

Maximum Power Point (Teacher Notes)

(The Principles of Optimizing Photovoltaic Cell Power Output)

Notes on Part 1:

Basic Electricity Review²

To understand photovoltaics, it is necessary to know something about electricity. There are three very important concepts, Voltage, Current, and Power.

- **Voltage**, measured in volts, is a measure of the electrical force between two points. Voltage is the cost in energy required to move a unit of positive charge from a more negative point (low potential) to the more positive point (higher potential).
 - A voltage potential can be thought of as the potential energy released when a unit charge moves “downhill” from the higher to lower potential. It is important to think of a voltage potential between or across two points in a circuit. Often a voltage potential is measured in reference to a single common point referred to as “ground,” located on the “-“ side of the voltage source.
- **Current**, measured in amperes or amps, is a measure of the number of electrons flowing through a wire in a particular time. It is analogous to gallons of water per second flowing in a hose.

*Note that voltage and current are totally different concepts. In an electrical circuit, the number of electrons that are moving is called the **amperage** or the **current**, and it is measured in **amps**. The “pressure” pushing the electrons along is called the **voltage** and is measured in **volts**. So you might hear someone say, “If you spin this generator at 1,000 rpm, it can produce 1 amp at 6 volts.” One amp is the number of electrons moving (1 amp physically means that 6.24×10^{18} electrons move through a wire every second), and the voltage is the amount of pressure behind those electrons.

- The third concept is that of **power**. Power is simply voltage times current. It is also the amount of energy that is delivered in a unit of time.

*Electric current always travels in a closed loop, a “circuit”.

Circuits: a synopsis from *howstuffworks.com*

Whether you are using a battery, a fuel cell or a solar cell to produce electricity, there are three things that are always the same:

² The following review materials on electricity and the nature of PV panels used in the Junior Solar Sprint were obtained from: <http://chuck-wright.com/SolarSprintPV/SolarSprintPV.html>, where Chuck Wright, renewable energy expert and consultant for the Texas State Energy Conservation Office's Renewable Energy Demonstration Program, “Infinite Power,” shares his wisdom and PV panel testing results for the panels recommended for use with the Solar Sprint cars. ² (If you are utilizing smaller PV panels, the included information will still be of great value.)

- The source of electricity will have **two terminals**: a positive terminal (typically represented in red) and a negative (typically represented in black) terminal.
- The source of electricity (whether it is a generator, battery, etc.) will want to push electrons out of its negative terminal **at a certain voltage**. For example, an AA battery typically wants to push electrons out at 1.5 volts.
- The electrons will need to flow from the negative terminal to the positive terminal through a copper wire or some other conductor. When there is a path that goes from the negative to the positive terminal, you have a **circuit**, and electrons can flow through the wire.
- You can attach a **load** of any type (a [light bulb](#), a [motor](#), a [TV](#), etc.) in the middle of the circuit. The source of electricity will power the load, and the load will do its thing (create light, spin a shaft, generate moving pictures, etc.).

The basic circuit of solar panel and motor is shown below. For the purposes of the investigation in this lesson, the resistor would represent the motor or load.

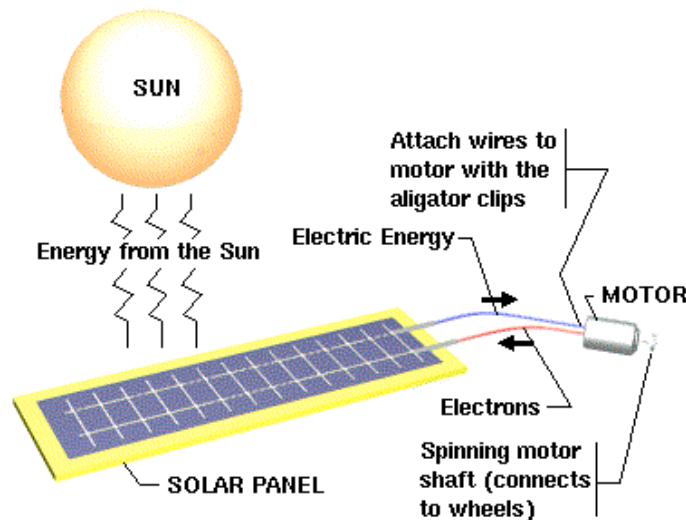


Figure 2: Solar Panel motor configuration

Source: http://eagle.chimacum.wednet.edu/middle/jss/Course_SolarPanel.htm

How Does A Solar Panel Work?³

When you look at the diagram above, you might ask, "How does the solar panel turn the sun's energy into electric energy?" The solar panel is made of a sandwich of two materials called *semiconductors*. Each material is made of millions of atoms. As you might already know, atoms have a positively charged *nucleus*, and negatively charged *electrons* which spin around the nucleus. When these two materials are put together in a sandwich, an interesting thing happens: electrons become pulled from the bottom half. But there's a problem. The electrons are all attached to atoms, and the atoms won't let go very easily. This is where the sun's energy helps out. If we shine sunlight on these

³ Chimacum School District Junior Solar Sprint Course.
http://eagle.chimacum.wednet.edu/middle/jss/Course_SolarPanel.htm, accessed 11 January 2006.

materials, the sunlight has enough energy to knock the electrons off of the atoms. The electrons will then be free to be pulled to the top of the sandwich.

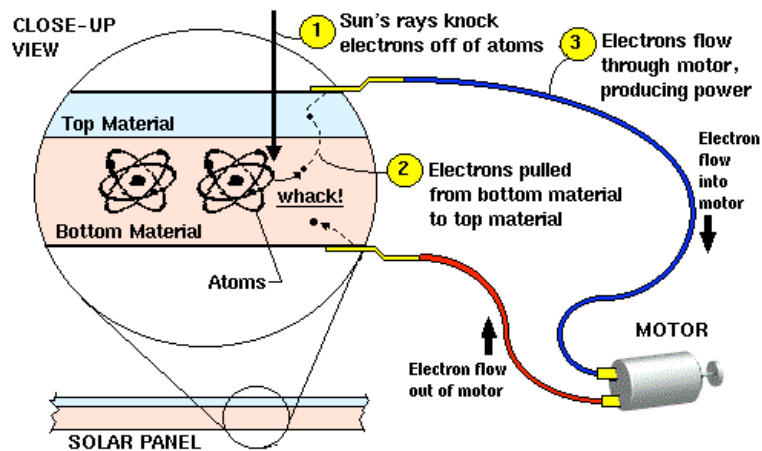


Figure 3: How a solar panel works

Notes on Part 2:

To be able to complete Part 2, students need to wire the circuit shown here:

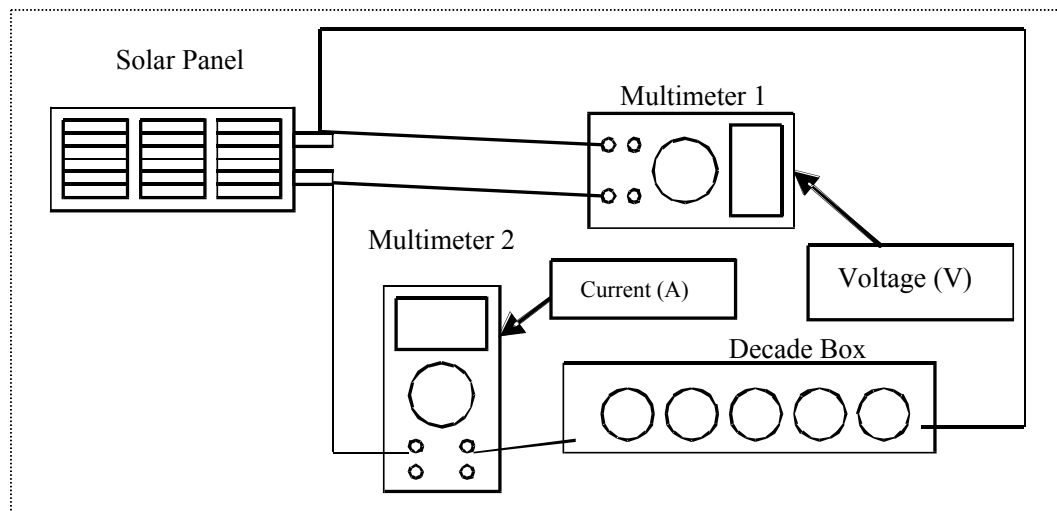


Figure 4. Solar cell circuit for use in Part 2.⁴

In Figure 1, the resistor (labeled decade box) is in series with the solar cell but the multimeter is in parallel with the resistor. In this condition the multimeter can measure V , but not I . You cannot use one multimeter and measure both V and I at the same time.

⁴ Graphic created by Professor Andy Lau of Penn State University's College of Engineering.

Construction of the Gnomon Stand

To allow students to experiment with solar orientation and angle of incidence without the hassle of trigonometry, Penn State Professor Andy Lau has devised the following set-up that is easy to make and reusable from year-to-year. A piece of 2' X 3' cardboard and a nail are all that you need to get going.

1. Attach a 2" gnomon of your choice to the cardboard.
2. Trace 8 circles onto the cardboard with the radii listed in the table below (The radii listed are for a 2" gnomon.)
3. Label the circles for each angle of incidence beginning with 10 at the smallest circle.

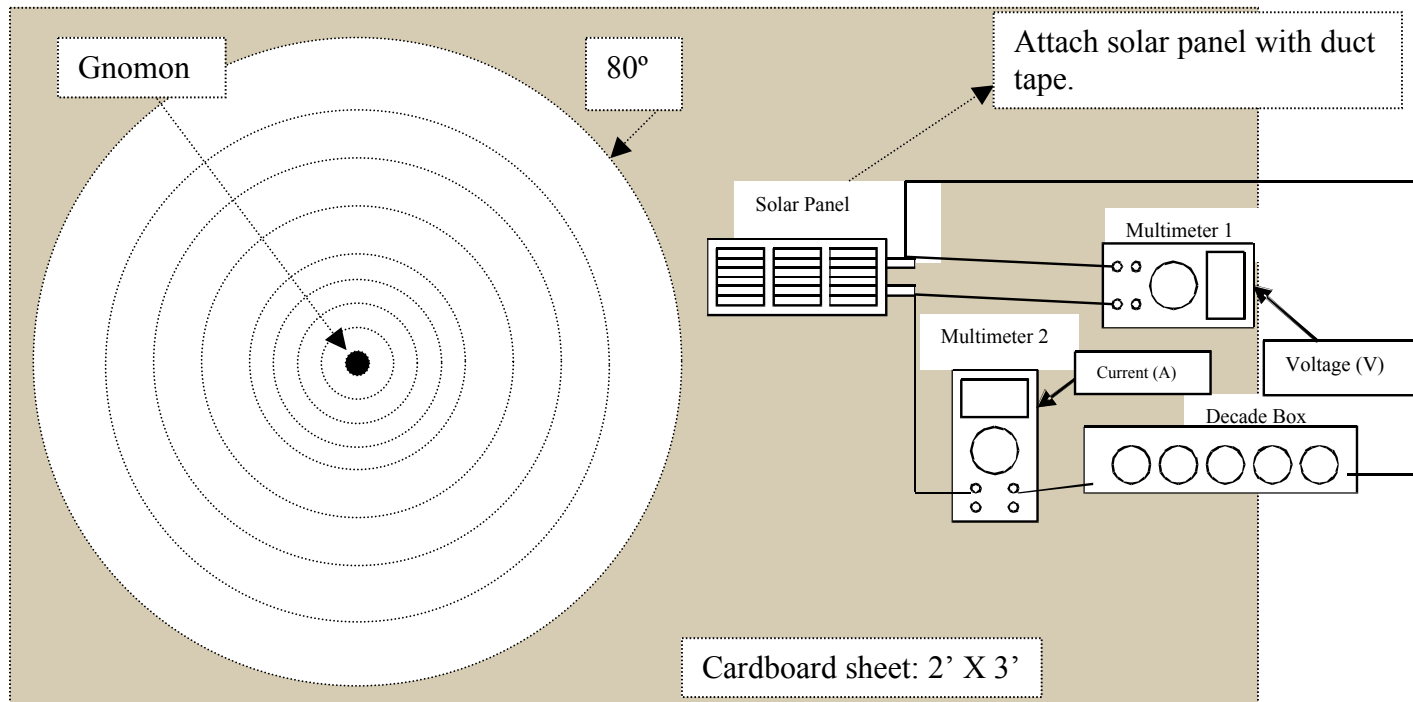


Figure 5. Gnomon Stand Diagram.

Table 1. Derived Circle Radii for a Two-Inch Gnomon

Angle of Incidence	tan of angle	Approximate Radius (inches)
10	0.176	0.325
20	0.364	0.728
30	0.577	1.154
40	0.839	1.678
50	1.192	2.4
60	1.732	3.5
70	2.747	5.5
80	5.671	11.4

This strategy works with the help of a little trigonometry. The gnomon acts like a normal that we would draw to the solar panel. Therefore, the length of the shadow cast by the gnomon can be our indicator of the angle of incidence as the attached panel is tilted. When the tip of the shadow created by the gnomon is on one of the circles, sunlight is

striking the panel at the corresponding angle of incidence. See Figure 6 below for the visualization of the relationship, $\tan(\text{angle } A) = X/h$.

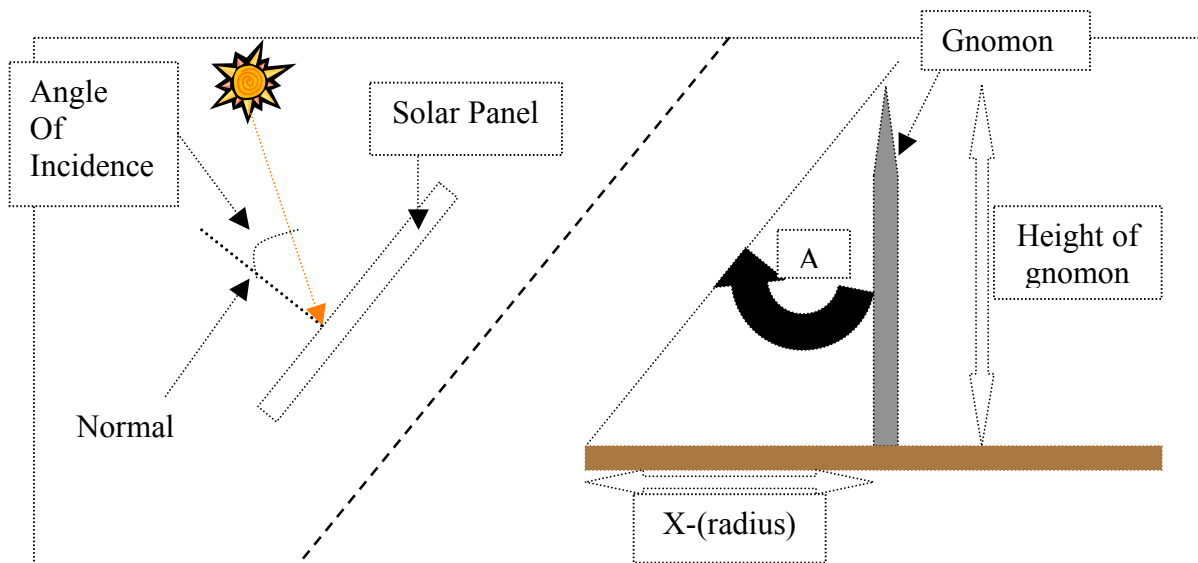
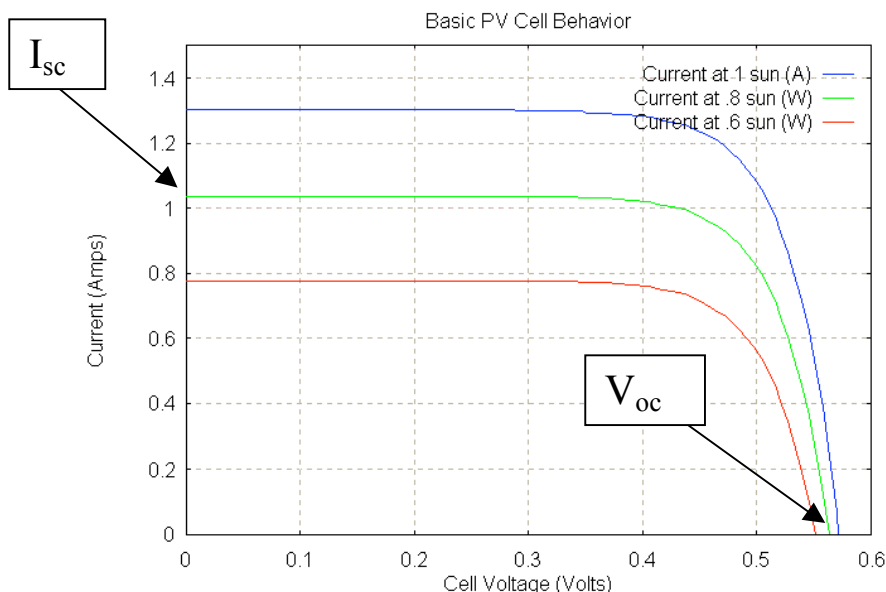


Figure 6. Diagram supporting the relationship used to derive circle radii.

Data Collection and Analysis: A suggested way for students to analyze their data is to plot two curves from the data collected in Part 2. The idea that orienting the panel towards the sun is intuitive for the most part; however, an important point to make, especially if students are trying to maximize the power output from the solar cell, is that there is a “Maximum Power Point” at which the cell operates.

The following graph from Chuck Wright’s Solar Panel exploration represents the behavior of a solar cell at particular intensities of solar radiation. Students will be creating one of these curves using data from Table 1. The explanations of short circuit and open circuit are included below the graph.

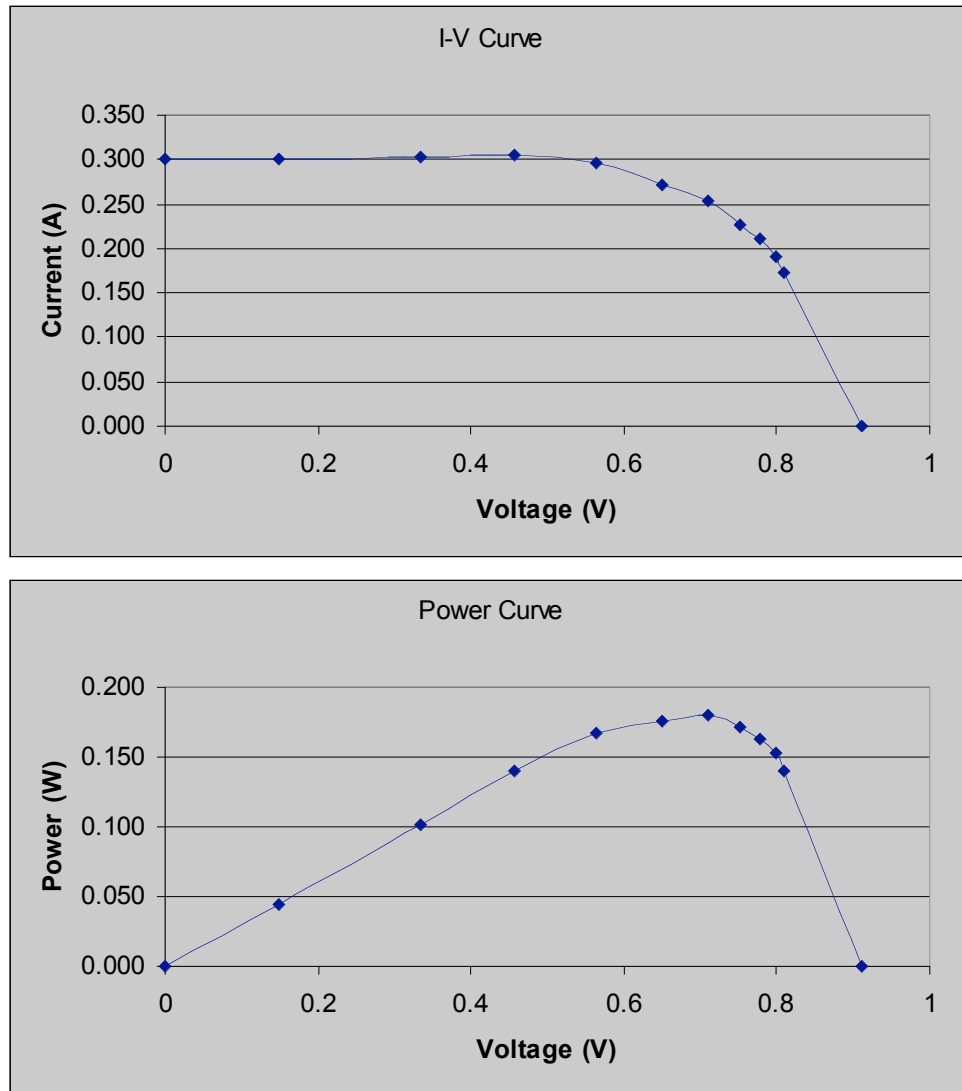


Note the point at which a curve intersects the vertical axis. This is known as the short circuit condition, and it defines how the cell operates if a wire is connected between its terminals, shorting it out. The current flow here is known as I_{sc} . Because there is no voltage, the cell delivers no power.

Now note the point at

which a curve intersects the horizontal axis. This is where the cell operates if it is unconnected. This is known as the open circuit condition, and the voltage produced is denoted V_{oc} . Because the current is zero, no power is delivered.

These following 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.⁵

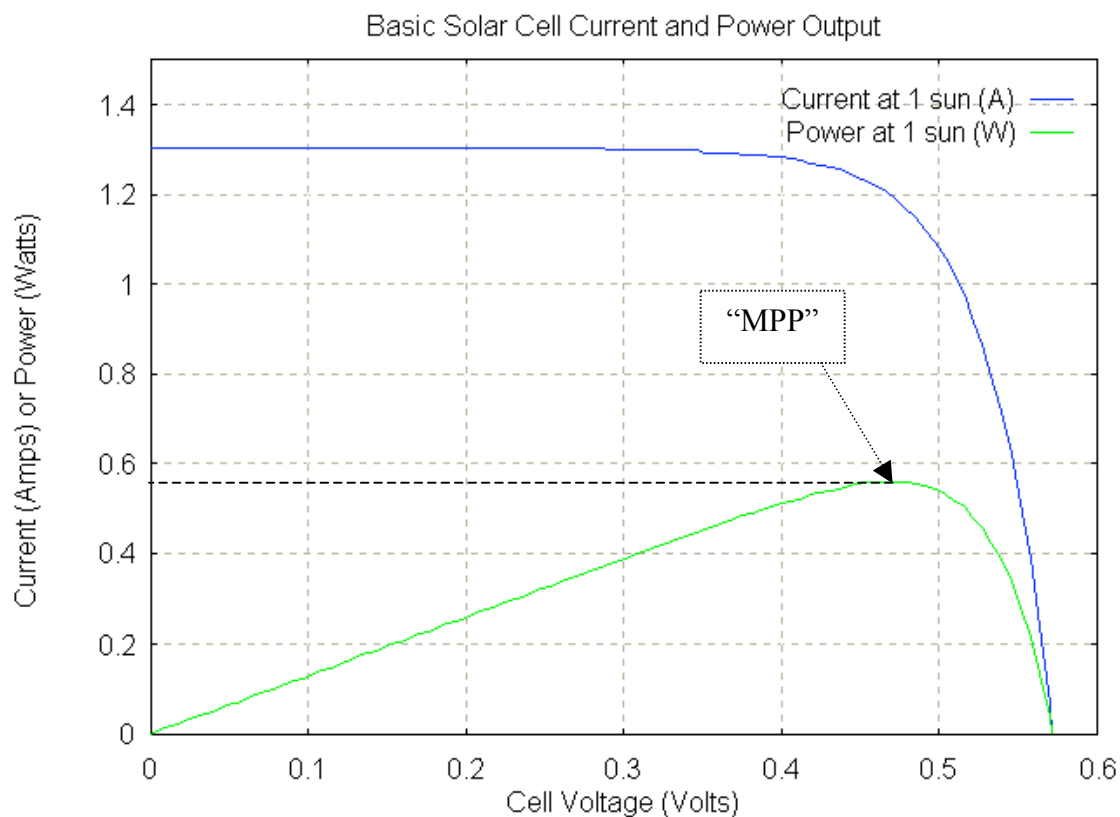


Source:

http://www.powernaturally.org/Programs/SchoolPowerNaturally/InTheClassroom/kitlessonsdocs/Solar_Kit_Lesson_11_Measpowermax.doc

⁵ School Power Naturally. "Solar Kit Lesson 11." Accessed 5 January 2006, http://www.powernaturally.org/Programs/SchoolPowerNaturally/InTheClassroom/kitlessonsdocs/Solar_Kit_Lesson_11_Measpowermax.doc

Note that the power is maximum at a single operating point. This is known as the "Maximum Power Point", or MPP. An important point to remind students is that, "If one is to get the most out of their solar cells, it is essential to operate around the MPP".⁶ This is particularly of interest if students may be utilizing a solar panel them to build a solar-powered car as a next step.



⁶ Wright, Chuck. "Solar Sprint PV." Accessed 7 January 2006, <http://chuck-wright.com/SolarSprintPV/SolarSprintPV.html>.