Physics 197 Lab 14: Solar Panel Output Variables

Equipment:

Item	Part #	Qty per Team	# of Teams	Total Qty Needed	Storage Location	Qty Set Out	Qty Put Back
Solar Panel Array (3 cells in series)	Solar Lab	1	8	8			
Lamp with Incandescent bulb		1	8	8			
Clip Stand for Lamp		1	8	8			
Digital Multimeter	Extech MN35	1	8	8			
Banana-Alligator Leads		2	8	16			
Banana-Banana Lead		1	8	8			
Decade Resistance Box	Eisco	1	8	8			
Measuring Stick		1	8	8			
Protractor		1	8	8			
Lab Jack		1	8	8			

Layouts:

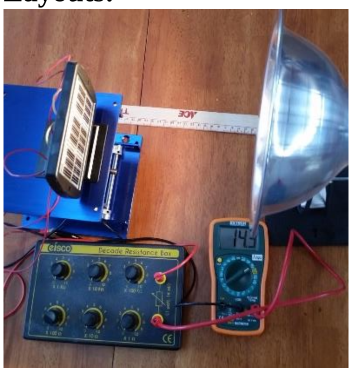

Figure 1, Optimize Load, Power vs. Distance

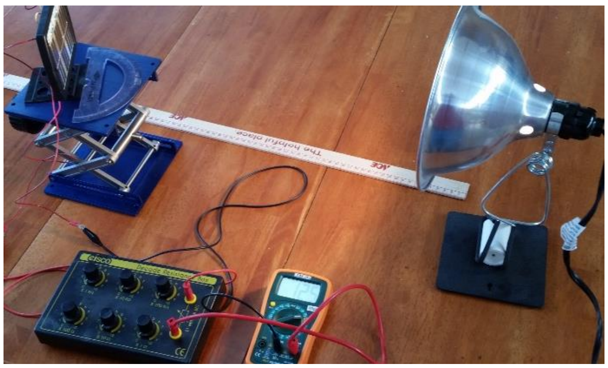

Figure 2, Power vs. Angle of Incidence

Figure 3, Power vs. Change in Temperature

Summary:

In this lab, students will explore solar power using a lamp and a small array of photovoltaic solar cells, as shown in figure 1. The amount of power generated depends on the illumination of the solar cells, the efficiency of the solar cells, and the load which is dissipating the power. By connecting a variable resistance box in series with an ammeter and the solar cell, the current can be measured as the resistance is changed, and the generated power can be calculated from $P=I^2R$. The value of resistance can then be set to maximize the power. With the power maximized, the effect of illumination intensity will be investigated by first changing the distance from the lamp to the solar panel, and by then varying the angle between the incident illumination and the solar panel. Finally, other effects which might affect solar panel efficiency such as temperature and shadowing will be investigated. Graphing data accurately by hand in the laboratory notebook will be emphasized during this experiment.

PreLab:

Print out a map for the United States showing the potential for Solar Energy (preferably in color). This might be labelled as Insolation, or Solar Irradiance. The relevant units will be something like kWh/(m^2Day). Here kWh is a unit of energy, and m^2 is area either parallel to the ground, or possibly perpendicular to the light from the sun. Tape the map in your notebook, and notice what part of the United States has the most potential for solar energy (based on average time of daylight without clouds and angle to the sun). Look up the average daily electrical energy usage in the United States. At a location with the highest amount of available solar illumination, determine what area of solar cells would be required to provide the amount of electricity used. (Assume the solar cells have an efficiency of 15 % and are kept at an optimal pointing angle). Put a square on your map which approximately matches your calculated area.

Lab:

(The room lights should be dimmed for these experiments to minimize the effects of background illumination).

Experiment A, Power versus Load

Obtain a small solar cell array, which should have six panels (3 horizontal by 2 vertical). Each vertical pair is connected in parallel, and reaches a voltage of approximately 1.5 volts when illuminated. It is possible to connect the three pairs of panels (arranged horizontally) in different configurations. For this laboratory they should be connected in series with jumpers so that the total voltage produced across the array with no load connected should be between 4.5V and 5V. Place the solar array on a lab jack and match the height to the height of an incandescent lamp on a stand as shown in figure 2. Use the multimeter (20V DC setting) to measure the open loop voltage put out by the solar array with the lamp on and the solar array at distances of 0.25m, 0.5m and 1m. Verify that the voltage is close to 4.5V and doesn't vary much with distance, even though the illumination intensity is much less at 1m than at 0.25m.

Now connect the solar cell array in series with the digital multimeter measuring current (200mA DC setting) and a variable resistor box using appropriate leads to form a closed electrical loop. Draw an appropriate circuit diagram in your notebook. (Leave the lamp off until you are all ready to collect data). Place the solar array at a distance of 0.25m from the front of the light bulb, making sure the array and lightbulb are at the same height and the array is perpendicular to the direction of the light. Create a table in your lab notebook with rows for resistances from 20Ω to 400Ω in 20Ω increments. Include columns for resistance (Ω), measured current (mA), converted current (A) and calculated power (W) calculated using $P=I^2R$.

Now turn on the lamp, and vary the series load resistance from 20Ω to 400Ω in 20Ω increments using the knobs on the variable resistor box. Record the measured current for each load resistance in the table. Work fairly quickly without changing the geometry between the lamp and solar cell array. (You want to work quickly so that the solar cells don't heat up too much during the experiment). When you are done collecting data, turn the lamp back off. Now fill in the column for current in amps, and then calculate the generated power for each load resistance. You should notice that at first the power increases, and then it decreases as the resistance is increased. This makes sense, because with no load resistance (a short circuit) any power would have to be dissipated in the solar cells themselves, and at very high load resistance (like an open circuit) no current will flow, but the solar cell array will still be at its maximum voltage of about 4.5V. Carefully plot the power (vertical axis on graph) versus load resistance (horizontal axis on graph) in your notebook. The horizontal scale should cover most of the notebook page, should start at zero, and should have resistance values scale linearly with x. Determine the load resistance under which your array is generating maximum power (for the illumination you used). Vary the resistance around this point by 10Ω increments for maximum power, and record this power value as a data point for a distance of 0.25m.

Experiment B, Power versus Distance

A number of variables impact the power generated by a solar array. The most obvious of these is the amount of light hitting the solar panels. (The wavelength distribution of the light is also very important, but we won't be investigating that here). For solar panels being used to generate electricity, the distance from the earth to the sun doesn't change by a large percentage during the year. However, other factors have a very large impact on the amount of illumination (day versus night, clouds, tree shadows, angle to the sun, etc.) In this laboratory we can easily change the amount of illumination by changing the distance to the lamp. Using a meter stick, set up the equipment as in figure 1 so that the distance between the lamp and the solar panel can now be set first at 0.5m, and then later at 1m. (You have already done a measurement at 0.25m distance).

At each of these two new distances (0.5m and 1m) vary the resistance until you achieve maximum power output from the solar array. This will require a quick calculation of $P=I^2R$ at each resistance you try. Write down the data (resistance, current and power) at those resistances you try. Come up with some way of iterating in to the optimal resistance load value. As a reference, at 0.25m I found the optimum somewhere around 100Ω, at 0.5m I found it somewhere around 200Ω, and at 1m I found it somewhere around 700Ω. Since these values depend on the output of the particular lightbulb and other solar array parameters, your resistance values may be different.

Write down and compare your maximum power output at distances of 0.25m, 0.5m, and 1m. Since the distances has been doubled each time, we should expect the illumination intensity, and thus the solar array output power to fall by a factor of 4 each time. Did you find this to be the case? Discuss why you would expect this amount of power fall off, and what might have led you to measure something different.

Experiment C, Power versus Illumination Angle

A very important factor in setting up a solar panel array is the direction the panels are pointed. To maximize power, the panels could track the position of the sun so that they are always perpendicular to the illumination. However, this is not typically practical or cost effective for a home rooftop installation. Typically in northern latitudes panels are oriented to point in a southerly direction, and angled from horizontal to maximize the power at some time of the year (since the sun is lower at noon during the winter than during the summer). How do you think the generated power will vary with the illumination angle of incidence on the solar cell array?

Set up the solar cell array at a distance of about 0.5 m from the lamp as in figure 2. Using a protractor, change the illumination angle between the solar cells and lamp from 0 degrees (normal incidence) to 90 degrees (perpendicular to illumination) in 22.5 degree increments. In a table record the measured current at each angle and calculate the power produced, again optimizing the power by varying the load resistance as you did in Experiment B. Make a plot of power versus angle. Overlay a plot of how power would vary with angle according to your prediction (normalized to the power at normal incidence). Do you think your prediction was right?

Experiment D, Power versus Temperature

With the lamp off, and after having allowed the solar cell array to cool off after any previous experiments, set up the lamp very close to the solar cell array as in figure 3. (Remember to record any relevant parameters in your notebook, describing what you are doing, recording the distance, etc.) Turn on the lamp at time t=0 and record the measured current. Record the current at 30 second intervals for 3 minutes. What did you observe? Feel the solar cell array – did it warm up significantly? Does it appear that the solar cells generate more power when they are cold or hot? Sometimes people propose putting solar arrays on ponds to help keep them cool.

Experiment E, Power versus Shadowing

With the solar cell array at a distance of about 0.5m from the lamp, and the load resistance adjusted for maximum power output, see what happens to the current when part of the solar cell array is covered with opaque material. Does covering a small part of the array cause a disproportionate decrease in the power output? This could occur if some of the individual solar cells connected in series with the others don't have any current carriers and thus develop a very high resistance. Because of this effect, it is important not to allow shadows (for instance from trees) to fall on rooftop solar installations.

When you are all done, make sure to write a general conclusion in your notebook about what you learned during today's laboratory.