much like a salt bridge in the voltaic cell.
4) One would expect a greater current on a clear sunny day than on a cloudy one. This is because the intensity of the light would be greater therefore more photons striking the surface of the TiO2 complex exciting more electrons.
5) One would actually expect the blackberry coated $TiO_2$ plates to yield the highest current, because they have a higher anthrocyanin content. What I observed was that of cherry, blackberry, raspberry, and Pb dots. Raspberry produced the highest current.
6) Something involving the variable in the amount of $TiO_2$ deposited on the plate, a massive difference in the resistance of the plate, the length of time the $TiO_2$ was maintained in contact with the dye medium, the surface area covered by $TiO_2$/ dye complex, etc…

Part II

7) Something to the effect of the $KI_3$ and $CH_2Cl_2$ don't mix very well.
8) The capillary action pulling the mixture across the $TiO_2$/dye matrix is much greater than that for the $KI_3$.
9) Wetting the pipette would reduce dripping of the high vapor pressure liquid.

Part III

10) Theoretically a dot should perform better than anthrocyanins, or at least a mixture of them should. This is because dots have tunable band gaps depending on the size of the dot so should be able to find the optimum absorption of photons for incoming solar energy.
11) When using Pb dots, the surface turns green upon the addition of $KI_3$. Still working on why and I'm not sure whether or not this would happen with other dot types. My best suspicion is that either the Pb or another metal present in the dot, or both are complexed with the Iodine.
12) Benefits: can tune dots depending on their size.

    Dots themselves can be used to coat a conducting surface.

    Drawbacks: Dots are more expensive than anthrocyanins

    Dots often contain toxic substances such as lead.

References/ Further Reading

[1]Greg P. Smestad (1998). Education and solar conversion: Demonstrating electron transfer. *Solar Energy Materials and Solar Cells*, Volume 55, Issues 1-2, 23 July 1998, 157-178.

[2] Semih OTLES. *Color Science: Anthrocyanins*. Retrieved April 13, 2003, from http://eng.ege.edu.tr/~otles/ColorScience/anthocyanins.htm

[3]*Abstract of Home Made Solar Cell*. Retrieved April 14, 2003, from http://resources.edb.gov.hk/~science/hkcho/5s/wongts.pdf

[4] Jinting Jiu, Seiji Isoda, Motonari Adachi, and Fumin Wang. (2007). Preparation of $TiO_2$ nanocrystalline with 3–5 nm and application for dye-sensitized solar cell. *Journal of Photochemistry and photobiology*, Volume 189, Issues 2-3, 25 June 2007, 314-321.

**Supply List for 10 Students**

10 (20Ω resistance) SnO coated glass plates

Nanocrystalline $TiO_2$, Aldrich Batch # 18521HH

10 Mortars/pestles

99.7% acetic acid Sigma Aldrich batch # 03228LD(or glacial acetic acid)

Distilled water

Titron X-100 surfactant  Sigma lot # 06621EH (or clear dish detergent)

10 Multimeters (with both needle probes and banana clips )

Clear plastic tape

10 Hot plates

10 Glass stirring rods

Ethanol

$KI_3$ electrolyte solution

$CH_2Cl_2$

Acetone

10 Candles

Matches

Several paper clamps

10 Tweezers

Berry Juices

- Bing Cherry, Oregon lot #PCBX3A
- Raspberry, Price Chopper Grade A
- Black Berry, Driscoll's  organic

**Placement**

This lab deals with concepts that are covered in Physics courses, but it is a little more involved than what is typically done in Physics labs. Also, the concept behind understanding quantum dots is something achieved in an upper level chemistry course. It is therefore suggested that this lab would work best in a Physical Chemistry lab.