Solar Education for NY
SchoolPower ...Naturally

Solar Kit Lesson #11
Power Maximum: An Electrical Determination

TEACHER INFORMATION

LEARNING OUTCOME
After standardizing test stations designed to measure a solar panel's maximum power output and working with output data for solar panels, students are able to

- identify variables that may affect test results,
- devise ways to control such variables so that comparable results can be obtained from each station, and
- identify construction considerations that might affect a solar panel's performance.

LESSON OVERVIEW
Students identify and implement methods to standardize testing stations that measure solar panel output power. After collecting electrical output data from several solar panels, they plot the current-voltage (I-V) and power curves. Working with the variable "amount of light," students identify voltage and current at maximum power output for several solar panels.

GRADE-LEVEL APPROPRIATENESS
This Level II Physical Setting, physical science, technology education lesson is intended for use in grades 6–9.

MATERIALS
Per work group

- two or three mini–solar electric panels*
- ten 0.5 ohm resistors
- multimeter capable of measuring milliamps, millivolts, and ohms to two decimal places
- a gooseneck lamp with 150 watt incandescent floodlight bulb
- masking tape
- handouts

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

Optional

- breadboard
- light meter

SAFETY
Warn students not to touch floodlight bulbs when they are on. The bulbs will be hot enough to cause a burn.

TEACHING THE LESSON

Planning and Preparation: Depending on your classroom resources, decide how students are to connect the resistors in series. You might have them twist wire leads together or, if you have breadboards available, instruct students how to make use of them.

Identify each mini–solar panel using an individual masking tape label such as *1* through *16* or *A* through *P*. Individual panels may be composed of two, three, or four solar cells. Prepare a set of panels for each team. To the extent possible, supply each set with panels made of differing numbers of cells.

A table such as the one shown in figure 1 is appropriate for teams to record their final data. Display such a table where students can access it. Provide a bulletin board or other space for teams to display their completed graphs.

Figure 1: Sample Class Data Table

Panel #	Pmax	V @ Pmax	A @ Pmax
1			
2			
3			
.			
.			
.			
16			

If your students do not know how to use a multimeter to measure electrical resistance, voltage, and current, demonstrate how to do this at the start of the lesson.

Suggested Approach: Introduce the lesson by revealing to students that, although all of the kit's 16 mini–solar electric panels are rated as 0.4 watt panels, each very likely produces a slightly different amount of power compared to the others. Tell students that they are to use electrical measurements to rate and rank the 16 panels from most to least powerful.

Describe how to set up the lab apparatus so that the floodlight is positioned at least 16 cm from the solar panel; otherwise, it might melt the panel's plastic cover. Form teams of two and distribute the materials and the handout "Standardizing Test Stations."

Have students contemplate how the class might ensure consistent results among lab setups. Allow the teams a few minutes to complete the handout "Standardizing Test Stations."

Guide the class as they identify one or more methods they believe will standardize test stations. If two likely methods are identified, have half the teams use one method and half the other method. (See the Acceptable Responses for Develop Your Understanding Section for sample standardization methods.)

Instruct students on how to connect the ten resistors in series. Distribute the remaining student handouts to each team and have students complete the instructions in them.

Once students have completed the data collection, have them perform the data analysis and post their findings.

Follow-up Discussion Points:

Review with students the data for all solar panels. Does any of the data lead to the belief that test results may have varied due to differences in test setups?

How might one test whether differences in individual teams' test setups influenced test results?

Are there construction details that may affect panel output?

What else might have an effect on the actual power output?

How do manufacturers ensure a quality product? Cite price differences between tested versus untested products.

Challenge students to propose other ways to test which mini–solar panel is the most powerful.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

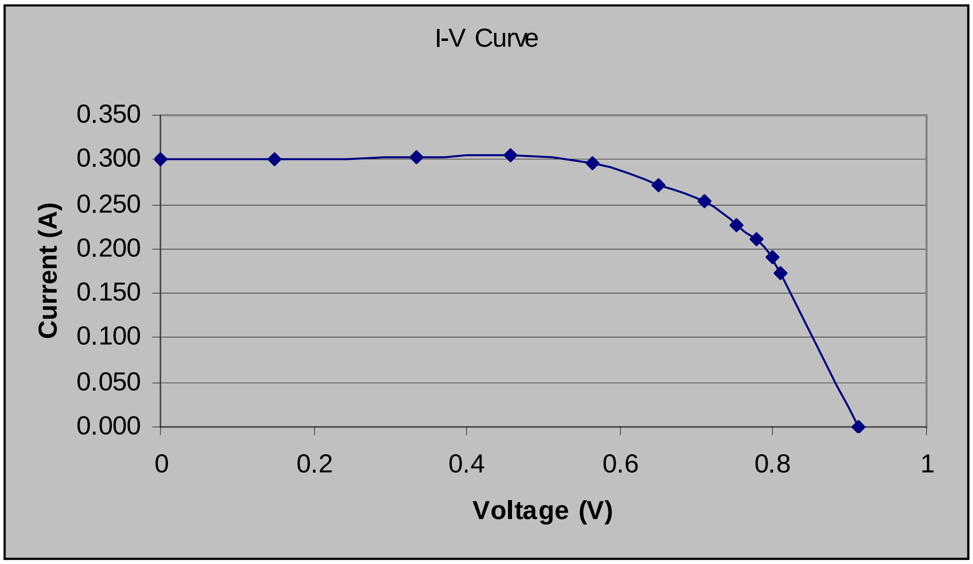
Standardizing Test Stations: Students should be aware that comparable results will not be possible unless all test stations are provided panels that receive the same level of light. Variables that affect this ideal situation are the

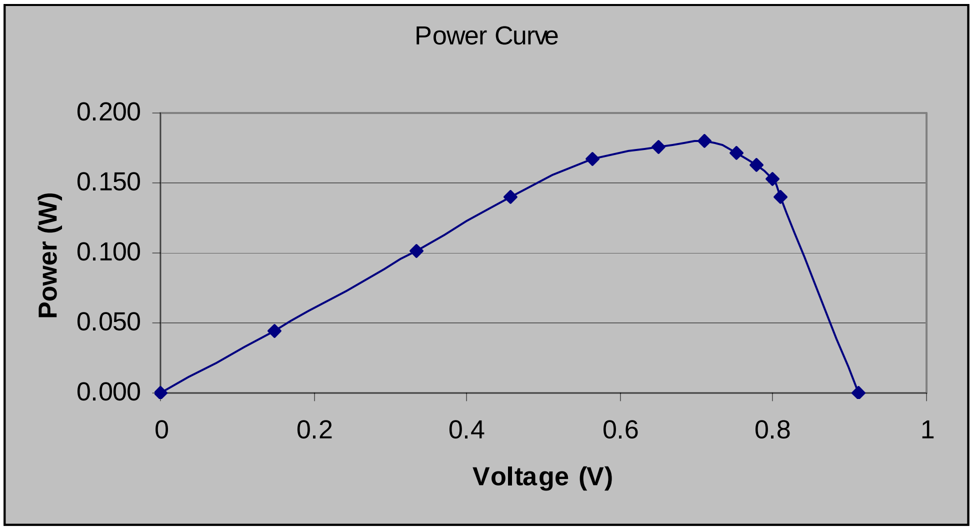
1) distance between a bulb and a solar panel,
2) the direction the bulb is facing,
3) the light output of the bulb, and
4) the position of the solar panel.

Some potential methods for standardizing testing stations include:

1) Use a standard and exact placement of the bulb and solar panel, although this ignores the potential difference in light output among bulbs.
2) Adjust each test station's lamp so it produces a standardized level of light for where the solar panels will be placed. Have a standard and exact placement of the solar panels.
    a. If a light meter is available to the class, students might use it to adjust the height of each lamp so that the solar panels at each test station are exposed to the same amount of light.
    b. Alternatively, students might use a mini–solar panel as a light meter. (See the Solar Kit lesson *Calibration Curve for a Radiation Meter*.)

Data Collection and Analysis: Students' data collection and analyses should result in a typical solar panel I-V and power graphs such as the one that follows. These sample graphs were obtained from a mini–solar panel rated for 1V, 400 mA illuminated by a 150 watt floodlight positioned 16 cm above the solar panel.





ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ACTIVITY

This is not an adapted lesson.

BACKGROUND INFORMATION

It doesn't matter if a solar cell breaks in two, because then you will have two working cells! Manufacturers of educational or small hobby solar panels rely on this fact and for reasons of economy purchase broken cells that are not acceptable to manufacturers of large solar panels.

Accordingly, it is typical to find that small hobby or educational solar panels are constructed from broken cells of a variety of sizes and shapes.

The cells in a solar panel are connected through soldered metal contacts. When a solar panel fails, the problem usually lies with the electrical connections, not the cells themselves. If a cell cracks and the two pieces are still fastened through the electrical contacts, the electrical performance of a panel might be nearly unchanged.

On the other hand, the electrical contacts between cells are susceptible to a variety of degradations from corrosion to mechanical failure. The grid of electrical contacts on the cell's surface is generally attached through a silkscreen process. The mechanical failure of the finger contacts is the most common cause of panel failure. Too high a temperature during soldering may loosen the fingers from the silicon; too low a temperature is likely to cause a "cold" solder joint. Either one, when present, causes an increase in the electrical resistance of contacts between cells.

REFERENCES FOR BACKGROUND INFORMATION

Practical Photovoltaics: Electricity from Solar Cells, Richard Komp, Ph.D., aatec publications, 2002

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Commencement Level

Standard 5—Technology Education: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms.

Key Idea 7: Project management is essential to ensuring that technology endeavors are profitable and that products and systems are of high quality and built safely, on schedule, and within budget.

Standard 6—Interconnectedness: Common Themes: Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions.

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Key Idea 1: The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena.

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Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

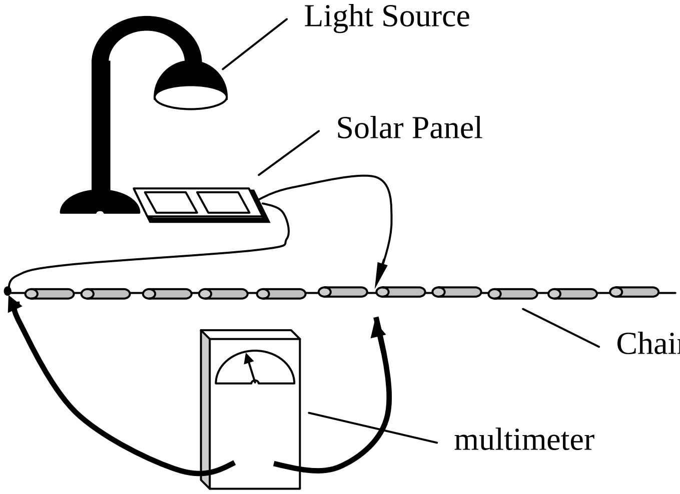
(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Standardizing Test Stations

Each team is to use the test setup shown below to measure the power output of two to four solar panels.



In order to accurately rate and rank the 16 panels from most to least powerful, the results of each team's test setup must be comparable with all other test setups.

1) Identify variables that exist between individual teams' test setups that may affect test results.

2) Propose at least one way the class might work together to minimize or eliminate the effects these variables would have on the data to be collected.

Data Collection

1) Standardize your test setup as decided in class.

2) Follow your teacher's instructions on how to connect the ten 0.5 ohm resistors in series. Connect the negative (black) solar panel lead to one end of this resistor chain. Do not connect the red lead to the resistor chain at this time.

3) Set the multimeter to measure resistance values of around 5 ohms. Connect the negative (black) lead to the end of the resistor chain connected to the solar panel's negative lead. Measure the electrical resistance values between this point and each node of the resistor chain. (Measure the resistance of first one resistor, then two in series, and then three in series, and so on up to ten resistors in series.) Record these values in the Solar Panel Power Data Log.

4) Position the first mini–solar panel directly under the light source. Use tape to secure the panel in place, making sure not to cover any of the actual solar cells. Use tape to mark the solar panel's position on the table.

5) Set the multimeter to measure voltages of around 1 volt. Turn on the light source.

6) Keeping the negative lead of the solar panel connected to one end of the resistor chain, connect the solar panel's positive lead in turn to each node of the resistor chain and measure the solar panel's output voltage. (Start with the voltage over one resistor, then over two in series, and then over three in series, and so on up to ten resistors in series.) Record these values in the data log.

7) Measure the solar panel's output voltage with nothing but the voltmeter connected to the leads. Record this as the open circuit output voltage. (Voltmeters in effect have infinite resistance across their leads). Record this value in the data log. Why don't we bother to measure open circuit output current? What should you record in the data log for open circuit output current?

8) Set the multimeter to measure current of around 0.5 amps. Measure the solar panel's output current with nothing but the ammeter connected to the leads. Record this as the short circuit output current. (Ammeters have very low resistance across their leads). Record this value in the data log. Why don't we bother to measure short circuit output voltage? What should you record in the data log for short circuit output voltage?

9) In turn, replace the first mini–solar panel with each of the panels provided by your teacher and repeat steps 4 through 7.

Name ___________________________________

Date ____________________________________

Solar Panel Power Data Log

Mini–solar panel number: _______________

Resistance (ohms)	**Voltage (volts)**	**Current (amperes)**	**Power (watts)**
0 short circuit resistance	short circuit output voltage	short circuit output current	
one resistor			
two resistors			
three resistors			
four resistors			
five resistors			
six resistors			
seven resistors			
eight resistors			
nine resistors			
ten resistors			
infinite open circuit resistance	open circuit output voltage	open circuit output current	

Solar Panel Power Data Analysis

Complete the following for each solar panel tested.

1) Use Ohm's law to calculate the output current for each resistance value and enter those values in the data log.

Ohm's law: Voltage (V) = Resistance (Ω) x Current (A)

2) Plot current versus voltage on graph paper (provided below) to obtain the panel's I-V curve. Plot current (A) on the *y*-axis and voltage (V) on the *x*-axis. Label and show the scale of each axis. Sketch the shape of the curve.

Electric power is measured in watts (W) where:

Power (W) = Voltage (V) x Current (A)

3) Calculate the output power for each resistance value and enter those values in the data log.

4) Plot power versus voltage on graph paper (provided below) to obtain the panel's power curve. Plot power (W) on the *y*-axis and voltage (V) on the *x*-axis. Label and show the scale of each axis. Sketch the shape of the curve.

5) From the bottom graph, what is the value of maximum power and what is the voltage at maximum power? Record these values at the bottom of the graph paper.

6) From both graphs, what is the current at maximum power? (From the maximum power point on the power curve, trace upward parallel to the *y*-axis until you intersect the I-V curve. Trace left parallel to the *x*-axis until you reach the *y*-axis.) Record this value at the bottom of the graph paper.

7) Enter your results in the table of solar panel comparisons provided by your teacher and display your graph results as instructed.

8) Review and take notes on the following items and be prepared to discuss them as a class.

   a. Review data for all solar panels. Does anything in the data lead you to believe that test results varied due to differences in individual teams' test setups? Explain.

   b. How might you test whether differences in individual teams' test setups influenced test results?

c. Inspect several panels that showed noticeably different values for maximum power output. Does the power output seem to have anything to do with how each panel was constructed? What else might have an effect on the actual power output?

d. What might a manufacturer of solar panels do to ensure a consistent product? Would ensuring a consistent product have an effect on the price of a panel? Support your response.

e. Knowing that power is the rate at which work is done (amount of work completed per unit of time) can help you to propose other ways to judge which mini–solar panel is the most powerful.

Name ______________________________ **Panel number** _____________

Date ______________________________

I-V Curve

Power Curve

Maximum Power (Pmax)________ Voltage at Pmax __________ Current at Pmax _________