Characterizing a Solar Cell

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Subject: Physics
Level: High School
Standards: New York State – Physics (www.emsc.nysed.gov/ciai/)
Standard 1 – Analysis, Inquiry, and Design
Standard 4.1 – Observe and Describe transmission of various forms of energy. (includes circuit and photocell analysis)
Standard 6 – Models

Schedule: Two to three 45 minute periods

Objectives:

A simple model (EMF-internal resistance) is used to describe a solar cell. Light incident on the cell will generate a measurable voltage and current, from which both power and resistance may be determined. Altering the intensity of the incident light influences cell current and power, but only modestly changes voltage. To alter the amount of incident light received at the cell, one might change the distance to the light source, place an obstacle (wire mesh) between the source and the cell, alter cell surface area, incident angle, or polarize the light. Analysis of load resistances leads to a discussion of impedance matching.

Students will:

- Demonstrate proper use of the voltmeter and ammeter
- Given a series circuit with known resistances and emf, determine the current, voltage, and power across each resistor
- Determine the maximum voltage and maximum current of a solar cell for a given constant illumination
- Evaluate a simple model for a solar cell by comparing measured values current to those predicted by the model
- Review and discuss concepts learned throughout the activity

Vocabulary:

Internal resistance
Model
Electromotive Force

Materials:

For Each Pair:
- Light Source: 60 watt light bulb (in a desk lamp); Laser pointer (?)
- Ring Stand and Clamp (x2)
- Solar Cell (or photoresistor?)
- Meter Stick
- Protractor
- Multimeter
- Wire Meshes (varied spacing)
- Polarizing Filters (x2)
- Cardboard
- 5 or 6 Resistors (within an order of magnitude of solar cell internal resistance)
- Decade Resistance Box (Cat # 82824)

Safety:

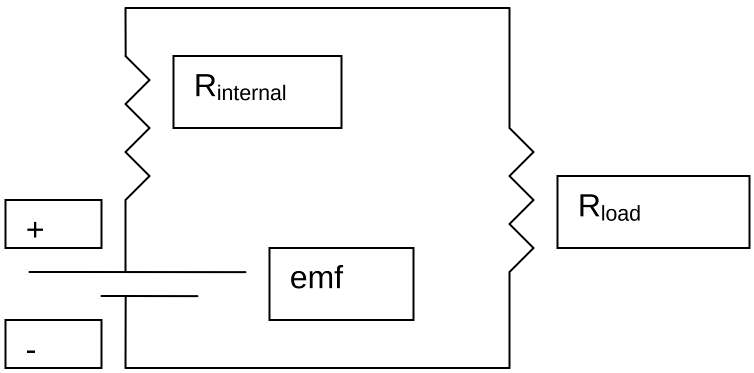
- Lamp (Heat and electrical issues)
- Laser (Watch the eyes!)

Science Content for the Teacher:

Pre-Teaching Concepts:

- Ohm's Law, V = IR
- Power dissipation in a circuit: P=VI
- Analysis of Series and Parallel Circuits
- The concept of modeling complex systems and the limits of those models
- Ammeters measure current and are connected in series; Voltmeters are connected in parallel.

EMF-Internal Resistance Model of a Solar Cell:



The solar cell is modeled as a voltage (emf) source connected in series with an "internal" resistance. The emf of the cell may be determined by placing a voltmeter in parallel between the terminals of the open circuit. To determine the maximum current of the cell, place an ammeter in series with an otherwise short circuit. It is then possible to define the "internal resistance" of the cell using Ohm's Law.

The load is then placed in series between the terminals of the solar cell. Use the meters to determine the resistance of the load and the current through the load. The measured value of the current may be compared to the current one would predict knowing the model: I_{exp} = (emf)/(R_{load} +R_{total}). Include a voltage measurement across the load and it is possible to calculate the power dissipated by the load. Students can determine experimentally that load power is maximized when the load resistance matches the solar cell "resistance."

Varying the intensity of the light incident on the solar cell allows for other important discoveries. As the intensity decreases, so will the short circuit current and power output of the cell, but voltage remains roughly constant. This discovery fits nicely with a discussion of the photoelectric effect. Students may also uncover the inverse square relationship between distance and intensity (for the light bulb!), determine the importance of incident angle on solar cell function, learn about intensity as a function of polarizing angle, or inquire about connecting panels in series or parallel.

Classroom Procedure:

Engage (Time: 15 min.)

- Explain the simple model for solar cell function
- Brainstorm: What factors affect the power output of a solar cell? (Share with class)
- How might we vary the intensity of the light with the available equipment?
- Each group chooses a single factor for testing and
  - forms a hypothesis
  - addresses the issue of control within the experiment

Explore (Time: 60 min.) Complete the following activities:

1. Determine the "open circuit" voltage and "short circuit" current under each condition: background lighting, Light source fully illuminated, dimmed illumination (various meshes placed between source and solar cell, source/cell distance changed, polarizing filter angles, changing the incident angle of the light source, covering part of cell, etc.)
2. For each trial, calculate "internal resistance," power.
3. With illumination constant,
   - Measure and record each load resistance
   - Place each resistor in the load position. Measure and record load voltage and current
   - Calculate power using measured voltage and current
   - Calculate expected load power from previously measured emf and internal resistance

Explain (Time: 20 min.) Each group shares results with class:

- How does brightness affect voltage across solar cell? Current? Output power?
- How does brightness affect "internal" resistance? (Can it justifiably be called "internal?")
- How did the expected load power compare to what was measured? (Share graphs, percent variation, etc.)
- Evaluate the effectiveness of the model for a solar cell.

Expand (Time: 15+ min.) Activities could include:

- Did you learn anything novel about your light source, polarizing filters, or any of the other factors that affected the intensity of the light received by the cell?
- Do any of these discoveries influence your understanding of how solar panels might be used to deliver power for everyday use?
- Would it be practical to use your solar panel as the energy source for common appliances? Learn about energy consumption of typical loads and describe the problems you might encounter.
- Could your solar panel be used to estimate the power output of the sun? Outline a procedure for doing so, and describe any difficulties you might encounter.

Assessment:

The following rubric can be used to assess students during each part of the activity. The term "expectations" here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

1= exceeds expectations
2= meets expectations consistently
3= meets expectations occasionally
4= not meeting expectations

	Engage	Explore	Explain
1	Shows leadership in the discussion and offers creative ideas reflecting a good understanding of the physics of circuits and light	Completes work accurately while providing an explanation for what is observed. Works well with partner.	Provides an in-depth explanation of findings, makes good use of graphs, charts, and vocabulary. Completes all questions.
2	Participates in the brainstorm and shows an understanding of the physics of circuits or light.	Completes work accurately and works cooperatively with partner.	Provides a clear explanation of findings and attempts to explain with charts and graphs. Completes all questions.
3	Contributes to the brainstorm, but shows little understanding of circuits or light	Works cooperatively with partner, but makes some mistakes with the procedure.	Provides a limited explanation of findings. Attempts most questions.
4	Does not participate in the brainstorm. Shows no understanding of circuits or light	Has trouble working with a partner. Does little to complete the procedure.	Does not explain findings clearly. Makes little or no use of charts and graphs. Does not attempt all questions.

Extension Activities: See "expand" section Classroom Procedure

Supplemental Information:

References:

W. Scheider, "Models in Physics and Engineering: A Student Lab Examining the EMF-Internal Resistance Model of a Solar Cell," *Phys. Teach.,* **24,** 488-491 (November 1986)

Safety:

Acknowledgments:

- Nev Singhota, Kevin Dilley, Jane Earle, and the entire CCMR educational outreach office
- The CCMR facility managers
- The NSF for sponsoring RET programs

Student Name: ____________________
Date: ____________________

Activity Sheet

CHARACTERIZING a SOLAR CELL

Section One: Determining the Internal Resistance of the Solar Cell

1. Which factor will you vary from trial to trial? Which factor(s) will remain constant during each trial? Be sure to measure and record these control factors in your report.
2. Measure and record the open circuit voltage of the solar cell by shining your light source on to the solar cell and placing a voltmeter between the terminals.
3. Measure and record the "short circuit" current of the solar cell by shining your light source on to the solar cell and placing an ammeter between the terminals.
4. You can now define the "internal resistance" of your solar cell by using Ohm's Law. Be sure to show all of your work clearly.
5. It is also possible to determine the maximum expected power output of your solar cell by using the relationship, P=VI
6. Proceed to your next trial by varying whichever factor your group has chosen to manipulate in order to change the brightness of the light. Be sure to record the new value of that factor. Be sure to complete enough trials that any patterns between brightness and solar cell function will be clear.
7. It is a good idea to have the voltage and current for the solar cell when your light source is NOT on (a background measurement).
8. Address these questions: What affect does the brightness of a light source have on the internal resistance of your solar cell? Is it really fair to call it an "internal" resistance? What affect does altering the brightness have on output power? Have you noticed any other patterns relating to your method of varying the brightness?

Factor	Voltage(volts)	Current(mA)	Resistance (Ω)	Power (Watts)

Section Two: Testing the EMF-Internal Resistance Model

1. *During this part of the lab, keep the illumination on your solar cell constant.*
2. With your light source on, once again determine the open circuit voltage and short circuit current of your solar cell. Determine the internal resistance of your solar cell under these conditions.
3. Use the multimeter to determine and record the resistance of each of your load resistors. Organize the resistors carefully so as not to confuse them.
4. Set the multimeter to voltage mode and build the circuit diagrammed. For each resistor, measure and record the voltage across the load.
5. Set the multimeter to current mode and build the circuit diagrammed. For each resistor, measure and record the current through the load. These are your measured current values.
6. Use your knowledge of series circuits to determine what you would expect the current through the load to be. Be sure to show all work clearly and record your expected values.
7. For each resistor, determine the percent variation between expected and measured current values. Record.
8. Complete a graph of current vs. load resistance. Plot on the same graph both the measured and expected current values (devise a system to distinguish those two sets of points).
9. Address the following questions: Did the EMF-Internal resistance model do an adequate job of predicting output currents? Why might this model not work perfectly? Do any errors appear to be random? How do your results compare with those of other groups?
10. Use the relation P=VI and your measured values of the load voltage and current to determine the power consumption of each resistor. Prepare a graph of power vs. load resistance.
11. Address the following questions: At which resistance does the load draw maximum power? Is there anything significant about this resistance?

Rload (Ω)	V_{load} (volts)	I_{meas} (mA)	I_{exp} (mA)	% Variation	P_{load} (Watts)

Section Three: Summarizing and Expanding

1. Prepare a brief summary of your results to be shared with the class. Include any graphs or novel discoveries you have made.
2. Do any of your discoveries influence your understanding of how solar panels might be used to deliver power in everyday situations?
3. Would it be practical to use your solar panel as the energy source for everyday appliances? What problems might you encounter and how might you fix them?
4. Could your panel be used to estimate actual solar output? What difficulties might you need to resolve in trying to do so?