LESSON PLAN

Cost-Effective Solar Cells

Lesson #7: Titanium Dioxide Solar Cell Construction and Testing

AUTHOR

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DESCRIPTION

This lesson is designed to be completed in two 80-minute sections. The teacher will show a basic procedure and video. The teacher will facilitate the construction of Organic Dye-Sensitized solar cells on coated glass plates with Titanium Dioxide. A fume hood with outlets for electric hot plates must be used for the first part of the construction. On Day 2, Teachers will facilitate final solar cell treatment and solar cell testing indoors and outdoors. Teachers should be knowledgeable of the Titanium Dioxide / Berry (anthocyanin) solar cell electron transfer mechanisms.

- Day 1: Introduce procedure and bake titanium dioxide onto coated class slides
- Day 2: Further treatment of slides, assembly of solar cell, and testing

GRADE LEVEL(S)

9, 10, 11, or 12

SUBJECT AREA(S)

Chemistry, Physics, Solar Panels, Solar Cells, Power, Current, Voltage, Electricity Generation

ACTIVITY LENGTH

2 days X 80 minutes

LEARNING GOAL(S)

1. Students will construct titanium dioxide coated “raspberry juice” solar cells
2. Students will test titanium dioxide coated “raspberry juice” solar cells under various conditions

CONTENT BACKGROUND

STUDENT BACKGROUND

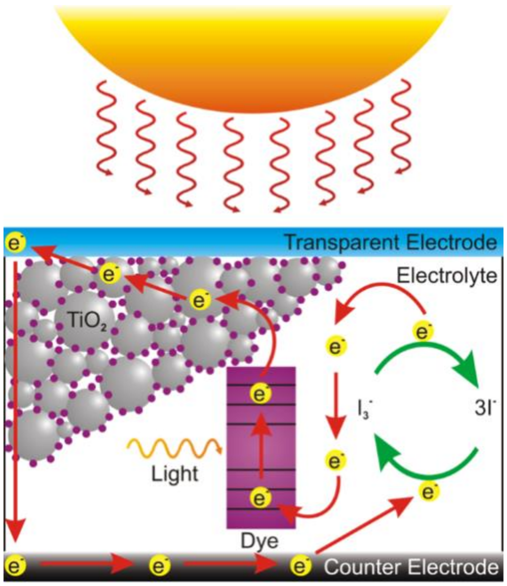
- Students participating in this lesson should be familiar with the following scientific practices and concepts:
  - Planning and Carrying Out Investigations
  - Collecting and Recording Data
  - Electricity Basics (Lessons 2, 4): Voltage, Current, Circuitry
  - Photovoltaic Effect in Solar PV Panels (Lesson 3)
  - Measuring Voltage and Current Using a Multimeter (Lesson 2)
  - Basic Laboratory Safety & Emergency Procedures

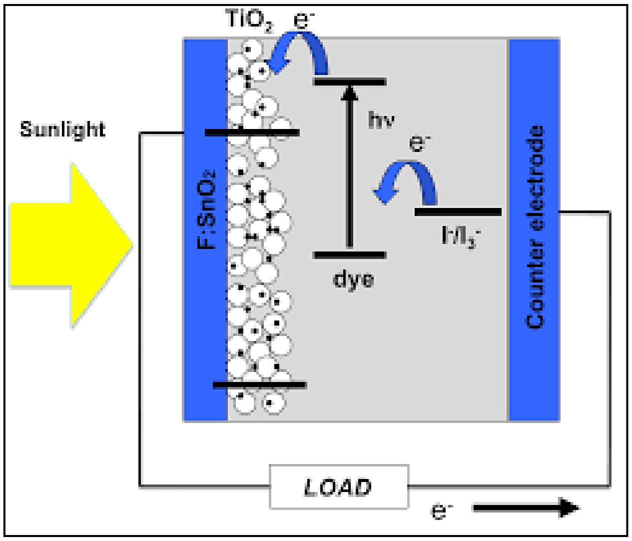
EDUCATOR BACKGROUND

Organic Dye-Sensitized Solar Cells:

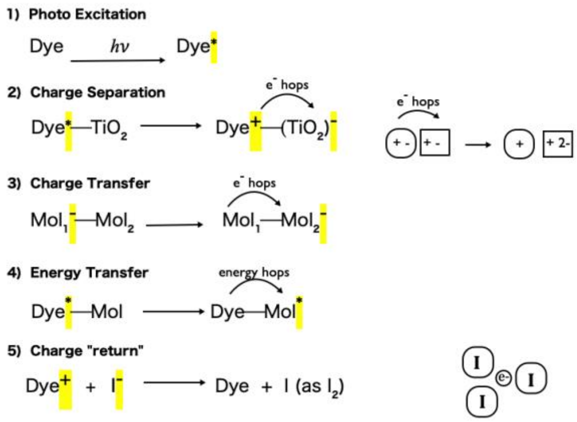
Students will be constructing and testing a solar cell made out of titanium dioxide and raspberry juice. The solar cells will be layered on Fluorine doped Tin Oxide (FTO chemical formula $F{:}SnO_2$)-coated glass (which makes the glass electrically conductive), while potassium tri-iodide (I_3K) and a carbon soot layer will complete the solar cell circuit. This solar cell functions well under sunlight, but has a limited lifespan based on the organic anthocyanins found in the raspberries.

The transportation of electrons is a bit more complex in this cell. The FTO layer of the glass slide provides a means of electrical conductivity along a transparent surface. The students will layer the conductive (FTO) side with Titanium dioxide (TiO_2), which helps capture light in the cell and serves as a binder for the anthocyanins. The anthocyanin will transport electrons when hit with light photons, allowing electrons to flow into the FTO conductive layer. A second FTO-coated cell is layered with carbon soot from a candle, acting as the counter electrode in the solar cell (the conductive material that closes the circuit). Finally, the electrons are cycled back to the anthocyanins via a potassium tri-iodide electrolyte solution.





The anthocyanins are found in raspberries and many other fruits, vegetables, and leaves with purple-red coloring such as blackberries, blueberries, blood oranges, pomegranates, cherries, grapes, eggplants, and plums. With light, the anthocyanin pigment reaches an excited state where electrons can then be transferred or “hopped” along the anthocyanin layer to the titanium dioxide layer and to the FTO layer of the solar cell. Electrical work can be performed and the electron returns to the positively charged dye interacting with the iodide anion. As the dye receives the electron, the iodide cycles into iodine. Images and concepts provided by Basil Paulson (https://drive.google.com/file/d/1b9NhoLYH2KP9uqVnHeCyM1USoigTlTA_/view?usp=sharing)



Photovoltaic Effect: https://cebrightfutures.org/learn/photovoltaics#Photovoltaic%20Effect

Photovoltaic Materials: https://cebrightfutures.org/learn/photovoltaics#Photovoltaic%20Materials

Multimeters: https://cebrightfutures.org/sites/default/files/multimeter-cheatsheet.pdf

Circuit: https://cebrightfutures.org/learn/circuits

Circuit diagrams:

Circuit diagrams show a visual representation of the components of a circuit. Components have common symbols as illustrated by the below diagram (from https://en.wikipedia.org/wiki/Circuit_diagram)

Solar Energy: https://cebrightfutures.org/learn/solar-energy

Incident Angle of Sunlight: https://cebrightfutures.org/learn/incident-angle-sunlight

MATERIALS NEEDED

HANDOUTS/PAPER MATERIALS

- Titanium Dioxide Raspberry Solar Cell Procedure and Data Sheet: https://drive.google.com/file/d/1L01bx-CeEPDAonu8rhMcx6GmHW2CKMSC/view

CLASSROOM SUPPLIES

- Fume hood
- Electric burner/hot plate
- Scotch tape
- Lighter or matches
- Water
- Light bulbs (incandescent or halogen) of two different wattages

- Stir rods
- Mortar and pestle
- Plastic syringes (optional for titanium dioxide paste)

ACTIVITY SUPPLIES (PER GROUP OF 3-4 STUDENTS)

- FTO (TEC15) 1" x 1" coated glass slides (2 per group)
    - These slides can be ordered here: https://www.msesupplies.com/products/fluorine-doped-tin-oxide-fto-coated-tec-15-glass-tec15-fto-can-customize-pattern-as-required?variant=19973837956
- Titanium dioxide (about 0.2 grams per group)
- Dilute acetic acid (a few drops per group)
- Anthocyanin-containing berries (raspberry, blackberry, blueberry, pomegranate) (a few berries per group)
- Tea candle (1 per group)
- Potassium tri-iodide solution (a few drops per group)
- Small binder clips (2 per group)
- Multimeter (1 per group)
- Alligator clips (2 per group)

LESSON PROGRESSION

PLANNING AND PREP

This lessons spans two days—one day for the titanium dioxide layer preparation and the other for final assembly and testing. On Day 1, students will first read the procedures for the lab. Then, they will begin coating their FTO-coated glass slides with titanium dioxide. The titanium dioxide can be prepared in a larger full class quantity. To do this, measure out about 2 grams of titanium and mix in dilute acetic acid until it reaches the consistency of correction fluid. Students can use spatulas or scoops to remove a little bit of paste or can load a plastic syringe with the paste for more controlled distribution.

The coated plates should be baked directly on a hot plate or electric burner inside of a fume hood to contain the titanium dioxide fumes. If leaving any cells overnight to cool, have the students clearly label their solar cells or heat sources.

For the testing portion of the lesson, set up 1-2 indoor light stations that will give additional light beyond the ambient indoor classroom light for the solar cells.

Copy /Adapt the Titanium Dioxide Raspberry Solar Cell Results Google form (https://docs.google.com/forms/d/e/1FAIpQLSfkWiaN7Tn5O6X-gA622q2ODtY2rwmqnAqbJn81-7iN-rh0Qg/viewform?usp=sf_link) to your classes' specifics. Share the edited form link with your students to collect responses.

LESSON SEQUENCE

Day 1 Procedure:

1. **(10 minutes).** Show the students a short video on the titanium dioxide raspberry solar cells. This video (https://www.youtube.com/watch?v=Jw3qCLOXmi0&feature=youtu.be) contains no sound, but has good visuals. Another video (https://www.youtube.com/watch?v=WHTbw5jy6qU) may be used instead of or in additional to the first video—this video has a strange audio narrator voice, several small differences in the procedure, but very good concept explanations and questions.
2. **(15 minutes).** Hand out the Titanium Dioxide Raspberry Solar Cell Procedure and Data Sheet (https://drive.google.com/file/d/1L01bx-CeEPDAonu8rhMcx6GmHW2CKMSC/view) to students. Distribute or identify the materials to the students or student groups. Have the students read the procedures and highlight or mark any text. Answer any questions the students have about the procedure.
3. **(55 minutes).** Have the students begin the lab procedures. Most students will end the class period with the titanium dioxide layers slowly cooling on the heat sources. The cells can be left overnight to finish cooling. Faster students might be able to stain their titanium dioxide cells with berry juice on Day 1, but should not add the Potassium triiodide solution on Day 1. Encourage the students to take photos and document their procedures in science notebooks at various points of their experiment if you plan on extending the lesson.

Day 2 Procedures:

1. **(10-30 minutes).** Have the students continue their procedure from yesterday. Students should be able to dye their titanium dioxide layers with berry juice. While they are staining the cells, the students can be preparing the carbon soot layer of the second glass slide.
2. **(40-50 minutes).** Facilitate data collection with the student solar cells. There should be 1-2 indoor light stations with different light bulb wattages. Let students know where they should test outdoors (weather dependent) under full shade, partial sun, and full sun.
   The data sheet contains space to write down the bulb wattage (if known) at the stations. Tell the students what wattage the bulb(s) at the station have for their data collection. For the outdoor testing, try to locate an area that has access to full shade, partial sun, and full sun for the solar cell testing.

3. **(10-20 minutes).** If there is time, the students can fill in responses for the Titanium Dioxide Raspberry Solar Cell Results Google form (https://docs.google.com/forms/d/e/1FAIpQLSfkWiaN7Tn5O6X-gA622q2ODtY2rwmqnAqbJn81-7iN-rh0Qg/viewform?usp=sf_link). Review and edit the form in advance. Share the edited form link with your students to collect responses. Because there is quite a bit of variation in the video procedures and the printed procedure, this form captures several of the variables that come up during the lab activity. These variables will be analyzed in further detail in Lesson #8.

ASSESSMENT AND EXTENSIONS

FORMATIVE ASSESSMENT

Progress on this lab activity can be monitored during the procedure. Formative assessment can be tied to NGSS SEP3 (Planning and Carrying Out Investigations) during the procedure.

Student lab notebooks may be used to document procedure, record observations and actual times. Have the students record the actual time of heating and cooling in their notebooks, relative thickness of the titanium dioxide layer, types of berries used, quantities of each substance used, time of berry staining, amount of remaining visible titanium dioxide after staining, along with qualitative observations of the color and appearance of the solar cell. Have students record voltage and current data in their notebooks. A model or sketch of the solar cell setup can be assessed as evidence of NGSS SEP2 (Developing and Using Models).

SUMMATIVE ASSESSMENT

Students will be submitting voltage and current data from their solar cell results, and can also submit lab notebooks documenting procedures and modeling of the system. Student work can be assessed with the following standards:

- NGSS HS-PS3-3:
  Design, build, and refine a device that works within given constraints to convert one form of energy into another.
- NGSS SEP3
  Planning and Carrying Out Investigations

LESSON EXTENSIONS

Students can explore variations during the solar cell testing. They can try to hook up multiple solar cells with other groups to generate more power. They can engage in further inquiry by testing more conditions on the solar cell including:

- Different types of berries or berry combinations
- More light conditions (light bulb wattage, or sunny vs. cloudy, or fall vs. winter)
- Differing amounts of baking and cooling times
- Different thicknesses of titanium dioxide layers
- Different amounts of Potassium Triiodide