Name____

Nanocrystalline Solar Cells Lab

Pre-Lab Assignment

- This pre-lab assignment is worth 5 points.
- This part of the pre-lab assignment is due *at the beginning* of the lab period, and must be done individually *before you come to lab!*

I. Background Preparation

- **Read this experiment thoughtfully**

Mentally note any procedural questions and plan how you and your partner will complete all experiments efficiently during the three-hour lab period.

II. Safety Hazards/Precautions

1. Complete the following table. Refer to the Safety Data Sheets (SDS) provided by your instructor. You can also search for a SDS by typing in the chemical name into the search box on the Sigma-Aldrich website: http://www.sigmaaldrich.com/united-states.html. After selecting the correct material, click on the SDS link to view.

Materials	GHS Pictograms (Circle all that apply)	Hazard Statements (Check and list all that apply)
titanium(IV) dioxide		☐ Corrosive ☐ Toxic ________________ ☐ Flammable ☐ Reactive ________________ ☐ Irritant ☐ Other? ________________
acetic acid		☐ Corrosive ☐ Toxic ________________ ☐ Flammable ☐ Reactive ________________ ☐ Irritant ☐ Other? ________________

ethanol		☐ Corrosive ☐ Toxic ____________________ ☐ Flammable ☐ Reactive __________________ ☐ Irritant ☐ Other? ___________________
Waste Disposal	Identify (briefly) how you will dispose of waste materials from this experiment.	

2. **Workplace/Personal Cleanup Notes** (indicate what you will do to clean up yourself and your lab space before you leave the lab):

Additional Safety Cautions

Safety goggles and gloves should be worn throughout the experiment. Any waste chemicals should be disposed of in waste containers. Preparation of the TiO_2 suspension should be done in a hood or a well-ventilated area. Never leave the hot plate unattended while it is on. Be careful when removing the glass slide from the hot plate and while it is cooling to avoid cracking.

III. Pre-Lab Questions

1. The dyes are all deep in color (purple, ruby, etc.). Why do you think these types of juices/teas were chosen vs. lemon juice for example?

2. Even though it's hard to see, the glass squares have a thin tin oxide (SnO_2) coating on one side. Why do you think this is important?

3. Why is the iodine electrolyte solution needed for your solar cell?

4. What is the function of the titanium dioxide nanoparticles in your solar cell?

5. You will have a choice in using titanium dioxide nanoparticles derived from pure bulk titanium dioxide or sunscreen. Describe potential issues with using a product with titanium dioxide as a source vs. pure, bulk titanium dioxide.

IV. Lab Design

1. Which dye source will your group choose and why?

2. Are there any potential issues you predict could arise from using this dye?

3. Which titanium dioxide source will your group choose and why?

4. Are there any potential issues you predict could arise from using the sunscreen as your titanium dioxide source?

Introduction

Solar cells, or photovoltaics, convert light energy into electricity by converting photons into free electrons, which can flow through a circuit. When these electrons run through a circuit, electricity is produced (Figure 1).

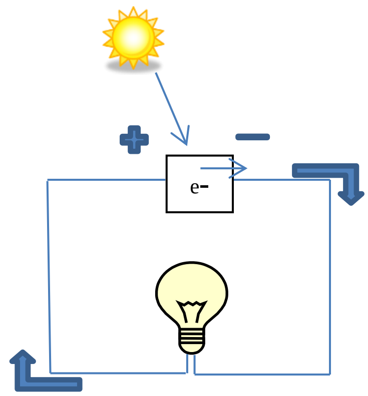


Figure 1. A simple circuit formed by a solar cell as photons are converted to free electrons

Main Types of Solar Cells

Crystalline silicon cells

Crystalline silicon (c-Si) solar cells are currently the most common solar cells in use mainly because c-Si is stable, it delivers efficiencies in the range of 15% to 25%, it relies on established process technologies with an enormous database, and, in general, it has proven to be reliable. Ironically, c-Si is a poor absorber of light and, what might be a sin in this micro-miniature age, it needs to be fairly thick and rigid.

Thin-film layer cells

Thin-film solar cells are potentially cheaper than traditional panels but less efficient. Otherwise identical in function and structure, the singular difference between thin-film and c-Si solar cells is the thin and flexible pairing of layers and the photovoltaic material: either cadmium telluride (CdTe) or copper indium gallium selenide (CIGS) instead of silicon.

Multi-junction cells

Multi-junction (MJ) solar cells are solar cells with multiple different semiconductor materials (typically allows of groups III & V). Each material will produce electric current in response to different wavelengths of light. The use of multiple semiconducting materials allows the absorbance of a broader range of wavelengths, improving the cell's sunlight to electrical energy conversion efficiency.

Emerging cells (include organic cells, inorganic cells, quantum dot cells and dye-sensitized cells)

While there are many solar cells that fall within the "emerging" category, this description will focus on dye-sensitized cells (DSC) since that is what you will be synthesizing in this lab. DSCs must be made of several parts, including a material that can absorb photons and in turn lose electrons; a semiconductor that can accept the lost electrons; an electrolyte that replaces the dye's lost electrons; and a counter electrode that moves the electrons from the semiconductor into the circuit. The whole device has a negative charge on one side and a positive charge on the other allowing for the completion of a circuit.

In this experiment, the anthocyanin dye from certain berries or teas (ex: blackberries) loses electrons as it absorbs light. The semiconductor in this lab, titanium dioxide (TiO_2), then accepts the dye's lost electrons, before passing them on to the conductive plate. To make the solar cell more efficient the semiconductor, TiO_2, is a layer of nanoparticles. The nanostructure of the TiO_2 has a higher surface area to volume ratio than a flat surface of TiO^2. Since the dye coats the TiO_2, the dye has more surface area as well, allowing more photons to be absorbed, more electrons to be transferred to the TiO_2, and more electricity to flow. An electrolyte (iodide/triiodide in this lab) is used to replace the electrons lost in the dye (Fig. 2). The free electrons then move through the conductive SnO_2 coated glass plates, through an external circuit (potentially powering a device), and then back to the electrolyte through the counter electrode (Fig. 3). A thin layer of carbon is added as a catalyst to increase the rate of reaction.

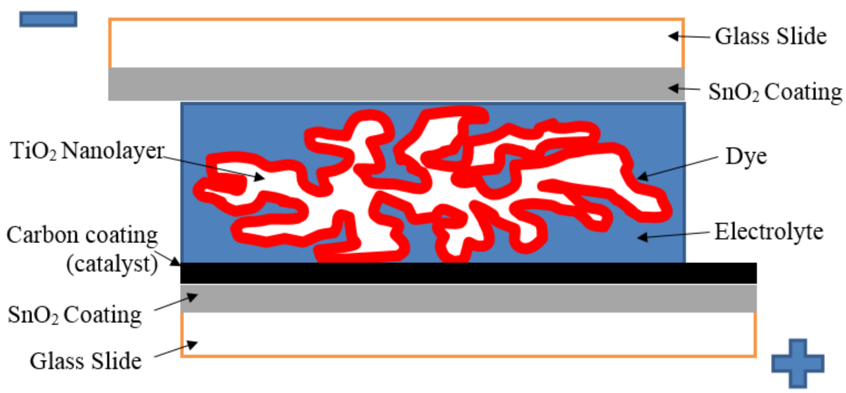


Figure 2: Parts of a Nanocrystalline solar cell

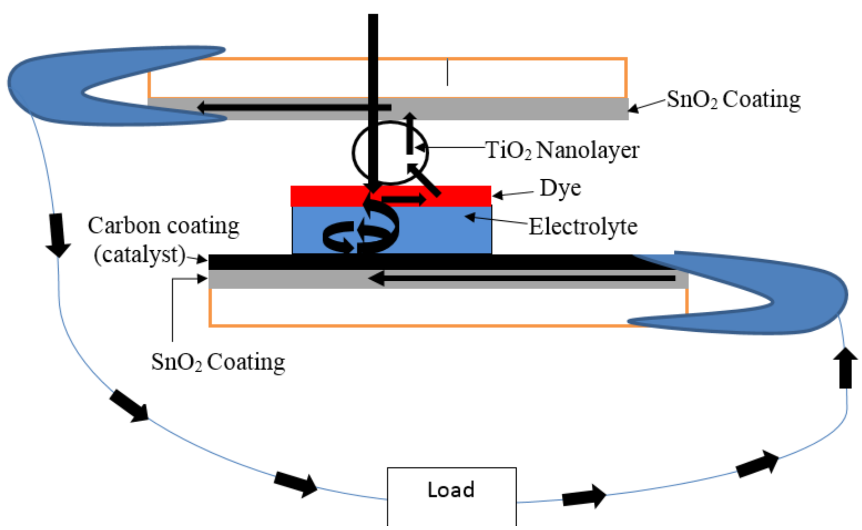


Figure 3: Flow of electrons through the circuit

Materials

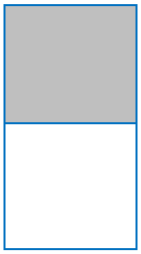
- 2 Conductive (tin dioxide coated) transparent glass plates*
- Colloidal titanium dioxide powder (Degussa P25)*
- Various brands of sunscreen
- Iodide electrolyte solution in dropper bottle*
- Binder clips
- Dropper bottle
- Soft graphite pencil
- Surfactant (dish soap)
- 10 mL 0.1 M Acetic Acid
- Mortar and pestle
- Transfer pipettes
- Graduated cylinder
- Overhead projector
- Hot plate
- Ethanol in wash bottle
- Deionized water in wash bottle
- Blackberries, raspberries, pomegranate seeds, Bing cherries, hibiscus tea, raspberry tea, any others you wish
- Multimeter, capable of measuring voltage, current & resistance
- Photometer/light meter
- Alligator clips (large – should exert a large pressure when closed)
- Tongs
- Weigh boat/Plastic tray
- Transparent tape
- Glass stirring rod
- Absorbent tissue paper (like Kim wipes)
- Buchner funnel
- Gloves
- Aqueous & organic waste containers

Experimental Procedure

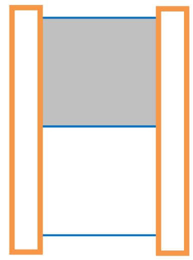
(i) Deposition of the TiO_2 Film

1. Rinse two of the conductive glass plates in ethanol and dry with a soft tissue. When handling the glass plates, take care to touch just the edges of the plates.
2. Set a multimeter to ohms (Ω).

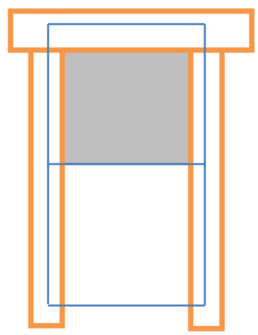
3. Place the ends of the black and red wires on the face of one of the glass plates to determine which side of the plate is conductive. If the side you are testing is conductive, the multimeter will read between 10 and 30 ohms. Repeat with the other plate.
4. Place one glass slide conductive side up. Place the other slide below this slide but with the conductive side down.



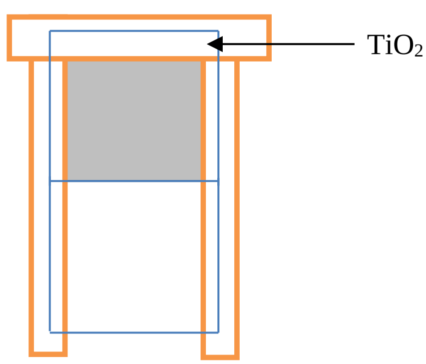
5. Take two pieces of **transparent** tape. Keeping the glass plates together (one with the conductive side up, one with the conductive side down), tape the two longer edges of the plates to the table while only covering no more than 1mm of the plates with tape. This will help to secure the plates as you coat them.



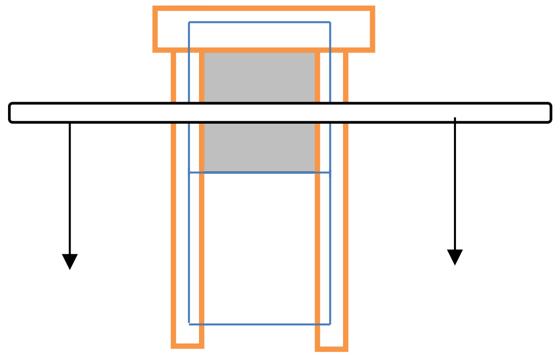
6. Take another piece of tape along the top edge of the conductive plate. This piece of tape should cover 4 - 5 mm of the plate.



7. To coat the conductive glass plate, apply a thin line of TiO_2 suspension (from whichever source your group chose) to the edge of the plate near the tape using the dropper bottle or a pipette.



8. Within 5 seconds after application of the TiO_2 suspension, slide a clean glass stirring rod over the plate to spread the TiO_2 as uniformly as possible. Slide the stirring rod toward the bottom of the plates. Do not lift the stirring rod. (The plate that is conductive side down does not need to be fully coated. It is used to aid in making it easier to coat the plate with the conductive side up.)



9. If the coating is not uniform, the TiO_2 can be cleaned off the slides with a lab tissue and reapplied with a clean stirring rod.

10. Carefully remove the tape.

11. Using the ethanol wash bottle and tissue, clean the plate that had the conductive side down.

12. Anneal (heat and then slowly cool), the TiO_2 film on the conductive glass by placing the slide on wire mesh on a hot plate. Heat for 10-15 minutes in a hood or well-ventilated area. The film may turn light brown, then black then white.

13. After annealing, allow the TiO_2 to cool to room temperature (about 15 minutes). The glass could crack if the plate is not cooled completely. While waiting for the slide to cool, move on to the next step.

(ii) Staining the TiO_2 with Dye

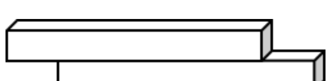
1. If your group chose berries/seeds: In the Buchner funnel, crush 5-6 berries/equivalent number of seeds in 2 mL of deionized water with the stir rod and filter into a plastic tray. This filtered solution is an anthocyanin dye solution.
2. If your group chose tea, make a dense solution that will result in at least 2-3 mL of solution.
3. Place the TiO_2 coated film in the solution with the TiO_2 coating face down.
4. As the film is soaking for 10 minutes, move on to the steps for carbon coating the counter electrode.
5. After 10 minutes, if white can be seen upon viewing the stained film from either side of the glass plate, place the plate back in the dye for 5 more minutes.

(iii) Carbon Coating the Counter Electrode

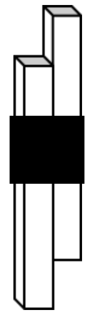
1. While the TiO_2 electrode is being stained in the berry juice, the counter electrode can be made from another piece of conductive SnO_2 coated glass.
2. Clean the glass plate with a lab tissue and ethanol like you would clean glasses. Be sure not to touch the faces of the plate.
3. Use the multimeter to determine which side of the glass plate is conductive, as done previously in this lab.
4. Holding the edges of the plate, use a graphite pencil to apply a light carbon film to the entire conductive side of the plate. Be careful not to miss any spots.
5. The carbon coating on the counter electrode should not be touched. It should not be rubbed or slid against the TiO_2 electrode or any other surface.

(iv) Assembling the Solar Cell Device

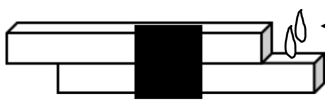
1. Using wash bottles, rinse the TiO_2 /dye-coated slide in water and then in ethanol. Note: the rinse water should be disposed of in the **aqueous waste** and the rinse ethanol should be disposed of in the **organic waste.**
2. Gently blot dry the TiO_2 film with a tissue. Do not rub the film; doing so will remove the film from the slide.
3. Place the dried electrode on a flat surface so that the TiO_2 film side is face up. Place the carbon coated counter electrode on top of the TiO_2 plate so that the carbon coated side faces down. To avoid excessive exposure of the stained film to air, this step should be completed within a minute after taking the plate out of the dye.
4. Gently lift the counter electrode and offset the two plates so that all of the TiO_2 is covered by the carbon coated counter electrode and the 4-5 mm strip of each glass plate is exposed.



5. Carefully pick up the assembly while it is in this orientation. Place two binder clips on the longer edges to hold the plates together.



6. Carefully place one or two drops of the iodide electrolyte solution at one edge of the plates.

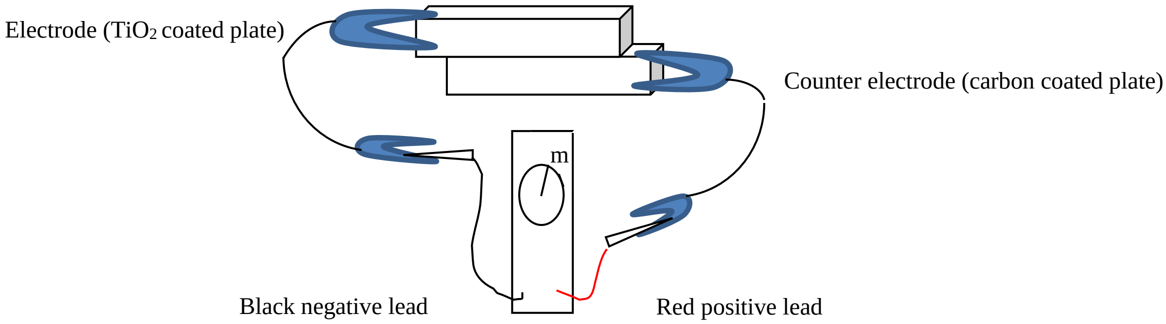


7. The liquid is drawn into the space between the electrodes by capillary action and wets the stained TiO_2 film. Make sure that all of the stained area is contacted by the electrolyte. If needed, alternately open and close each side of the solar cell by releasing and returning the binder clips.
8. Wipe off the excess electrolyte from the exposed areas of the glass using cotton swabs and tissues dampened with ethanol. It is important that the electrolyte is completely removed from the two exposed sides of the cell.

(v) Testing your Solar Cell

1. Attach an alligator clip to each exposed end of the glass slides.
2. Attach the other end of the negative electrode, the TiO_2 coated glass, alligator wire to the negative wire (black) of the multimeter.

3. Attach the other end of the positive counter electrode, the carbon coated glass, alligator wire to the positive wire (red) of the multimeter.



4. Holding the TiO_2 side up so as to absorb the light, measure the amount of electricity produced when light from an overhead projector is absorbed by the solar cell. Record your results.
5. Measure the amount of electricity produced when the solar cell is exposed to the sun.

(vi) Optional Extensions

- Using all of the solar cells built by your class, connect them in series in order to light a small LED bulb or something else.

Acknowledgements

Seattle's Hub for Industry-driven Nanotechnology Education: www.seattlenano.org
North Seattle College: www.northseattle.edu
Alicia Cohn, North Seattle College: alicia.cohn@seattlecolleges.edu
Melissa Baker, Newport High School: bakerm@bsd405.org
Ted Rodriquez, Sno-Isle Technical Skills Center: RodriquezTN@mukilteo.wednet.edu

This material is based upon work supported by the National Science Foundation under Grant Number 1204279. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Name:____

Partner's Name:____

Nanocrystaline Solar Cells Lab Report Sheet

Data and Results

	*I, Current (amps)**	*E, Voltage (volts)*	*P, Power (watts) (I*E)*
Light source in classroom (such as an incandescent light bulb in an overhead projector—keep solar cell 6 inches from source)			
Sun			

*Note: Use the setting pictured below to give you the milliamps produced by your solar cell (you will need to divide by 1000 to convert to amps to record for this table)

Data Analysis

1. Describe how your output data compares with the class data. Please explain any discrepancies.

2. Draw a picture of how you could connect all the class solar cells to produce higher outputs:

3. The average # of kWh used by Newport High School in 1 month in 2015 was 137,100 KWh. **The peak Wattage required is 577,000 Watts.** Calculate the approximate number of dye-sensitized solar cells (based on your output data) it would take to power your school.

4. The average solar panel output (from solar panels not made from sunscreen & berry juice) is around 200 Watts. How many of these solar panels would be required to support your school's peak Wattage?

5. How could you make your solar cell more ***efficient***? List at least two ideas.

6. Investigate the current best research solar cell efficiencies. Discuss below: i.e. What type of solar cells are producing the highest % efficiencies right now?

7. Point out at least two steps from the lab procedure that would most likely lead to variable results depending on how they were performed.

8. Why is the **nano**structure of the TiO_2 film important to the solar cell?

9. Label the different parts of the solar cell below and sketch the path of the electrons through the circuit.