To our teachers:

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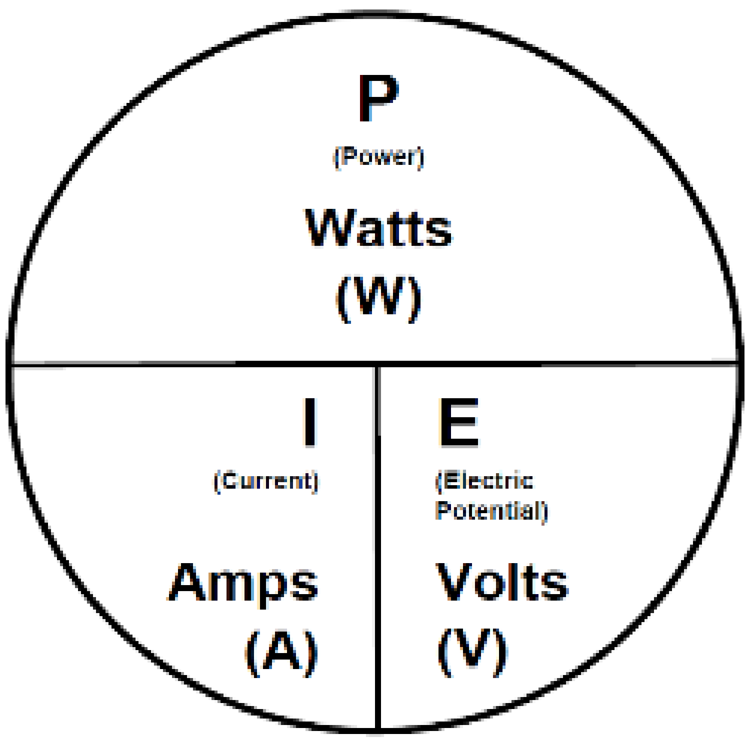
Center for Renewable Energy Advanced Technological Education

SOLAR PV:
MODULE AMPS AND VOLTS

INSTRUCTOR'S ANSWER KEY

1. Ohm's Law



1a. **Power** is the rate at which work is done (and energy is used) in an electrical circuit. Write the unit and abbreviation for **Power**.

*** Watts, W**

1b. **Current** is the rate at which electrons flow through an electrical circuit. Write the unit and abbreviation for **Current**.

*** Amps, A**

1c. **Electrical Potential** is the amount of potential energy available to push electrons through an electrical circuit. Write the unit and abbreviation for **Electrical Potential**.

*** Volts, V**

2. Your Solar PV Module

2. Write notes on your **Solar PV Module** below**.** Here are some notetaking prompts:

- How does your module work?
- How is your module wired?
- What is a module nameplate?

*** Students should note here what you emphasize from the Student Orientation PowerPoint.**

3. Your PV Module Nameplate

What are the **Standard Test Conditions (STC's)** for a solar PV module?

3a. Module **Temperature** of:

*** 25° Celsius**

3b. Light intensity (**Irradiance**) of:

*** 1000 Watts / meter^2**

3c. **Atmospheric Mass** of:

*** 1.5**

3d. **Open Circuit Voltage** is the electric potential (volts) of your module in an open circuit condition. This is the maximum Volts the module can produce at STC. What is your module's **Voc**?

*** Voc for your module**

3e. **Short Circuit Current** is the current (amps) your module will produce in a short circuit condition. This is the maximum Amps the module can produce at STC. What is your module's **Isc**?

*** Isc for your module**

3f. **Maximum Power Voltage** is the maximum electric potential (volts) of your module when connected to complimentary equipment at STC. What is your module's **Vmp**?

*** Vmp for your module**

3g. **Maximum Power Current** is the maximum current (amps) your module will produce when connected to complimentary equipment at STC. What is your module's **Imp**?

*** Imp for your module**

3h. **Maximum Power Point** is the maximum power (Watts) your module will produce when connected to complimentary equipment at STC.

Since watts = volts X amps, Pmax = Vmp X Imp.

What is your module's **Pmax**?

*** Pmax for your module**

4. Sacrificial Leads

4. Write notes on your **Sacrificial Leads** below. Here are some notetaking prompts:

- Why do we use them?
- How do we use them?

*** Students should note here what you emphasize from the Student Orientation PowerPoint.**

5. Your Tools of the Trade

5a. Write notes on your **Pyranometer** below. Here are some notetaking prompts:

- Why do we use it?
- How do we use it?
- What is its unit of measure?

*** Students should note here what you emphasize from the Student Orientation PowerPoint.**

5b. Write notes on your **Multimeter** below. Here are some notetaking prompts:

- How do we use it?
- What is its unit of measure?

*** Students should note here what you emphasize from the Student Orientation PowerPoint.**

5c. Write notes on your **Amp Clamp** below. Here are some notetaking prompts:

- Why do we use it?
- How do we use it?
- What is its unit of measure?

*** Students should note here what you emphasize from the Student Orientation PowerPoint.**

6. Module Positioning

6a. **Solar Azimuth** is the compass degree (0° - 360°) that describes the position of the sun along the horizon at any given time. Approximately what will be <u>your module's</u> azimuth during this lab activity?

*** Your answer is time and location dependent.**

6b. **Solar Altitude (or Solar Elevation)** is the vertical angle formed between the horizon and the center of the sun's disc at any given time. Approximately what will be <u>the sun's</u> altitude during this lab activity?

*** Your answer is time and location dependent.**

Pre-lab Questions

7. Answer the following questions about solar PV modules at Standard Testing Conditions.

7a. A module's Maximum Power Voltage (Vmp) is 58 Volts and its Maximum Power Current (Imp) is 5.7 amps. What is the module's Maximum Power (Pmax)? Give your answer with its correct unit label.

*** 330.6 Watts DC [58.0 Volts x 5.70 Amps]**

7b. A module's Pmax is 50 Watts DC and its Imp is 2.85 Amps. What is the module's Vmp? Give your answer with its correct unit label.

*** 17.5 Volts [50 Watts / 2.85 Amps]**

7c. A module's Vmp is 30.6 Volts and its Pmax is 240 Watts DC. What is the module's Imp? Give your answer with its correct unit label.

*** 7.84 Amps [240 Watts / 30.6 Volts]**

8. As you have learned, standard conditions for testing solar modules are:

- Module temperature of 25ºC (77ºF).
- Light intensity (irradiance) of 1000 watts/m^2.
- Atmospheric air mass of 1.5.

Explain why solar modules need to be tested under the same set of environmental conditions.

*** Tested under the same set of controlled environmental conditions, we have a starting point for comparing the performance of every PV module that's manufactured to any other.**

9a. Why do dual-axis tracking solar PV arrays generate more electricity than their fixed-in-position counterparts?

If needed, do a little research comparing and contrasting fixed vs. dual axis tracking solar PV arrays if you don't know much about them. In constructing your answer to the question, you must use each of these terms at least once:

- fixed array
- tracking array
- sun
- solar azimuth
- ideal tilt angle
- perpendicular

Highlight or underline the terms as you use them in your answer to the question.

*** A dual axis tracking array will almost always generate more electricity than a fixed array, all other factors kept equal. This is because a dual axis tracking array moves to keep the face of its array perpendicular to the rays of the sun throughout the day. Another way of saying this is that it maintains the ideal solar azimuth and ideal tilt angle throughout the day. Constantly facing the sun this way, a tracking system is always receiving the maximum sunlight available throughout the day. From moment to moment, it's generating the maximum electricity possible. An array that's fixed in position is seldom generating at its maximum capacity during the day. Its fixed orientation is seldom in the right position to receive sunlight perpendicular to the array.**

9b. Depending on location, dual-axis, or two-axis tracking PV systems produce 20-50% more electricity than their fixed-in-position counterparts. In view of this, why are more residential PV arrays installed today in a fixed position?

*** These answers are not necessarily given in order of importance.**

● A two-axis tracking system is more expensive. It usually has more mounting hardware, it always has a motor and moving parts, and usually have sensors to keep the array facing the strongest sunlight.

● A two-axis tracking system needs periodic checking and routine maintenance. It is almost always more costly to repair than a fixed system.

● In addition, the installed cost per watt of solar has dropped significantly over the years. For this reason, most people choose to install more (less expensive) modules in a fixed position. They can avoid both the short term and long term expenses that come with a two-axis tracking PV system, and often produce more

electricity in the process.

10a. Consider what you know about electrical potential (volts). Without researching, make a prediction. What will happen to volts as irradiance increases?

*** There are numerous predictions possible. The important consideration here is that students think sensibly about what results may occur before beginning the lab.**

10b. Consider what you know about electrical current (amps). Without researching, make a prediction. What will happen to amps as irradiance increases?

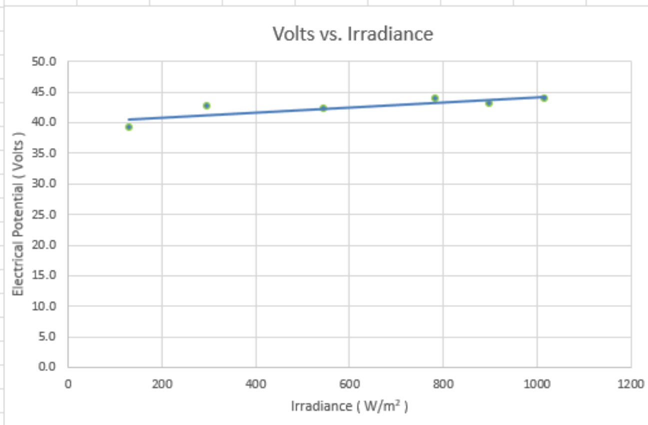
*** There are numerous predictions possible. The important consideration here is that students think sensibly about what results may occur before beginning the lab.**

Lesson Summary Questions

1. Place digital images of the graphs your teacher instructed you to produce where directed, below. Images should be clear and neatly cropped. Arrange your images so they are not broken and separated over two pages.

1a. Lab 1: Volts and Amps vs. Irradiance

Tilt Angle	Irradiance	Volts
150°	130	39.2
130°	296	42.7
90°	784	43.9
60°	1017	43.9
30°	898	43.1
0°	546	42.3



Volts % Increase
8%

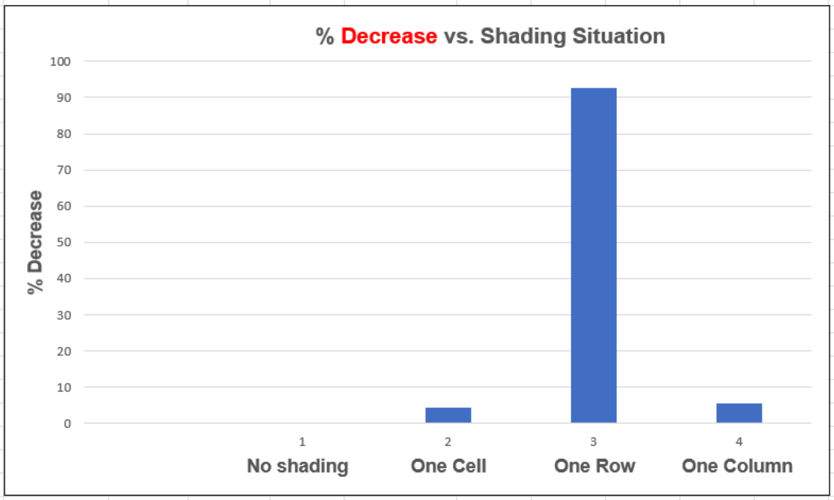
Tilt Angle	Irradiance	Amps
150°	145	0.2
120°	280	1.7
90°	797	4.6
60°	1086	5.5
30°	1000	5.2
0°	583	3.3

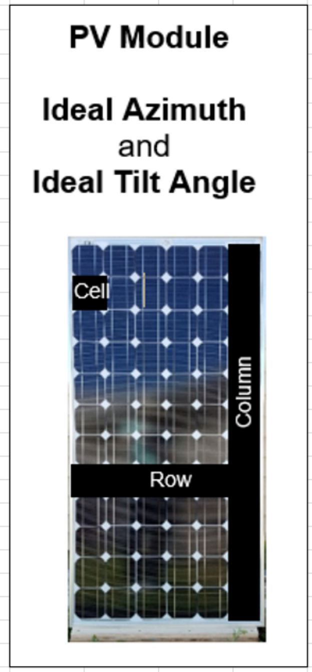
Amps % Increase
1560%

[This data was taken from a full size module. The trends in your data should resemble the trends you see here.]

1b. Lab 2: Shading

Module	Situation	Isc Amps	% Decrease
No shading	1	5.2	0
One cell	2	5.0	4
One row	3	0.4	93
One column	4	4.9	5

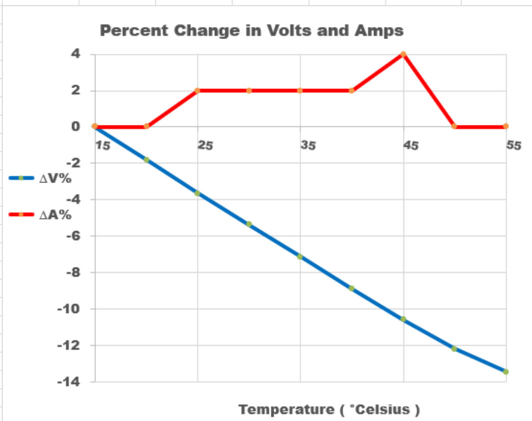


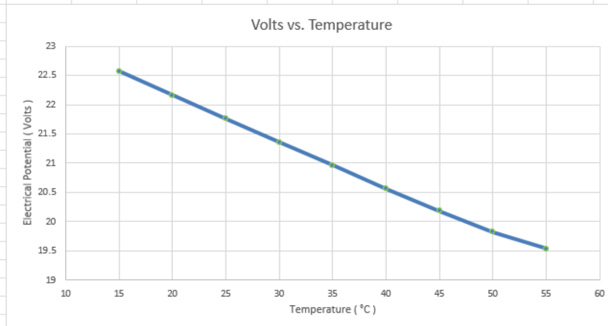


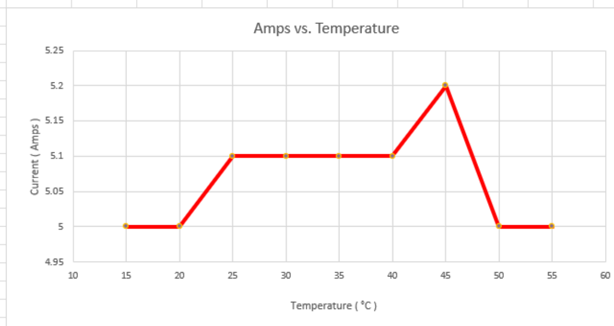
[This data was taken from a full size module. The trends in your data should resemble the trends you see here.]

1c. Lab 3: Volts and Amps vs. Temperature

Temp °C	Volts	ΔV	ΔV%	Amps	ΔA	ΔA%
15.0	22.57	0.00	0.00	5.0	0.00	0.00
20.0	22.16	-0.41	-1.82	5.0	0.00	0.00
25.0	21.76	-0.81	-3.66	5.1	0.10	2.00
30.0	21.36	-1.21	-5.36	5.1	0.10	2.00
35.0	20.96	-1.61	-7.13	5.1	0.10	2.00
40.0	20.56	-2.01	-8.91	5.1	0.10	2.00
45.0	20.18	-2.39	-10.59	5.2	0.20	4.00
50.0	19.82	-2.75	-12.18	5.0	0.00	0.00
55.0	19.53	-3.04	-13.47	5.0	0.00	0.00







[This data was taken from a full size module. The trends in your data should resemble the trends you see here.]

2a. Which environmental condition (irradiance or temperature) primarily affected current (amps)? *** Irradiance affected Current (Amps) the most**.

2b. Explain your answer to 2a. in detail, using specific data from the lab.

*** As can be seen from my data, the higher the irradiance, the higher the Amps (or the lower the irradiance, the lower the Amps).**

3a. Which environmental condition (irradiance or temperature) primarily affected electrical potential (volts)? *** Temperature affected Electric Potential (Volts) the most.**

3b. Explain your answer to 3a. in detail, using specific data from the lab.

*** As can be seen from my data, the lower the temperature, the higher the Volts (or the higher the temperature, the lower the Volts).**

4. In the lab you observed very low current (amps) in low light (irradiance) conditions. However, you observed high electrical potential (volts) in the same low light conditions. Explain why this is important to know and understand as an occupational safety issue for solar PV installers and technicians.

*** A very low light setting may deceive someone into believing there is no danger in working with a solar PV module or array. But electrical potential (volts) can be high even in low light (irradiance) conditions. Under conditions of high electrical potential (volts) there is always the danger of electrical shock.**

5. You placed your module face down in the grass to connect and disconnect sacrificial leads. Using what you learned during the lab, explain why you placed the front of your module in such a low irradiance situation to do this.

*** From our lab we observed that even at low light the solar module was energized. Our electrical potential (volts) measurements were relatively high—high enough to deliver an electric shock. But when we placed the module face down in the grass, we saw current (amps) measurements drop dramatically. When current is very low, the risk of module arcing is significantly decreased. For this reason having the module face down in the grass promotes the best student safety and equipment protection possible and prevents module arcing or carbonization of quick connectors while we perform the lab.**

6. In **Lab 2: Shading**, you only took measurements of current in amps. You did not measure electrical potential in volts. Explain why you measured only amps and didn't measure volts for this lab. Make specific references to lab results in your answer.

*** As we saw in the lab, Volts is primarily influenced by temperature. Regardless of shading, Volts measurements will be similar. As we also saw, Amps are primarily influenced by irradiance. Shading will (and did) affect Amps more.**

7a. Most people assume that shade over just a small portion of a module will not affect its performance very much. Is this true? Explain your answer completely, making reference to lab results.

*** This is not true. From our results it appears a small amount of shade extending across the entire module will reduce current (and as a result, power) to nearly zero. Shading that doesn't extend across the module will reduce current (and as a result, power), but not nearly so much.**

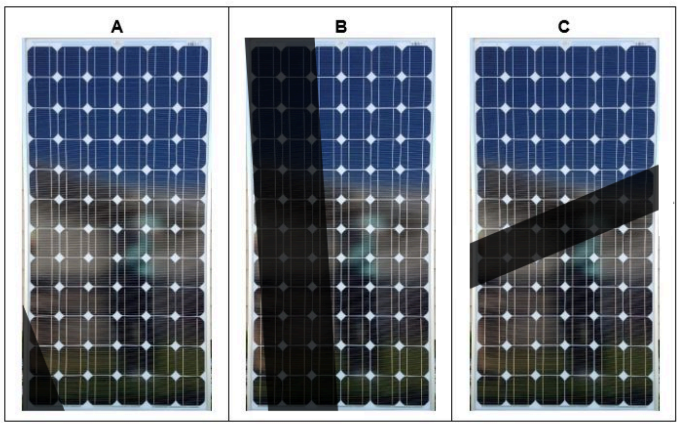
7b. Most people would reason that module performance will fall in proportion to the number of PV cells covered. Or, that it will fall in proportion to the percentage of module surface covered. Explain why this is <u>not true</u>, using specific data from the lab.

*** By shading across the module, current (and as a result, power) is reduced to nearly zero. However, covering more cells vertically on the module did not reduce current (and as a result, power) nearly so much.**

7c. Consider the shading profile that decreased module performance the most. That profile was not the one that covered the greatest number of module cells. Explain why that particular shading profile had such a significant effect on module performance.

The shading profile that had the most significant effect on module performance was not the one that covered the greatest number of module cells. Rather it was the profile that extended across the module. Current (and as a result, power) was reduced to nearly zero. This is because the shading interrupts all of the electrical series connections running through the module.

8. Isc measurements for each shading profile (below) were taken at the same time, at the best performing azimuth and tilt angle.



Which choice (A, B, or C) will probably cause the largest reduction in module amps (and power output)? Explain why the shading profile you chose would produce the biggest decrease in module performance.

Your complete answer must mention and use this version of Ohm's Law:

Amps X Volts = Power

*** C would cause the greatest reduction in amps (and power output). We observed this in the lab. Shading similar to condition C from our lab reduced module current to nearly zero. Shading profile C (across the face of the module) interrupts all of the electrical series connections running through the module. Lab conditions similar to A and B didn't cause as big a decrease in module amps. Since current is nearly zero, very little power output from the module is possible with shading profile C. Ohm's law, amps X volts = power tells us this. Amps (close to zero) X volts = power (also close to zero).**

[Recall in Lab 1 that volts measures were relatively high even at extremely low irradiance levels.]

9. By now you know the electrical power output of a PV module or array is calculated this way:

Electric Potential **(Volts) X** Current **(Amps) =** Electric Power Output **(Watts)**

The table below describes four different sets of environmental conditions. With each set of conditions, assume you have a two-axis tracking solar PV array that is always ideally positioned to harvest sunlight.

Situation Number:	Sunlight Condition	Temperature Condition	PV Array Position
1.	Very Low Sunlight	Very Low Temperature	Ideal Position
2.	Very Low Sunlight	Very High Temperature	Ideal Position
3.	Very High Sunlight	Very Low Temperature	Ideal Position
4.	Very High Sunlight	Very High Temperature	Ideal Position

9a. In which set of conditions will the PV array output be the highest? Explain your answer by making reference to your experience in this lab activity.

*** Power output will be highest with Very High Sunlight (resulting in high amps) and Very Low Temperature (resulting in high volts) at an ideal azimuth and tilt angle.**

9b. In which set of conditions will the PV array power be the lowest? Explain your answer by making reference to your experience in this lab activity.

*** Power output will be lowest with Very Low Sunlight (resulting in low amps) and Very High Temperature (resulting in low volts) at an ideal azimuth and tilt angle.**

9c. Why is it important to know the extremes of sunlight and temperature? Explain your answer completely and in detail.

*** Solar PV balance of system complimentary equipment needs to be properly designed for extremes of current (amps) and electrical potential (volts). A well planned system has the rated capacities of its components properly matched for safety, to avoid equipment damage, and to perform effectively.**

10. Imagine you perform this lesson activity under conditions of strong, direct sun and no clouds. At any time of the day which module position or orientation would achieve the best performance? Explain your answer choice completely, using information you learned in this lesson.

*** At any time of day, the best module performance will be achieved with the sun's rays hitting perpendicular to the face of the module. Irradiance will always be highest in this situation, which was observed in the lab.**

This situation is always achieved with the module pointing toward the sun (ideal azimuth) and tilted toward the sun (ideal tilt angle = 90° - the sun's altitude).

11. Most PV modules manufactured today have quick connector wire leads like those you worked with in the lab activity. Quick connectors snap together, making wiring simpler and faster. Connections are sure and secure, they meet National Electric Code requirements, they're UL certified, and most electrical inspectors prefer to see them used. Quick connectors resist corrosion and environmental degradation from the elements. Once connected, they will not disconnect without the use of an unlocking tool.

Quick connectors are also "finger safe." This means you cannot touch any energized part of the electrical connection. Explain why this was an important consideration for you in this lab activity, and why it is an important consideration for solar PV installers.

*** Finger safe quick connectors prevent accidents. It should not be a surprise that even experienced electricians can make mistakes in wiring and connecting modules. Finger**

safe connectors prevent you (and solar PV installers) from being shocked by electricity in the wire connection process.

12. Describe the most important idea, concept, principle, or fact you learned while completing this this part of the lesson. Explain why it is important for you (and probably other people) to know and understand.

*** A variety of answers are acceptable here. Answers should be meaningful and fully explained.**