Shine On – Student Guide

Concept Statement
A photovoltaic cell, or solar cell, is an electronic device that converts solar light energy into electrical energy. How much energy depends upon environmental and electrical factors.

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Shine On
An Introduction to the Photovoltaic Cell

INTRODUCTION
You are the founding members of one of four Solar Solutions companies. Your company provides solar products, services, and solutions for commercial business and residential customers. Your products and services utilize energy from the sun to provide renewable power to small, medium, and large-scale electronics, homes, and commercial buildings throughout the state.

When your company is hired to install solar panels at different buildings, what types of technical and environmental aspects do you have to consider?

Your company has a reputation for using cutting technology and providing the highest Quality services for its customers. A representative from Advanced Solar (a high quality solar panel maker) would like to sell you the new Super Sun Sucker 4000 (SSS4G) solar panel. This is their most efficient (and expensive) solar panel. The representative has sent you a sample for testing purposes.

What types of things do you want to know about the SSS4G before deciding if you want to use it?

Materials:
Each of the following is required per group:
- 6-in-1 Solar kit
- Solar cell
- Electronic module
- Protractor
- Lamp
- Dimmer Switch
- Digital Multimeter
- Module/Multimeter Instruction Sheet
- Illuminance Meter (Lux meter)
- Scientific Calculators (1 for each student)
- Stopwatch

EXPLORATION 1: Harnessing Light Energy
As a small company research and development (R&D) an essential part of what makes you so good at what you do. Your company uses both qualitative and quantitative methods to learn about solar energy.
For your qualitative research phase, you will use your solar powered airplane (from the 6-in-1 solar kit). Using your lamp and your dimmer switch, find out whether brightness of light effects your airplane and how. Record your observations and thoughts below:

For your quantitative research, use your lux meter, solar cell module, lamp, dimmer switch, multimeter, electronic module, and module/multimeter instruction sheet to measure the brightness of the light from the lamp, and the power output of your solar cell. Follow the graphics and instructions below:

1. Adjust brightness and/or height of the bulb to reach the target illuminance with the lux meter.
2. Measure both the current (I) and voltage (V) that the solar module is producing.
3. Repeat for other target lux values.

Experiment 1. Varying “brightness”

3. Adjust the light source using the dimmer to yield close (within 5%) to the target illuminance given in Table 1 using the illuminance (lux) meter.
4. Measure the voltage (V) and current (I) that the solar cell module produces as a result of the light from the source. If results are in millivolts (mV), remember 100 mV = V. Use your Module/Multimeter sheet for instructions on how to use your electronic module and multimeter.
5. Repeat for increasingly bright light from the source, using “Target illuminance of Light Source” in Table 1.
6. Calculate the power produced from the solar cell module and record. (P = IV)
Table 1: Solar cell data from variable indoor light bulb

Data for R = 33 Ohms. The rest of the data can be found in the spreadsheet handout.

<table>
<thead>
<tr>
<th>Light Source Brightness</th>
<th>Target Illuminance of Light Source (Lux)</th>
<th>Voltage (V) Produced by Solar Cell Module (V)</th>
<th>Current (I) Produced by Solar Cell Module (mA)</th>
<th>Calculated Power (P) Produced by Solar Cell Module (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - Dim</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2000</td>
<td></td>
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</tr>
<tr>
<td>4</td>
<td>5000</td>
<td></td>
<td></td>
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<tr>
<td>5- Brightest</td>
<td>15000</td>
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</table>

CONCEPT DEVELOPMENT 1: Harnessing Light Energy

1. Ask your instructor for a “I-V Curve” handout, then record your data for the current and voltage of your solar cell at each illuminance level and answer the associated questions.
2. What happens to the current produced by the solar cell as the illuminance (brightness) is increased?
3. What happens to the power created by the solar cell as the illuminance (brightness) is increased? (remember that power = current x voltage)
4. Now check out the other groups’ solar cell modules (look closely). What is the difference between what is connected to one of the green connectors?
5. Your instructor will provide a graph for everyone’s combined data at the front of the class, record your data on this graph.
**EXPLORATION 2: Electrical Loads**

You’ve been given a windmill driven by a motor to power with your solar cell module.

1. What do you think will happen as a result of adding this extra load to the circuit?

   a. Do you think the windmill will work based on your initial data? Why or why not? How well?

   b. How much light (in lux) do you imagine will be necessary to turn the windmill on?

2. Connect your motor to the module in the designated area by replacing the purple wire in the green Phoenix connector.

3. Make sure the switch on the module is set to “Current”.
4. Set the light source so that 2000 lux is incident on the solar cell.
5. Is the solar cell producing enough power to operate the device?
YES or NO (circle one)

6. How many revolutions does the shaft rotate every 10 seconds at 2,000 lux?

7. Determine the minimum amount of light per square meter (Illuminance) that is needed for the device to operate.

Please record your data for 6 and 7 on the instructor’s board.

CONCEPT DEVELOPMENT 2: Electrical Loads

1. Connect all the points on your I-V chart that represent 500 lux.
2. Mark the points on your curve that represent zero power. (Remember: P = IV)
3. Mark the point on your curve that represents the maximum amount of power.
4. What happens to the solar cell’s power output on either side of the max power point for a given illumination?

5. Physically, what is happening when the load (resistance) is too high? (Data below the maximum power point.)

6. What is the issue when the load (resistance) is too low? (Data to the left of the maximum power point.) Think about using all available power.

7. Fill in the blanks in the statement below based on your explorations.
   a. When ____________strikes a solar cell, _____________is produced. It will provide a constant current for a given _______________level up to a certain ________________, where the maximum power point lies. After this point, the power ________________dramatically.
8. Connect all of the points on your I-V handout that were produced from 2000 lux. Mark your I-V data point on the graph for 2,000 lux that was measured in Table 1 of Exploration 1 with an X.

9. What effect did adding the motor (extra resistance) to the circuit have on this point?

10. Considering the point on the I-V curve where your module normally operated at 2,000 lux, does the response of the motor (extra load) make sense? Why or why not?

11. Provide a reason as to why the device either works or does not. (Hint: Think about the added resistance of the device and the resulting available power.)

12. Connect all of the points on your Current vs. Voltage handout that represent both 5,000 and 15,000 lux. What is happening to the curves?

**EXPLORATION 3: Solar Panel Orientation**

1. Using the solar airplane (from the 6-in-1 solar kit) and lamp, try powering the device with the light bulb in a set location with a set brightness. Find out whether the angle of the solar cell surface impacts the power created by the solar cell. Record your observations and thoughts below. Is there an angle that works best?
2. Remove the airplane and green column from the base of the device, leaving only the base and a solar cell.
3. Use your protractor to set the angle of the lamp as shown in the diagram.
4. In this exploration use you will be using the same experimental setup, but will keep the illumination on the solar cell constant. We will, however, be varying the angle of the solar cell. At 5,000 lux, please measure the current and voltage and calculate the power produced by the solar cell module on table 2.

![Diagram of solar cell setup](image)

<table>
<thead>
<tr>
<th>Angle of Solar Cell (θ)</th>
<th>Solar Cell Voltage (V)</th>
<th>Solar Cell Current (mA)</th>
<th>Solar Cell Power Output (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>90</td>
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Remember that $P = IV$. 
CONCEPT DEVELOPMENT 3: Solar Panel Orientation


6. Describe the relationship between Power and Angle that you have just graphed.

7. At what angle was the maximum power output found?

8. What is special about this particular angle?

9. What can be said about the angle that sunlight strikes the surface of the solar cell in relation to both the time of day and year and the power output of the solar cell?

10. Go outside and measure with the sun’s illuminance with the instructor’s lux meter.
Sun Illuminance = ___________ lux.

11. The sun emits light and it hits earth’s outer atmosphere with an illuminance of about 132,000 lux. How does this compare to the values that we have just measured?

12. What are your initial thoughts about why the values are so much different?

CONCEPT APPLICATION: Scale/Magnitude

1. Typical cellular phones need 3.6 volts to operate and draw 275 mA of current while talking. How many cellular phones could you operate under maximum power conditions for 2000 lux with a 150 cm x 150 cm solar cell similar to the one you used today?

2. The manufacturer for the OWI-608 solar cell claim that their cell can provide a maximum of 350 mA @ 1.4 V when ~100,000 lux of sunlight is shining on the cell. However, these numbers represent what the cell can do if there is nothing attached to it to be powered! If you remember from your I-V curves, as the light increased from 500 to 2000 lux, our curve started to flatten out. This has a bad affect on the power output of the cell. It turns out that this cell has a “fill factor” of about 50%. This means that if we had enough sunlight (~100,000 lux) to get 350 mA @ 1.4 V out of our cell with nothing attached to it, we could only get about 50% of that quoted power when something is attached to it. Considering this fact, how many of these cells would we need to power 2 cellular phones at maximum power output for our solar cells @ 100,000 lux?
3. A Sony PS3 gaming console uses roughly 200 W of power while playing a video game. How large of a panel (similar to the one used today) would you need to power this device at 2000 lux? How large of a panel would you need to power a Nintendo Wii (AVG Power Consumption is around 18W)?

4. How large of a panel would you need to power the Sony PS3 with state of the art solar cells that are nearly 40% efficient (~ 10 times more efficient)?

**AUTHENTIC ASSESSMENT**

1. The school of meteorology wants to put a weather station in the courtyard. The SSS4G solar panel should provide enough power for the station if there is minimal shading. Use the Solar Finder to select the best location in the courtyard for the weather station's panel and determine the impact of shading for that spot. (Locations are marked on the map below and have been marked outside).
(a) Examine the solar pathfinder. Look at the reflective glass, the reflection of any obstructions (trees, buildings, poles, fixtures) represent blockage of sunlight. The vertical axis down the center represents the months of the year and each month has a corresponding arc. Notice numbers that are largest in size printed across the bottom arc; they represent AVG sunlight hours/day.

(b) Take the solar pathfinder to each of the marked locations.

(c) Using the solar pathfinder’s built in compass; adjust it so that it is facing south.

(d) Complete the table below

<table>
<thead>
<tr>
<th>Location</th>
<th>AVG July Sunlight Hours /Day</th>
<th>AVG % January Sunlight hours/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
<td></td>
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<tr>
<td>4</td>
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</tbody>
</table>

(e) Which location would be the best for the SSS4G panel in July, and why?

(f) Will there be a better location between July and January? Why?
2. The OU College of Engineering (CoE from now on) wants the Engineering Practice Facility (EPF from now on) to be a national trendsetter among engineering colleges across the U.S.A., so they have decided to make 100% of its electricity green, meaning they would like for the building’s electrical power to be renewable and sustainable. The CoE has asked your company to install solar panels on the rooftop of the EPF.

Your company was impressed with the SSS4G’s solar panel and has decided use it for the CoE installation. Use the following information and tools to determine if this is possible.

**Key information:**

- EPF average electrical power consumption: 48,807 kWh/month
- EPF rooftop area: 20,000 square feet

**Materials**

- SSS4G solar panel
- Multimeter

(a) Take materials to one of the locations on the map above.

(b) Adjust the panel to the angle of max power.

(c) Record the voltage, current, and power (must be calculated) on the table below.

**NOTE:** When measuring currents of greater than .5 A, one must move the binding posts on the multimeter to the fused section. Make sure the circuit is broken and reconnected through the meter so the fuse does not blow. If you need assistance, please ask an instructor.

<table>
<thead>
<tr>
<th>Voltage (V) Produced by Solar Cell</th>
<th>Current (I) Produced by Solar Cell (A)</th>
<th>Calculated Power (P) Produced by (mW)</th>
</tr>
</thead>
<tbody>
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<td></td>
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</tbody>
</table>
(d) Use the “July AVG sunlight hours/day” from the table in authentic assessment question 1 and power (W) to estimate the number of watt hours per day and per month the SSS4G can generate. Use the equations below. Record your answers in the table above.

\[ 1 \text{ Watt Hour} = 1 \text{ Watt} \times 1 \text{ Hour} \]

\[ \text{WattHours/day} = \text{Power (W)} \times \text{Avg sunlight hours/day} \]

\[ \text{WattHours/month} = \text{WattHours/day} \times 30 \text{ days/month} \]

(e) Given the estimated WattHours/Day produced by the SSS4G, how many of these panels will you need to provide electrical power for the EPF every month? (Hint: use “key information”)

(f) Is the rooftop area of the EPF large enough to fit the number of solar panels calculated above? (Hint: use “key information”)
Your authentic assessment will be graded for each component using this rubric:

<table>
<thead>
<tr>
<th>Components</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Power</td>
<td>Skips this question</td>
</tr>
<tr>
<td>Environmental Factors</td>
<td>Skips this question</td>
</tr>
<tr>
<td>Angle of incidence</td>
<td>Skips this question</td>
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