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Title: Dye-sensitized Solar Cells
Subject: Chemistry / Physics / Engineering
Grade Levels: Middle / High school
Group Structures: Small group
Lesson length: 90 minutes
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Short Introduction to the lesson

This focus of this activity is to create and understand the Grätzel photovoltaic cell using inexpensive supplies that include an electrolyte, conductive glass, Nano-particles, and natural plant dyes. Grätzel solar cells are in commercial operation in producing electrical energy and cost about half as much as the more common silicon solar cells. This process is also considered to be biomimicry in that it mimics the photosynthesis process that is found in nature.

Objectives

- *Create a working* dye-sensitized *solar cell*
- Communicate how a dye-sensitized solar cell (DSSC) converts light waves into electricity
- *Test the voltage, current, and power of the solar cell.*
- Evaluate a dye-sensitized solar cell's performance in comparison to a silicon solar cell

Instructor Content Background Information

Science Content (for HS):
Solar cells absorb photons from sunlight that boosts electrons from a semiconductor into a state where it is mobile, which then conducts to produce energy. In the nano-particle TiO_2 semi-conductor the valence-conduction band gap is too wide to excite electrons enough to get them to conduct. However, sunlight can excite the electrons across the smaller band gap blackberry dye: Photon + dye → electron + dye^{+}. These excited electrons are transferred from the blackberry dye to the TiO_2, which transfers it to the electrode, producing electricity. Because this leaves the blackberry dye slightly positive (oxidized), it accepts an electron from the graphite counter electrode to make it neutral again. 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, which is called an electrical current.

Materials:

Scotch tape	Nanocrystalline Titanium Dioxide (TiO2)	
Multimeter	Alligator clip leads (2)	Plastic dish (2)
Distilled water	Isopropanol	Graphite pencil
Binder clips (2)	Conductive glass slides (2)	triiodide electrolyte
Glass stirring rod	Blackberries, raspberry, or blueberries	

Word Bank

Potential difference	Photon	Electrode
Semiconductor	Photovoltaic Cell	Current
Electrolyte	Conductive	Voltage

Set Up

Prepare the electrodes

- Take one piece of the FTO glass and use the multimeter to find the conductive side.
- Set the multimeter to the resistance setting denoted by the symbol ohm (Ω) to 100-200 setting.
- Press the points of the two metal probes onto the surface of the glass, careful that the metal points don't touch. The conductive side will have a reading around 30 ohms.
- If you see the value of "1", flip the glass over and try the other side.
- Use scotch tape to cover approximately 1/8" of the conductive surface edge on three sides the glass. The remaining open surface area will be covered with the TiO2 paste. The taped off strip will be blank glass which is necessary for assembly in the end.
- Add a couple drops of the TiO2 solution in the center of the exposed glass. squeegee the solution down and up once or twice with a glass stir rod. Aim for a thin, even coating of the paste.
- It should be a slightly transparent white color. Allow the paste to dry then remove the tape from the glass.
- Transfer the glass to a hotplate with the TiO2 film side face up. The hotter the plate, the faster it will be done. The surfactant and solvent in the paste will evaporate while on the hotplate, leaving behind just the TiO2 nanoparticles. The glass will appear to turn brown or burned, and then white again.
- Once the color turns brown and then back to white remove the electrode to slowly cool.
- Prepare the dye by thoroughly crushing blackberry, raspberry or blueberry inside a closed plastic bag.
- Place the TiO_2 electrode into the blackberry juice for 5 minutes. The white TiO_2 paste should turn completely purple. The darker the better.
- While you wait, coat the conductive side of your other piece of FTO glass with graphite (pencil lead).
- Using tweezers pull the dyed TiO_2 piece of glass out of the berry juice and completely rinse it off with water, then dab it gentle with paper towel. Be careful not to rub or scratch off the dyed TiO_2 coating.

Assemble the solar cell

- Assemble the two electrodes with the two conductive and coated sides facing inward with a 1/8" off set so that one of the uncoated Tio_2 edges is exposed on one side and the same amount of the graphite edge is exposed on the other side.
- Use binder clips to secure the other two sides of the cell that are not off set.
- add a couple of drops of iodide/triiodide electrolyte solution using a pipette to the seam of the glass.

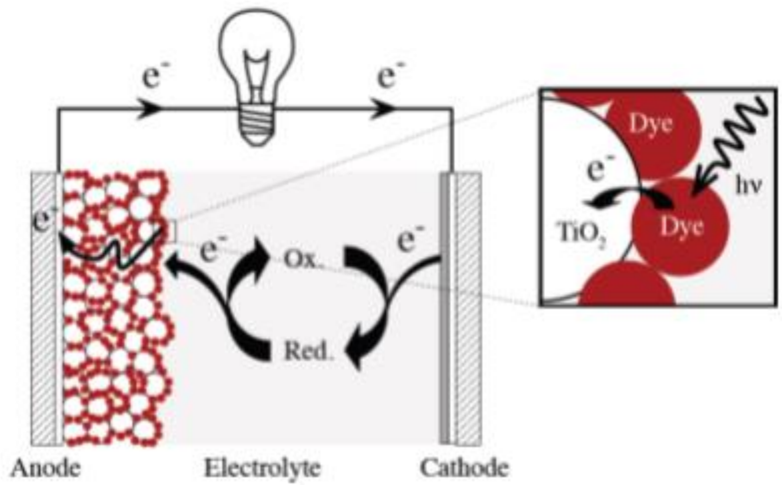
Test the solar cell

- Attach one end of 2 alligator clip to each of the overhanging pieces of electrodes. Clip the other ends of the alligator clips to each of the metal multimeter probes.
- Set the multimeter to DC milli-volt range and note the voltage output when the dye infused side of the solar cell is exposed towards a heat lamp or direct sunlight. Typical voltage is 400-600mV.
- Then switch the multi-meter setting to DCA (Direct Current Amperage) to measure the current. The setting of 2000µ is usually sufficient to measure the current output. Typical value is .7 mA or 700 µA in direct sunlight.
- Finally, the voltage and current readings can be multiplied together to obtain the overall power of the cell. Be sure to convert the voltage from mV to V and µA to A before multiplying.
- Calculating solar cell efficiency: Efficiency is defined as the ratio of power in to power out. Efficiency = $P_{max}/P_{in} = I*V/P_{in}$

- P_{in} is generally assumed to be 100 mW/cm^2. For a 1 cm x 1 cm solar cell the input power is 100 mW. P_{max} is the product of the measured voltage and current of your solar cell.

Helpful Hints for Teachers

- What components make up a solar cell?
  - Like photosynthesis, two main processes needed are: (1) absorption of solar energy by the leaf dye, chlorophyll, and (2) conversion of the absorbed solar energy into chemical fuel. We want our solar cell to mimic photosynthesis, where solar energy produces electrical energy instead of plant food.
  - Not all natural dyes work or work as well. A good light absorber is essential for good results. Dyes like from blackberries, raspberries, and blueberries contain a strongly light-absorbing molecule called anthocyanin, which makes them good light absorbers. Strawberries have low concentrations of anthocyanin, thus making them a poor dye for light absorption.
  - Once the dye absorbs light, the electrons get excited to higher energy levels in the dye, then are transferred and fall to the lower conduction band of the TiO_2 nano-particles. Electrons then travel through the connected alligator clip to the counter graphite coated electrode. These extra electrons transfer to and reduce the triiodide to iodide. Iodide is then oxidized to release an electron back to the dye molecule and the process is repeated.



Solaronix [1]

Assessment

- 1. Communicate how a dye-sensitized solar cell (DSSC) converts light waves into electricity.
  - In groups of 2-4, draw a diagram of a dye-sensitized solar cell, label the components, and explain on how the cell converts light into electricity. Remember to consider the absorber and converter in your explanation. Make sure your solar cell forms a complete circuit.
- 2. Design and build a dye-sensitized solar cell from basic components and blackberry juice dye.
  - Before or after introducing the information from the background section, provide your students with a list of the basic components necessary to make a DSSC. Have them try to place them in the correct order and present their design to the class. Discuss the designs as a class or in small groups. Then, give them the lab procedure and let them build a DSSC.
- 3. Refine their solar cell design through the comparison of various fruit dyes.
  - The day before you have the class perform the lab, ask them to vote on one other fruit besides a blackberry to test as a DSSC. Have them list what makes a good absorber in a solar cell. While students fabricate their own blackberry DSSCs, make one DSSC with the class's fruit of choice. Have students compare the data of both DSSC. Return to the initial list of characteristics of good absorbers. Let the class decide if the new DSSC is better or worse than the blackberry DSSC.

- 4. Evaluate a dye-sensitized solar cell's performance in comparison to a silicon solar cell.
    - Have your students complete the same analysis they performed on their DSSCs on a commercial silicon solar cell by taping off a similar area as the DSSC and measuring voltage and current with a multi-meter. Ask your students to complete a table as shown on the next page and compare these values to that of their blackberry DSSC and other fruit DSSC. Calculate the power (P = I*V) and conversion efficiency (below) of the silicon solar cell. Which solar cell performs best? Why?

Deepen Your Knowledge

- Extension activities
    - *Compare the voltage with different natural dyes*

Next Generation Science Standards

- 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.
- HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
- HS-ESS3- 2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios
- MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
- MS-PS1-2 Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

References

1) "Dye Solar Cells for Real – The assembly guide for Making Your Own Cells", Solaronix

2) S. Ito et al., "High-efficiency (7.2%) flexible dye-sensitized solar cells with Ti-metal substrate for nanocrystalline-TiO2 photoanode", Chem. Commun., 2006, 4004-4006.

Acknowledgements

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