Understanding Solar Modules

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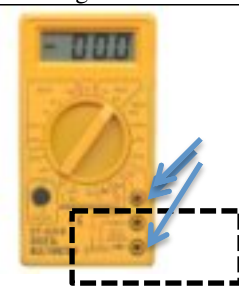
Subject: Engineering
Schedule: 90 minutes
Materials per Group: 1 solar panel, 2 DMMs, 6 wires with alligator clips, 1 Charge Controller, 1 10-Watt Light Bulb with 1 Screw, 1 Light Meter, 1 Extension Cord, 1 Kill-A-Watt, 1 Inverter,

<u>Please note</u> that all the parts in the plastic storage box must be carefully handled and returned to the box after usage!
<u>DONOT leave</u> before your box is checked by one of the mentors!

Pre-Lab: Understanding the Parts

Read this section carefully to understand what electrical parts and devices are used in this laboratory activity.

Component	Figure
Digital Multimeter (DMM): These devices allow us to measure DC/AC currents and voltages, among other electrical characteristics. When a DMM is used in a circuit to measure voltage it is called a **Voltmenter**. The dashed square shows which pins of the DDM are used when it is used as a voltmeter. When a DMM is used in a circuit to measure current it is called an **Ammeter**. The blue arrows in the figure indicate which pins of the DDM are used when it is used as an Ammeter.	
Charge Controller: A charge controller, or charge regulator is basically a voltage and/or current regulator to keep batteries from overcharging. It regulates the voltage and current coming from the solar panels going to the battery. Most "12 volt" solar panels put out about 16 to 20 volts, so if there is no regulation the batteries, which are connected to them to be charged will be damaged from overcharging. Most batteries need around 14 to 14.5 volts to get fully charged.	
Light Bulb: When the bulb is hooked up to a power supply, an electric current flows from one contact to the other, through the wires and the filament (filament sits in the middle of the bulb). Electric current in a solid conductor is the mass movement of free electrons a negatively charged area to a positively charged area. As the electrons zip along through the filament, they are constantly bumping into the atoms that make up the filament. The energy of each impact vibrates an atom -- in other words, the current heats the atoms up. As a result, as filaments are heated to a high enough level -- around 4,000 degrees Fahrenheit (2,200 degrees C) in the case of a light bulb -- they will emit a good deal of visible light. There are many different types of lamps, characterized by how they are built and much power (in Watts) they consume.	
Alligator Clips: These clips are used to make connections between the devices when they don't reach one another. It is important to ensure adjacent wires do not touch each other, as this can damage the device or burn your hand. 	

Kill-A-Watt: Using these devices you can monitor how much electricity an electrical appliance is consuming. Kill-A-Watt also monitors the voltage, current, and frequency of the AC signal turning on the appliance.	
Power Inverter: These devices convert the variable direct current (DC) output of a photovoltaic (PV) solar panel (or just a battery) into a utility frequency alternating current (AC) that can ultimately be fed to turn on an electrical appliance. In front of the Inverter you can see a USB interface, providing a 5-Volt output.	
Extension Cord: Use the extension cord between the lamp and the inverter.	
Light Meter: A light meter is a device used to measure the amount of light. In photography, a light meter is often used to determine the proper exposure for a photograph. In this laboratory exercise we use light meters to show how the generated electricity from a solar panel is related to the intensity of the sunlight.	
Battery: While there are many different types of batteries, the basic concept by which they function remains the same. When a device is connected to a battery, a reaction occurs that produces electrical energy. This is known as an electrochemical reaction. For this experiment we use a 12 V battery.	
Solar Panel/Module: The solar cells, also called photovoltaic (PV) cells, as the name implies (photo meaning "light" and voltaic meaning "electricity"), convert sunlight directly into electricity. A solar module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays.	

Part I: Tracking the Sun

The power incident on a photovoltaic (PV) module depends not only on the power contained in the sunlight, but also on the angle between the module and the sun.

Pre-Lab Concepts:

- Electricity and movement of electrons
- Amp-hour and Watt-hour
- Difference between DC and AC current
- Ohm's Law (V = I*R) and appropriate units
- Power dissipation in a circuit (P=V*I) and its unit
- How to use digital multi meters
- Solar cells, panels, and modules
- The concept of building a circuit
- Measuring Lux

MAKE SURE THE WIRES ARE NOT TOUCHING ONE ANOTHER!!!! Use TAPE to cover exposed wires!

Experiment:

1- Place the solar panel as shown in the Figure 1. Make sure the panel is well secured and it does not fall! Connect the digital multi-meter (DMM) to the solar panel. Set the dialer to $\overline{V}$=200. You can use the alligator clips if needed. Record the DC voltage reading (don't forget units): Voltage Recorded ________________

Note that your reading must be a positive number. Having a negative number means the wires are crossed and must be switched (see Figure 1)!

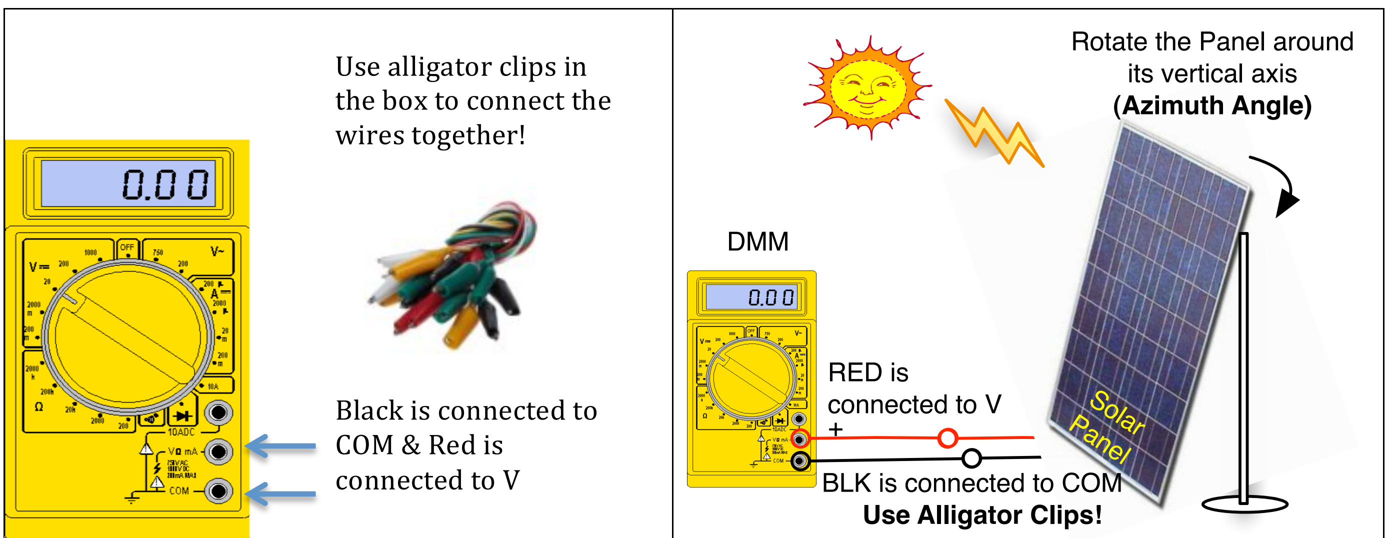


Figure 1

2- Rotate the panel around its vertical axis until you get the maximum voltage reading from the digital multi-meter (DMM). This is called changing the solar **azimuth angle** (see Figure 1). Secure the solar panel.

3- Record the measured voltage (don't forget units):

Time of the Measurement: ___________________

Voltage Recorded (Vref) ___________________ (this number may slightly change)

4- Mark the position of the solar panel on the ground as Zero Angle!

5- What happens as you stand in front of the solar panel or create a shadow? This in effect is like having a cloudy day! Record the DC voltage reading:

Voltage Recorded ___________________

6- Rotate the solar panel slightly to each direction around its vertical axis (see Figure 1). Assume the angle of the reference point, where you measured Vref, is zero; rotating clockwise represents a Negative angle, while rotating counter clockwise represents a Positive angle. Make sure as you make your measurements are no shadows. You should complete the table below:

Table 1: Changing the Azimuth angle.

Angle	Voltage (V)	Notes
0	Vref =	Reference Point
-30		Rotate to Left
-60		Rotate to Left
-90		Rotate to Left
-120		Rotate to Left
0	Vref =	Reference Point
+30		Rotate to Right
+60		Rotate to Right
+90		Rotate to Right
+120		Rotate to Right
180 or -180		Rotate to Right or Left

7- Reverse the wires connected to the DMM. What happens to Vref (voltage reading)?

8- Pick up the LX1010B Light Meter (shown below) and open up its cover. Turn it ON and hold it directly against the sunlight. If you don't get any reading make sure the SCALE button is properly set (e.g., x100). Move the light meter and see at which angle you get the maximum Lux reading (e.g., luminous flux per unit area). Record your reading; don't forget to record the setting (e.g., x100):

Light Meter[1] _________________________ (Lux)

9- Is the angle in which you are holding the light meter to receive the maximum Lux consistent with your azimuth angle, where you measured Vref?

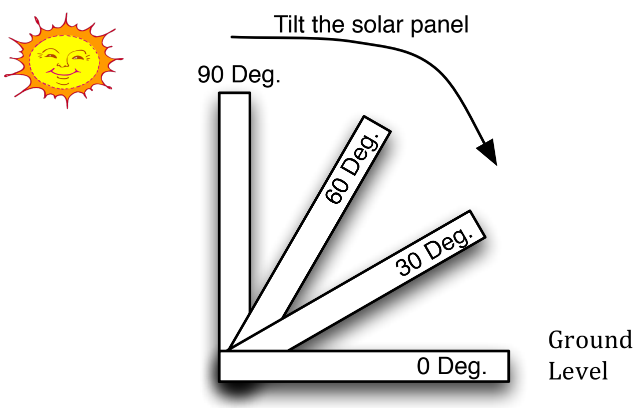
PLEASE MAKE SURE YOU TURN OFF THE LIGHT METER!

[1] Read more about Lux: http://en.wikipedia.org/wiki/Lux

Part IIA: Tracking the tilt angle

In this experiment you need to tilt the solar panel between 0 to 90 degrees. Note that this is a manual process and needs a bit of patience!

1- Place the solar panel as shown in Figure 1 (in the previous section).
2- Make sure all the wires are properly connected as shown in Figure 1.
3- Make sure the panel is well secured and it does not fall! Connect the digital multi-meter (DMM) to the solar panel. Set the dialer to $\overline{\overline{V}}$**=200**. You can use the alligator clips if needed. Record the DC voltage reading: Voltage Recorded ________________



Tilt Angle

Angle (Degrees)	Voltage (V)
0	
15	
30	
45	
60	
75	
90	

Table 2: Changing the Tilt (Elevation) angle.

4- Record your results in the Table 2 as you tilt the panel manually. Make sure you don't drop the panel! Record the values for all seven angles.

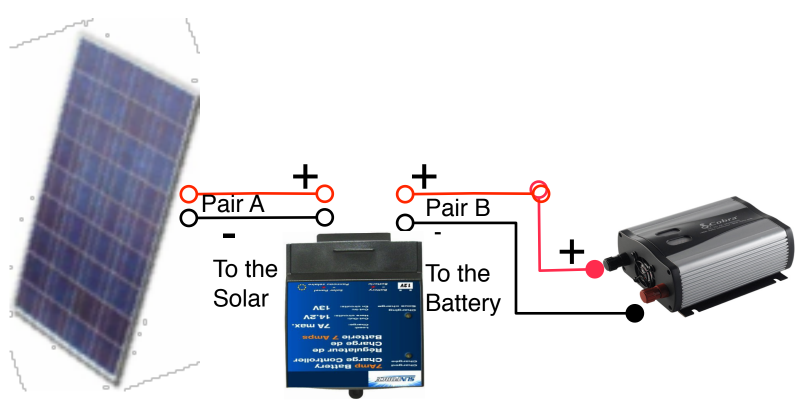
Part IIB: Understanding the charge controller function

In this experiment you learn what exactly the charge controller does. Follow the following steps:

1- Place the solar panel as shown in the figure. Make sure all the wires are properly connected as shown in the figure.

2- Connect the wires from the Solar panel (Pair A, as shown in the figure to your Voltmeter. Record the measured value: ______________ (V)

3- Connect the wires from the Charge Controller (Pair B, as shown in the figure to your Voltmeter. Record the measured value: ____________ (V)



4- Is there any difference between the two values above? What is the function of the charge controller?

Part III: Characterizing the solar panel

In this experiment you learn how we can generate AC signal using a 12V battery.

Pre-Lab Concepts:

- Charge Controller
- Inverter
- AC signals and frequency concept
- AC power measurements
- DC power measurement

MAKE SURE THE WIRES ARE NOT TOUCHING ONE ANOTHER!!!! Use TAPE to cover exposed wires!

Experiment:

1- Make sure the Inverter is **OFF**!
2- Use the cardboard for covering the solar panel as your work space and place all the components on top of it. Construct the setup shown in Figure 2.
3- Check all the connections.
4- Turn on the Inverter. Is the light bulb on? If you hear the inverter making noise, that is the indication that the inverter does not receive enough power from the solar power.
5- What is lacking to turn on the inverter? Sufficient current or voltage? Explain.
YOUR ANSWER HERE:

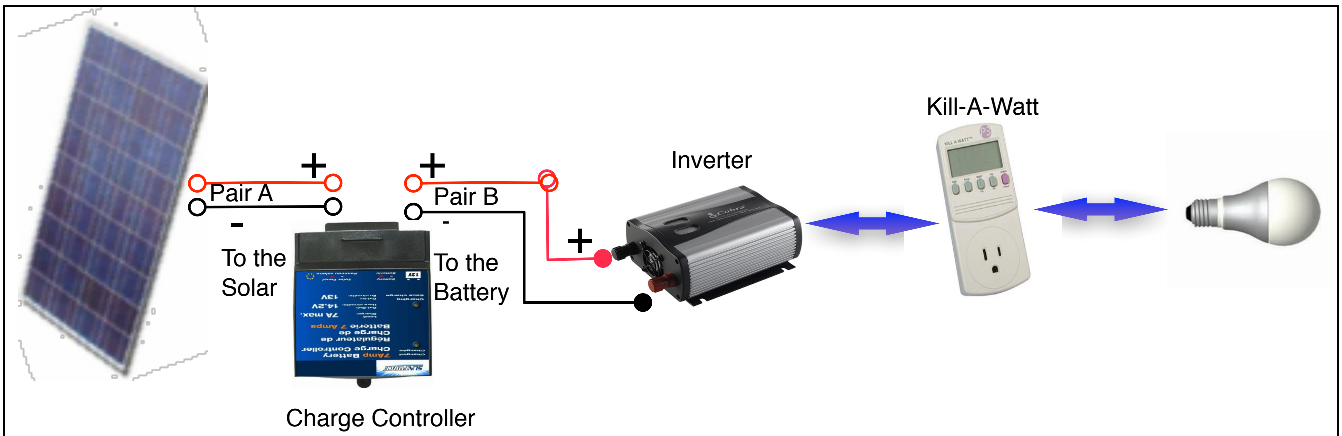


Figure 2

6- Make sure the Inverter is **OFF**!
7- Remove the solar panel and connect the Battery instead of the solar panel. Remember to connect the POSITIVE and NEGATIVE wires properly to the Charge Controller.
8- Measure the battery voltage using a voltmeter at Pair B: ______________ (V)
9- Make sure the Inverter is **ON**! Is the light on? If so, continue. If NOT, turn the Inverter **OFF** and check your connections.
10- Measure the battery voltage using a voltmeter at Pair B when the light bulb is on: ______________ (V)

11- Complete the measurements in the table below (NOTE: in cases where the readings are changing, record the average values). Disconnect the battery as soon as you are done to save battery for the next group!

Table 3.				
Setup	Reading from Kill-A-Watt			
	AC Volt	AC Amp	Watt	Hz
Inverter OFF + Connect Kill-A-Watt + Light Bulb ***				
Inverter ON + Connect Kill-A-Watt + Light Bulb ***				

Please make the measurements quickly and disconnect the battery as soon as your measurements are completed!

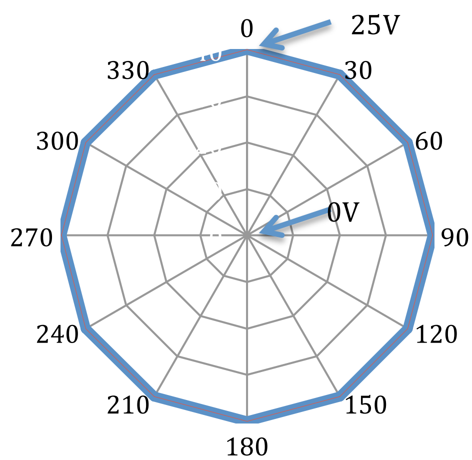
After completing the experiment please make sure you TURN OFF all the Multimeters (DMM)!

Place all the wires in the provided plastic bag!

Discussion Questions Related to Parts I and II:

1- Is the output of the solar panel DC or AC? Does it have a frequency?

2- Plot the measured voltages recorded in Table 1 in the provided space below. Connect all the measured points together. Note that you are plotting voltage as a function of azimuth angle. The voltage value is represented by the length of the line starting from the center of the circle. We refer to this plot as the solar radiation plot.



Solar Radiation Plot

3- What is the purpose of the charge controller?

4- Does a 30-degree change of azimuth angle from direct sunlight make a significant difference in terms of output voltage of the solar panel?

5- Briefly, explain what happens as you tilt the panel. Why are solar panels installed on the roofs of buildings are slightly tilted?

6- Name FIVE possible factors that can impact the output power of a given solar panel.

Discussion Questions Related to Parts III:

1- What is the frequency and voltage of the AC signal coming out of the wall outlet?

2- What is the power consumption of the light bulb?

3- In Table 3, compare your measurements for *Inverter ON + Connect Kill-A-Watt + Light Bulb*, and *Inverter OFF + Connect Kill-A-Watt + Light Bulb*. How are your AC Volt, AC Amp, and frequency measurements on the Kill-A-Watt different?

4- Assume that we want to power up an 8-Watt light bulb. If we use a solar panel generating 20 V DC. How much current is required for the solar panel to generate? Does your solar panel generate this much current? How do you know?

5- Assuming the average cost of electricity in California is 12 cents per kWatt-hr what will be the annual cost of electricity to operate a new 22 CF (cubic feet) side-by-side refrigerator consuming 56 KW-h? HINT: See the example below.

6- Repeat the same calculations for a 100-Watt light bulb being on 8 hours a day.

Appliance	Watt	kWatt	Hrs ON/day	kWatt * Hr/day	kWatt-hr/year	Cost of Electricity /year
TV	200	0.200	4 hrs	0.2 * 4=0.8	0.8 * 365=292	292*0.12=$35
Refrigerator						
100-Watt Light Bulb						