LESSON PLAN

# Cost-Effective Solar Cells

## Lesson #8: Titanium Dioxide Raspberry Solar Cell Data Sharing


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DESCRIPTION

This lesson is designed to be completed in one 80-minute section. The teacher will facilitate the sharing of student titanium dioxide solar cell results with emphasis on variables during data collection. Teachers will demonstrate spreadsheet sorting for students and allow time for students to draw conclusions from the class data using an optional framed paragraph for conclusions. Teachers will guide students in making connections to the titanium dioxide, anthocyanin, and potassium tri-iodide electron system.

GRADE LEVEL(S)

9, 10, 11, or 12

SUBJECT AREA(S)

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

ACTIVITY LENGTH

1 days X 80 minutes

LEARNING GOAL(S)

1. Students will collect and analyze titanium dioxide coated “raspberry juice” solar cell data.
2. Students will discuss results and draw conclusions about variables that may affect power generation.

## CONTENT BACKGROUND

STUDENT BACKGROUND

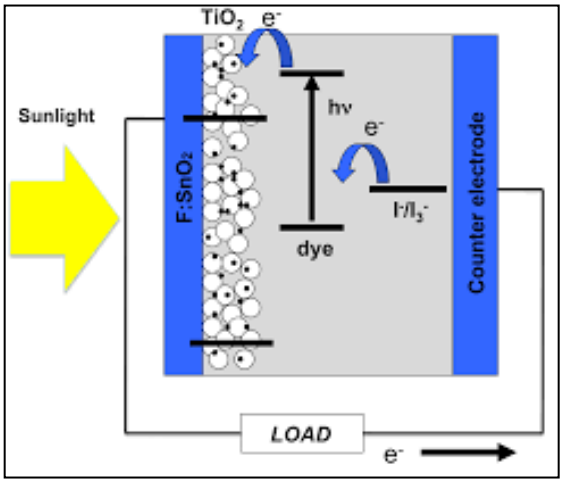
- Students participating in this lesson should be familiar with the following scientific practices and concepts:
    - Analyzing, Sorting and Interpreting Data
    - Argument with Evidence
    - Electricity Basics (Lessons 2, 4): Voltage, Current, Circuitry
    - Photovoltaic Effect in Solar PV Panels (Lesson 3)
    - Measuring Voltage and Current Using a Multimeter (Lesson 2)

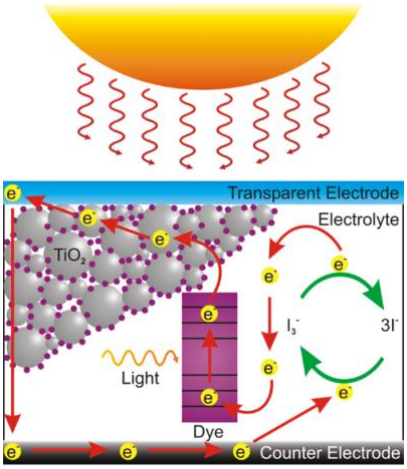
## EDUCATOR BACKGROUND

Multimeters were used to collect data on voltage, current, and resistance in Lesson 7.

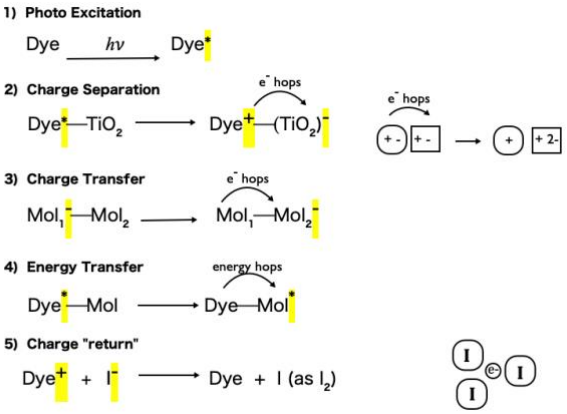
In Lesson 7, students constructed and tested a solar cell made out of titanium dioxide and raspberry juice. The solar cells were layered on FTO-coated glass, while potassium tri-iodide and a carbon soot layer completed the solar cell circuit. This solar cell functions well under sunlight, but has a limited lifespan based on the organic anthocyanins found in the raspberries.

The 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)

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

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

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 )

Parallel Circuit Wiring: https://cebrightfutures.org/learn/parallel-circuit-wiring

- Voltage in Parallel Wiring: https://cebrightfutures.org/learn/parallel-circuit-wiring#Voltage%20in%20Parallel%20Wiring
- Current in Parallel Wiring: https://cebrightfutures.org/learn/parallel-circuit-wiring#Current%20in%20Parallel%20Wiring

Series Circuit Wiring: https://cebrightfutures.org/learn/series-circuit-wiring

- Voltage in Series Wiring: https://cebrightfutures.org/learn/series-circuit-wiring#Voltage%20in%20Series%20Wiring
- Current in Series Wiring: https://cebrightfutures.org/learn/series-circuit-wiring#Current%20in%20Series%20Wiring

Solar Cell Wiring Diagram:

Examples of solar cell wiring diagrams that students might generate during this lesson can be found below:

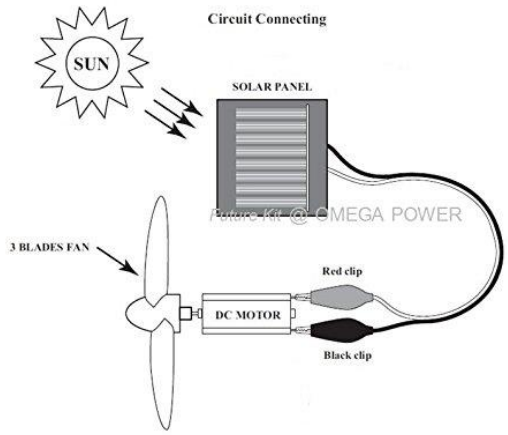



Image from: https://www.amazon.in/Solar-Electronic-Circuit-Student-Learning/dp/B00KUL9VX6

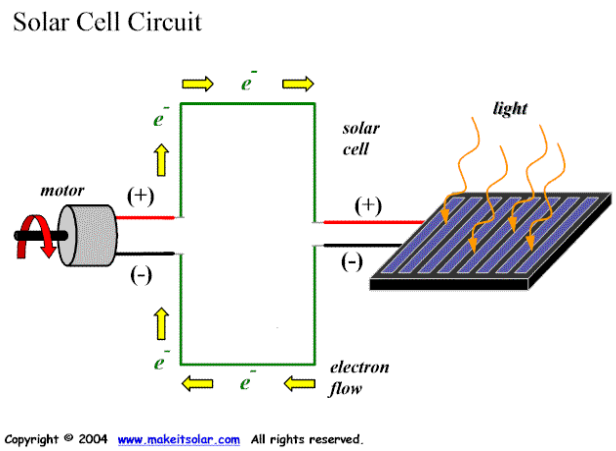



Image from: http://www.makeitsolar.com/science-fair-ideas/07-solar-parallel-circuit.htm

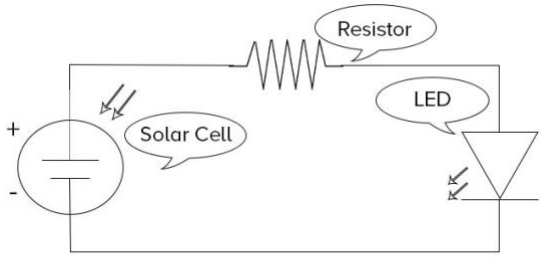



Image from: https://www.sciencefriday.com/educational-resources/hack-a-solar-circuit/

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

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

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

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

## MATERIALS NEEDED

*HANDOUTS/PAPER MATERIALS*

- Titanium Dioxide Raspberry Solar Cell Data Sheet from Lesson 7: https://drive.google.com/file/d/1L01bx-CeEPDAonu8rhMcx6GmHW2CKMSC/view
- Titanium Dioxide Raspberry Results Form (Google Forms) https://docs.google.com/forms/d/e/1FAIpQLSfkWiaN7Tn5O6X-gA622q2ODtY2rwmqnAqbJn81-7iN-rh0Qg/viewform?usp=sf_link
- Titanium Dioxide Raspberry Results Response Page (Generated from the above Google Form and using Google Sheets)

*CLASSROOM SUPPLIES*

- Teacher and student computer access to Google Forms

*ACTIVITY SUPPLIES (PER GROUP OF 3-4 STUDENTS)*

- N/A

## LESSON PROGRESSION

PLANNING AND PREP

This lesson is designed to take place in 80 minutes. Students will share their Titanium Dioxide Raspberry solar cell data and results via a Google Form. Responses will be collected and shared with the students by the teacher. Before students arrive, make sure to edit 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 customize the questions for your classroom and lab experiences. Share the form link with the students in advance by clicking on the "SEND" button in the upper-right corner of the form. This will generate a URL link that can be posted on your digital learning management system (Canvas, Blackboard, Moodle, Website, etc.). Also, post a link for view-only access to the Google sheets responses connected with the form. To do this, click on the "Responses" tab of the editable form. Then, click on the green and white Sheets logo to create a spreadsheet for the data. To share the responses with your students, click the blue "SHARE" button on the top right corner of the sheet. Click on "Get Shareable Link." On the pop-up window, use the drop-down menu to ensure that students **can view** the response page. Then, click on "Copy link" to copy the link to your clipboard. Paste the link on your Learning Management System or write the URL on the board for students.

Students will make a new copy of the response page and will sort data on the form in order to answer questions about the relationship between lab procedure variables and the solar cell power results. Familiarize yourself with this process (detailed in the lesson sequence) to a level that you feel comfortable showing your students.

For the formal Conclusion (CLAIM-EVIDENCE-REASONING), a student example response can be found here: https://drive.google.com/file/d/1rzmDd-bRWqjmpuNEKPbQLNgDsREjhJKX/view?usp=sharing

## LESSON SEQUENCE

**Day 1:**

1. **(10 minutes).** Have students share their data using the Google form link described in the "Planning and Prep" section above. Hand back the Titanium Dioxide Raspberry Solar Cell Procedure and Data Sheet (https://drive.google.com/file/d/1L01bx-CeEPDAonu8rhMcx6GmHW2CKMSC/view) if you collected it in Lesson #7. Remind students to use the appropriate units for voltage and current.
2. **(15 minutes).** Share the response page link with the students as described in the "Planning and Prep" section above. Demonstrate how to sort data for the students by walking them through the following steps:
    - Open up the response page on their own computers
    - Scroll right to find the "Which berries did you use?" heading in Row 1 of the spreadsheet. You can use any of the questions as an example instead of this one.
    - Hover your cursor over the column title letter (e.g. "L") above the "Which berries did you use?" heading. A drop-down menu (small triangle) will appear to the right of the letter. Click on this drop-down menu.
    - Select "Sort Sheet A → Z" from the drop-down menu to sort the responses by type of berry.
    - Scroll through the responses to show the students that the data is now sorted by berry type or berry combinations. Point out that the voltage and current data is now organized by berry type and averages could easily be calculated.

- Say the example question, “How does the type of berry affect the voltage and current of a solar cell?” Ask the students, “Can you now use this data in the spreadsheet to answer that question?”

3. **(5-10 minutes).** Have the students generate their own questions in the form of “How does _____ affect the voltage and current of a solar cell?”
4. **(45-50 minutes).** Have the students answer the questions they generated in step 3 using the shared classroom results by writing a formal Conclusion to the lab in the lab notebooks or as a separate assignment. The conclusion should contain the following elements:
    - Answer the generated question in a statement that describes the relationship between the variables (CLAIM)
    - State multiple pieces of data (individual data points, averages, ranges) to support the claim (EVIDENCE)
    - Explain how the evidence connects to the claim. (REASONING)
    - Explain why you think the results turned out the way you calculated (CLAIM)
    - Find a scientific principle (via google or google scholar searches) to back up your claim. (EVIDENCE)
    - Explain how the scientific principle played a role in your titanium dioxide berry results (REASONING)

## ASSESSMENT AND EXTENSIONS

### FORMATIVE ASSESSMENT

Cross-cutting concepts (CCC1, CCC2, and CCC5) are being used by student groups as they share data.

### SUMMATIVE ASSESSMENT

Students will be sharing, analyzing and interpreting data of their classmates via student lab notebooks or a separate assignment, which can be used to assess student understanding. Student sharing, discussion, data analysis, and conclusions can be assessed using 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.
- CCSS.ELA-LITERACY.SL.11-12.1
  Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
- NGSS SEP4
  Analyzing and Interpreting Data
- NGSS SEP7
  Arguing with Evidence

### LESSON EXTENSIONS

Students and teachers could extend this lesson by having students take the whole class data and design their own inquiry experiments for titanium dioxide solar cells. The lines of inquiry could include:

- Different surface areas of titanium dioxide
- More light conditions (light bulb wattage, or sunny vs. cloudy, or fall vs. winter)

- Different thicknesses Titanium Dioxide
- Differing amounts of Potassium triiodide
- Different baking and cooling times
- Additives to the $TiO_2$ mixture

This might also be a good opportunity to teach a unit on crystals and atomic arrangements in crystals as students begin to understand electron flow in conductive and semi-conductive materials. The practical experience growing crystals can serve well as the unit develops and students begin to research nanocrystalline layers on perovskite and other solar cells. Students can grow and maintain various crystals such as:

- Borax crystals on pipe cleaners: https://www.stevespanglerscience.com/lab/experiments/magic-crystal-snowflake/
- Copper Sulfate crystals: https://www.instructables.com/id/Grow-Crystals/
- Alum crystals: https://www.raci.org.au/document/item/249
- Silver nitrate crystals: https://sciencenotes.org/silver-crystal-tree-chemistry-demonstration/

BB boards made of empty CD jewel cases filled with copper BBs can be used to model crystal defects in this lesson by ASM: https://cpb-us-w2.wpmucdn.com/u.osu.edu/dist/3/38814/files/2017/05/ASM-Crystal-Defects-27vdwoz.pdf

Styrofoam models of crystal structures can be made with these ASM lesson plans: https://www.asminternational.org/documents/10192/1942078/modelsofcrystalslab.pdf/1536b49e-2218-46d2-b7f3-5fb8c581dfe7