Name: ______________________________

Date: ____ / ____ / ____ Class Hour: ____

SOLAR PV: MODULE PERFORMANCE

Introduction

Like most people, you probably understand that a solar PV module works best in lots of sunlight. But do you know how an array of solar PV modules should be positioned to get maximum sunlight in the first place? What about shading? Sometimes a small amount of shading on a PV array is unavoidable. But is all shading the same? What other environmental factors significantly affect module performance and in what ways?

In this lesson, you'll answer these questions by taking common industry measurements on a solar PV module. In doing so, you'll use tools of the trade in everyday use in the solar industry to measure:

- How much sunlight is hitting a module's surface
- Module temperature
- Module electric potential (Volts)
- Module current (Amps)

By the conclusion of the lesson you'll know the most important factors affecting solar PV module performance, and the critical relationships between them.

Materials

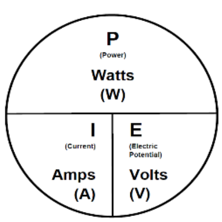
- Solar PV Module
- Multimeter with alligator leads
- Pyranometer
- Protractor
- High intensity LED Lamp (optional)
- Wire connector
- Amp clamp
- Infrared thermometer
- Pre-cut module shading materials

Prelab Preparation

On the following four pages, note and highlight important concepts and equipment your teacher reviews before performing this lab activity. Enter specific values into the tables provided where indicated.

Electrical Measurements

- Volts
- Amps
- Watts
- Relationships



Using A Multimeter

- Measuring DC Volts
- Measuring DC Amps

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Power (P) is measured in units of **Watts (W)**

Power is the rate at which work is done (and energy is used) in an electrical circuit.

Current (I) is measured in units of **Amps (A)**

Current is the rate at which electrons flow through an electrical circuit.

Electric Potential is measured in units of **Volts (V)**

Electric Potential is the amount of potential energy available to push electrons through an electrical circuit.

Your Solar PV Module

- How it works
- How it's wired
- Nameplate
- Standard Test Conditions
- Voc
- Isc
- Other nameplate values

*

Standard Test Conditions STC

Standard conditions for testing solar modules:

- Module temperature of 25ºC (77ºF).
- Light intensity (irradiance) of 1000 Watts/m2.
- Atmospheric air mass of 1.5.

Open Circuit Voltage Voc

*

Electric potential (Volts) of your module in an open circuit condition. This is the maximum Volts the module can produce at STC.

Short Circuit Current Isc

*

Current (Amps) your module will produce in a short circuit condition. This is the maximum Amps the module can produce at STC.

Maximum Power Voltage Vmp [Vmpp] [Vpm]

*

Maximum electric potential (Volts) of your module when connected to complimentary equipment at STC.

Maximum Power Current Imp [Impp] [Ipm]

*

Maximum current (Amps) your module will produce when connected to complimentary equipment at STC.

Maximum Power Point Pmax [Pmp] [Pmpp]

*

Maximum power (Watts) your module will produce when connected to complimentary equipment at STC.

Since Watts = Volts X Amps, Pmax = Vmp X Imp.

Your Solar PV Module

- Measuring Voc
- Polarity
- Measuring Isc
- Wire connector
- Zeroing

Using A Pyranometer

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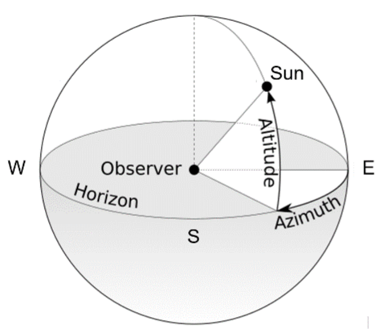
Using An Infrared Thermometer

*

Module Positioning

- What is “Ideal?”
- Azimuth (direction)
- Altitude (elevation)



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Module Positioning

- Tilt Angle
- How to locate "Ideal"

*

Solar Azimuth

*

Solar azimuth is the compass degree (0° - 360°) that describes the position of the sun along the horizon at any given time.

Solar Altitude (Solar Elevation)

*

Solar Altitude is the vertical angle formed between the horizon and the center of the sun's disc at any given time.

Ideal Tilt Angle (Lab)

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The Ideal Tilt Angle we'll use for this lab:

(90°) **—** (sun's current Solar Altitude) **=** Ideal Tilt Angle

Prelab Preparation: Summary Questions

1. Complete the following solar module nameplates:

1a.

Detail	**Answer**
MAXIMUM POWER STC:	* watts DC
MAXIMUM POWER VOLTAGE VMP (V):	58.0 Volts
MAXIMUM POWER CURRENT IMP (A):	5.70 Amps

1b.

Detail	**Answer**
MAXIMUM POWER STC:	50 watts DC
MAXIMUM POWER VOLTAGE VMP (V):	* Volts
MAXIMUM POWER CURRENT IMP (A):	2.85 Amps

1c.

Detail	**Answer**
MAXIMUM POWER STC:	240 watts DC
MAXIMUM POWER VOLTAGE VMP (V):	30.6 Volts
MAXIMUM POWER CURRENT IMP (A):	* Amps

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

- Module temperature of 25ºC (77ºF).
- Light intensity (irradiance) of 1000 Watts/m2.
- Atmospheric air mass of 1.5.

Explain why is it important that all solar modules be tested under the same set of environmental conditions?

*

3a. 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 these terms at least once:

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

Underline the terms as you use them in your answer to the question.

*

3b. Dual-axis, or two-axis tracking PV systems usually produce about 50% more electricity than their fixed-in-position counterparts. In view of this, why are more fixed PV arrays installed today?

*

Lab Activity, Part One: Experimenting with temperature, irradiance, and tilt angle

Keep your solar PV module in a cool, shaded place during the entire Practice Portion of this procedure (steps **P1** - **P12**). After you've set up and practiced with your module in the shade, you'll take your first set of lab measurements in full sun. The first full sun measurements need to be taken quickly with your module as cool as possible. Once moved into the sun, your module warms up fast.

P1. Gather and familiarize yourselves with how to use the equipment for the lab activity. If you are unsure about how to set up your module or use any piece of equipment, talk with your teacher right away.

Practicing a Temperature Measurement:

P2. Practice taking the temperature on the back of your module so that it can be done quickly and efficiently later. The infrared thermometer should be used about 8 inches from the back of the module.

Practicing an Irradiance Measurement:

P3. Hold the pyranometer along the edge of your module. Arrange the face of your pyranometer and the front face of the module in the same plane. Take the Irradiance measurement on the face of your module.

P4. Does your measurement make sense? Discuss your measured value to resolve any questions within your group. If necessary, talk with your teacher to resolve questions.

Practicing a Voc Measurement:

P5. While taking a Voc measurement, never let the exposed copper ends of your module wires touch anything except the alligator clips of your multimeter.

P6. Take the Electric Potential (Volts) measurement on your module in an open circuit condition (Voc). Verify that you have a positive polarity with your measurement.

P7. Does your measurement make sense? Discuss your measured value to resolve any questions within your group. If necessary, talk with your teacher to resolve questions.

Practicing an Isc Measurement:

P8. **This step must be done by turning your module away from the sun while performing the lab activity.** Without touching the exposed copper, use the wire connector to connect the copper ends of the module wires together.

P9. Take the Current (Amps) measurement on your module in a short circuit condition (Isc) in the shade.

P10. Does your measurement make sense? Discuss your measured value to resolve any questions within your group. If necessary, talk with your teacher to resolve questions.

P11. **This step must be done by turning your module away from the sun while performing the lab activity.** Remove the wire connector from the ends of your module's wires. Separate the wires without touching the bare copper ends. Do not let the exposed copper ends touch anything (except your alligator clips for Voc measurement) until the next time you have to connect them together.

Performing the Lab:

Find a convenient location where your module will be in full sunlight. Prepare to face your module toward the sun (approximate azimuth). Have your protractor available for measuring your module's Ideal Tilt Angle when needed.

1. Reminder One: Take all four measurements for **Position 1.** described in

Table 1. before moving on to **Position 2.** Then take all measurements for

Position 2. described in **Table 1.** before moving on to **Position 3.** Continue this way throughout the lab activity. In this way your measurements at each position will match the best, especially if there are clouds in the sky.

2. Reminder Two: You'll connect and disconnect your module's wires with the wire connector five times during this lab. **Each time you connect and disconnect with the wire connector, your module must be turned away from the sun (follow steps P8 and P11).**

3. Reminder Three: Prepare to take your first set of measurements in **Position 1.** quickly, while the module is as cool as possible. Your module will warm up quickly in full sun.

4. Take your module and equipment to your full sun location. Set up your module in **Position 1: Ideal direction** and **ideal tilt angle**, **module cool**. Take your measurements across the table quickly. Enter them in your data table.

5. Complete the remainder of your lab activity, position by position, as directed. After completing **Position 1**, speed in taking your measurements is no longer critical.

6. After taking your final measurement (5d), follow these directions. **This step must be done with your module turned away from the sun.** Remove the wire connector from the ends of your module's wires. Separate the wires without touching the bare copper ends.

7. Put your equipment away as directed by your teacher.

Table 1.

Module position or orientation ▼	a.  Irradiance **W/m^2**	b.  Temperature **ºC**	c.  Electric Potential (Volts) open circuit condition **Voc**	d.  Current (Amps) short circuit condition **Isc**
1. Ideal direction and **ideal tilt angle**, **module cool** *Ideal azimuth and ideal tilt angle*	*	*	*	*
2. Ideal direction and **Vertical** (module upright at 90º) *Ideal azimuth and 90º tilt angle*	*	It is not necessary to take a **temperature** measurement on your module here.	It is not necessary to take a **Volts** measurement on your module here.	*
3. Horizontal (face up, flat on the ground) *Azimuth doesn't matter and 0º tilt angle*	*	It is not necessary to take a **temperature** measurement on your module here.	It is not necessary to take a **Volts** measurement on your module here.	*
4. Facing north and **vertical** (no sunlight hitting module front) *0º azimuth and 90º tilt angle*	*	It is not necessary to take a **temperature** measurement on your module here.	It is not necessary to take a **Volts** measurement on your module here.	*
5. Ideal direction and **ideal tilt angle**, **module warm** *Ideal azimuth and ideal tilt angle*	*	*	*	*

Lab Activity, Part One: Summary Questions

1a. Which environmental condition (irradiance or temperature) primarily affected Current (Amps)? *

1b. Explain your answer to 1a. in detail, using specific data from the lab.

*

2a. Which environmental condition (irradiance or temperature) primarily affected Electric Potential (Volts)? *

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

*

3. Imagine you were to perform this lesson activity in a condition of perfect sun with no clouds. Which module position or orientation would achieve the best performance? Explain your answer choice completely, and in detail.

*

4. Most PV modules manufactured today have quick connect wire leads. Quick connectors snap together, make 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 it is an important consideration for solar PV installers. Also, explain what you did during the lab activity to avoid this risk.

*

5. By now you know that 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.

Environmental Conditions: Sunlight	Environmental Conditions: Temperature	PV Array Orientation
Very Low Sunlight	Very Low Temperature	Ideal
Very Low Sunlight	Very High Temperature	Ideal
Very High Sunlight	Very Low Temperature	Ideal
Very High Sunlight	Very High Temperature	Ideal

5a. 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.

*

5b. 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.

*

5c. Why is it important to know the extremes of sunlight and temperature? Explain your answer completely and in detail.

*

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

- Module temperature of 25ºC (77ºF).
- Light intensity (irradiance) of 1000 Watts/m2.
- Atmospheric air mass of 1.5.

Why were the environmental conditions of temperature and irradiance selected for standard testing (especially compared to a variety of other environmental conditions that could have been selected)? [You may ignore the standard test condition of atmospheric air mass in answering this question.]

*

7. 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.

*

Lab Activity, Part Two: Experimenting with module shading

Place your module in a convenient location where it will be in full sunlight. Face the module toward the sun (approximate azimuth). Place your protractor at the base of the module stand for measuring your module's Ideal Tilt Angle when needed.

1. Reminder One: Take all four measurements for **Position 6.** described in

Table 2. before moving on to **Position 7.** Then take all four measurements for **Position 7.** described in **Table 2.** before moving on to **Position 8.** Then take all four measurements for **Position 8.** In this way your measurements at each position will match the best, especially if there are clouds in the sky.

2. Reminder Two: You'll connect and disconnect your module's wires with the wire connector three times during this lab. **Each time you connect and disconnect with the wire connector, your module must be turned away from the sun (follow steps P8 and P11).**

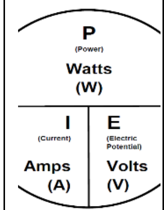
3. Take your module to **Position 6: Ideal direction**, **ideal tilt angle**, and **one cell shaded**. Take the measurements across the table (a-d). Enter them in your data table.

4. Complete the remainder of your lab activity, position by position, as directed.

5. After taking your final measurement (8d), follow these directions. **This step must be done with your module turned away from the sun.** Remove the wire connector from the ends of your module's wires. Separate the wires without touching the bare copper ends.

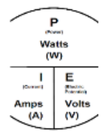
6. Put your equipment away as directed by your teacher.

Table 2.

Module position or orientation ▼	**a.**  Irradiance **W/m^2**	**b.**  Temperature **ºC**	**c.**  Electric Potential (Volts) open circuit condition **Voc**	**d.**  Current (Amps) short circuit condition **Isc**	**e.** 
6. Ideal direction (azimuth), **ideal tilt angle**, and **one <u>cell</u> shaded**	*	*	*	*	*
7. Ideal direction (azimuth), **ideal tilt angle**, and **one <u>row</u> shaded**	*	*	*	*	*
8. Ideal direction (azimuth), **ideal tilt angle**, and **one <u>column</u> shaded**	*	*	*	*	*

Lab Activity, Part Two: Summary Questions

1. Label **column e.** in **Table 2**. as shown to the right. Then go through each row (module position or orientation) and perform the Watts calculation to complete the table.

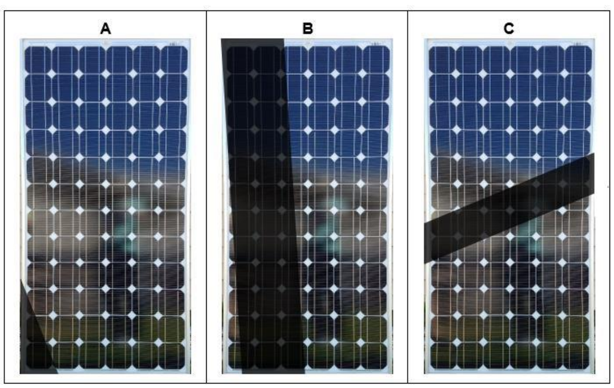
e.
 Module Power or output **Watts**

*

2. Consider **Table 2**. 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 your results.

*

3. Which of these types of shading would produce the greatest effect on a module's power output? Explain why that type of shading would probably produce the greatest effect on performance.



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4. 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.

*