**To our teachers:**

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Name: *______________________________

Date: *____ / ____ / ____   Class Hour: *____

| | |
|---|---|
| CREATE |  **Center for Renewable Energy Advanced Technological Education** |

## SOLAR PV:
## MODULE AMPS AND VOLTS

### Lab Activities

**Lab 1: Volts and Amps vs. Irradiance** (outdoors)

**Lab 2: Shading** (outdoors)

**Lab 3: Volts and Amps vs. Temperature** (classroom)

### Getting Started Outdoors

1. Assemble your group and materials outside on the flat, grassy, unshaded area assigned by your teacher.

2. Set your module stand perpendicular to the sun's azimuth. Keep it in place throughout the lab.

3. Face your module toward the sun, with the module wire connectors toward the top of the module. Set the bottom edge of your module in the slot on the module stand. Keep your module in that slot throughout the remainder of your time outside.

4. Lower the front of your module slowly, face down into the grass to a tilt angle of 180° (keeping the bottom edge of the module in the slot on the module stand).

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

## Volts vs. Irradiance

1. **Stop!** Review your prediction. What do you predict will happen to volts as irradiance increases?

2. Set up your equipment to measure open circuit voltage (Voc). Your module should be face down in the grass. Connect alligator clips from your multimeter to the open, copper ends of your module cable leads. Turn on your multimeter and set it to measure DC volts. Check for correct polarity.

3. Turn on your pyranometer. Set it to measure watts/meter$^2$. Place the sensor of your pyranometer in the same plane as the front (the face) of your PV module.

4. Take your first measurements of volts and irradiance at precisely the same time. Record them into the first row of **Data Table 1.** at 180°.

5. **Stop!** Consider your prediction. Is your first measurement of volts at this irradiance what you expected?

6. Raise your module up to a tilt angle of 150°. Place the sensor of your pyranometer in the same plane as the front, or face of your PV module. Record your second set of measurements simultaneously.

7. Continue to reposition your module to all required tilt angles. Take volts and irradiance measurements simultaneously at each stop. Continue until all tilt angles in the data table are filled.

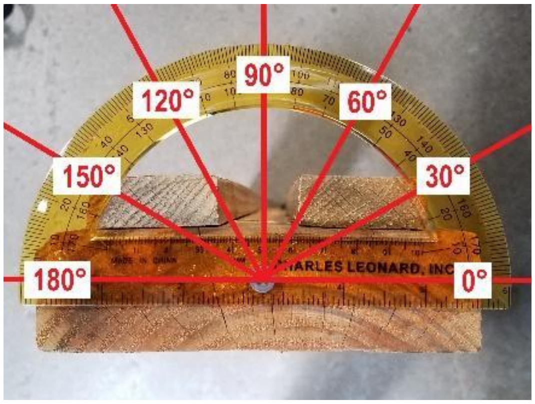
8. Rotate the front of your module up, then forward. Then lower the face of your module slowly into the grass to a tilt angle of 180°. Keep the module stand in place and the bottom edge of the module in the slot of the module stand.

9. Remove the alligator clips of your multimeter from the open, copper ends of your module cable leads. Turn your multimeter off and set it aside.

10. **Stop!** Did the volts measurement at your highest irradiance change significantly from your first measurement of volts at your lowest irradiance? Why or why not?

11. **Stop!** Consider your prediction. Did your measurements of volts as irradiance increased match your prediction?

**Photo 1.**
A protractor showing the positions at which you'll take measurements with your module.




**Data Table 1.**
Write your irradiance and Volts measurements by the asterisks indicated in the table.

| **PV Module Position**<br><br>Best azimuth and this **Tilt Angle** | **Irradiance**<br><br>**(W/m$^2$)** | **Electrical Potential (Volts) open circuit condition**<br><br>**(Voc)** |
|---|---|---|
| Face down, **180°** | *<br>**[You'll record, but won't graph this data.]** | *<br>**[You'll record, but won't graph this data.]** |
| **150°** | * | * |
| **120°** | * | * |
| Vertical, **90°** | * | * |
| **60°** | * | * |
| **30°** | * | * |
| Face up, **0°** | * | * |

## Lab 1: Volts and Amps vs. Irradiance

### Amps vs. Irradiance

1. **Stop!** Review your prediction. What do you predict will happen to amps as irradiance increases?

2. Set up your equipment to measure short circuit current (Isc). Your module should be face down in the grass. Wire the open, copper ends of your module cable leads together with the wire connector. Turn on your amp clamp and set it to measure DC amps. Zero your amp clamp. Clamp it around a wire for amp measurements.

3. Turn on your pyranometer. Set it to measure watts/meter$^2$. Place the sensor of your pyranometer in the same plane as the front (the face) of your PV module.

4. Take your first measurements of amps and irradiance at precisely the same time. Record them into the first row of **Data Table 2.** at 180°.

5. **Stop!** Consider your prediction. Is your first measurement of amps at this irradiance what you expected?

6. Raise your module up to a tilt angle of 150°. Place the sensor of your pyranometer in the same plane as the front, or face of your PV module. Record your second set of measurements simultaneously.

7. Continue to reposition your module to all required tilt angles. Take amps and irradiance measurements simultaneously at each stop. Continue until all tilt angles in the data table are filled.

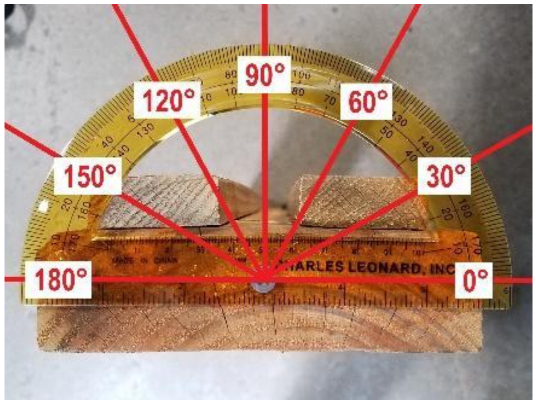
8. Rotate the front of your module up, then forward. Then lower the face of your module slowly into the grass to a tilt angle of 180°. Keep the module stand in place, and the bottom edge of the module in the slot of the module stand.

9. Leave the wiring arrangement of your module alone. Set the amp clamp on the back of the module for continued use in a few minutes. Turn your pyranometer off and set it aside.

10. **Stop!** Did the amps measurement at your highest irradiance change significantly from your first measurement of amps at your lowest irradiance? Why or why not?

11. **Stop!** Consider your prediction. Did your measurements of amps as irradiance increases match your prediction?

**Photo 1.**
A protractor showing the positions at which you'll take measurements with your module.




**Data Table 2.**
Write your irradiance and Amps measurements by the asterisks indicated in the table.

| **PV Module Position**<br><br>Best azimuth and this **Tilt Angle** | **Irradiance**<br><br>**(W/m$^2$)** | **Current (Amps) short circuit condition**<br><br>**(Isc)** |
|---|---|---|
| Face down, **180°** | *<br>**[You'll record, but won't graph this data.]** | *<br>**[You'll record, but won't graph this data.]** |
| **150°** | * | * |
| **120°** | * | * |
| Vertical, **90°** | * | * |
| **60°** | * | * |
| **30°** | * | * |
| Face up, **0°** | * | * |

## Lab 2: Shading

As a reminder, in this short lab you will measure the impact of different kinds of shading on your solar PV module.

1. **Stop!** Look at the table you'll use for this lab, **Data Table 3.** Note that you'll measure only amps as you apply different shading strips, while holding your module at its best azimuth and tilt angles. Within your group, answer this question. Why are we measuring just amps, and not measuring volts for this lab?

2. **Stop!** Without researching, make predict what you think will happen to amps in each of the shading situations given. Write down which situation you believe will have the *greatest decrease*, the *second greatest*, and *smallest decrease*. Write your predictions into the **Your Predicted Decrease** column in **Data Table 3**.

3. **Stop!** Summon your teacher. Review your answer to number 1, and your predictions in number 2 with them.

4. At the conclusion of **Amps vs. Irradiance** you left your module and equipment in readiness to perform this lab. If not, follow step 2 from **Amps vs. Irradiance**.

5. Use your pyranometer (or your protractor and notes) to raise your module to the tilt angle of your highest measured irradiance. Keep your module at precisely this angle for the following four required measurements.

6. Record your first measurements of amps with no shading.

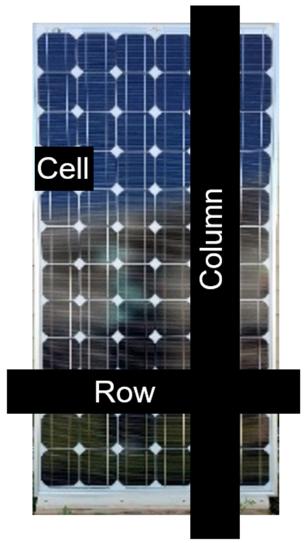
7. Cover one cell. Record your second measurement of amps. Continue and conclude this part of the lab with amps measurements covering one row of the module, and then one column of the module.

8. Look at the predictions you wrote in your data table. Discuss and explain unexpected results.

9. Rotate the front of your module up, then forward. Then lower the face of your module slowly into the grass to a tilt angle of 180°. Remove your module's cable leads from the wire connector and leave them disconnected.

10. Organize and gather all of your materials. Return to your classroom.

**Photo 3.**
A solar PV module with shading strips showing the different shading situations you'll examine. [Instructional size PV modules may not have this traditional look and this cell and wiring arrangement. Your shading strips may be different.]




**Data Table 3.**
Write your irradiance and Amps measurements, percent decrease in Isc, and your predicted decrease by the asterisks indicated in the table.

| **PV Module**<br><br>**Best irradiance Azimuth** and **Tilt Angle** | **Current (Amps) short circuit condition**<br><br>**(Isc)** | **Your Actual Percent Decrease In Isc**<br><br>**( % )** | **Your Predicted Decrease**<br><br>(Read instructions Step 2.) |
|---|---|---|---|
| **Best azimuth**, **best tilt angle**, and **<u>no shading</u>.** | * | **0** | **0** |
| **Best azimuth**, **best tilt angle**, and **one <u>cell</u> shaded.** | * | * | * |
| **Best azimuth**, **best tilt angle**, and **one <u>row</u> shaded.** | * | * | * |
| **Best azimuth**, **best tilt angle**, and **one <u>column</u> shaded.** | * | * | * |

**Lab 3:  Volts and Amps vs. Temperature**

In our final lab, you'll determine relationships between volts and temperature, and amps and temperature.  You'll perform your final lab by watching the video **Solar PV  Volts and Amps vs Temperature**.

1. During the video you'll have opportunities to record volts and amps data at regular temperature intervals.

2. Your teacher will give you instructions on how to watch the video (individually, in a group, or as a class), how to record data, and where to record data.

3. **Stop!**  Consider what you know about electrical potential (volts).  Without researching, make a prediction.  What will happen to volts as temperature increases?

4. **Stop!**  Consider what you know about electrical current (amps).  Without researching, make a prediction.  What will happen to amps as temperature increases?

5. Watch the video and record data according to your teacher's directions:

   **Solar PV  Volts and Amps vs Temperature:** https://youtu.be/_R6jIpgPQAo

6. Perform required calculations from your data.  Graph the data according to your teacher's directions.  Draw conclusions from your data and graphs.

**Table 4.**
From the video, for each temperature indicated in **Table 4**, write the:

- Volts
- Change in Volts
- Percent change in Volts (from 15°)
- Current (Amps)
- Change in Amps
- Percent change in Amps (from 15°)

by the asterisks indicated in the table.

| **Temp, °C** | **Volts, V** | **ΔV (from 15°)** | **ΔV% (from 15°)** | **Current, A** | **ΔA (from 15°)** | **ΔA% (from 15°)** |
|---|---|---|---|---|---|---|
| 15° | * | * | * | * | * | * |
| 20° | * | * | * | * | * | * |
| 25° | * | * | * | * | * | * |
| 30° | * | * | * | * | * | * |
| 35° | * | * | * | * | * | * |
| 40° | * | * | * | * | * | * |
| 45° | * | * | * | * | * | * |
| 50° | * | * | * | * | * | * |
| 55° | * | * | * | * | * | * |

## 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**

*** Place image here**

**1b. Lab 2: Shading**

*** Place image here**

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

*** Place image here**

**2a.** Which environmental condition (irradiance or temperature) primarily affected current (amps)? *** Answer here**

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

*** Answer here**

**3a.** Which environmental condition (irradiance or temperature) primarily affected electrical potential (volts)? *** Answer here**

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

*** Answer here**

**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.

*** Answer here**

**5.** You placed your module face down in the grass to connect and disconnect your module's cable leads to the wire connector. 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.

*** Answer here**

**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.

*** Answer here**

**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.

*** Answer here**

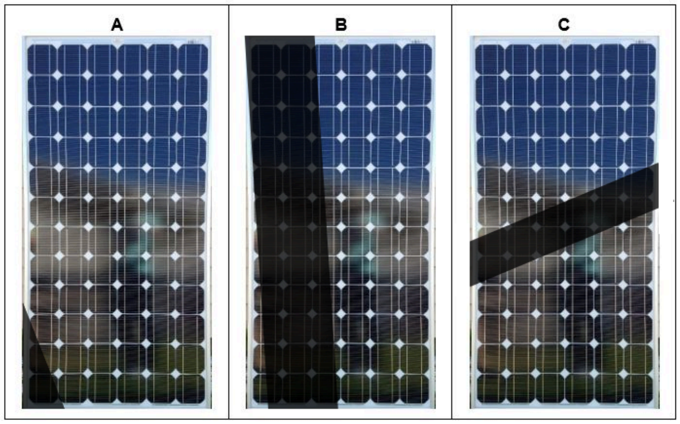
**7b.** Most people would reason that module performance will fall in proportion to the number of PV cells covered. Or, that it will fall in proportion to the percentage of module surface covered. Explain why this is <u>not true</u>, using specific data from the lab.

*** Answer here**

**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.

*** Answer here**

**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**

*** Answer here**

**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.

*** Answer here**

**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.

*** Answer here**

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

*** Answer here**

**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.

*** Answer here**

**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.

*** Answer here**

**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.

*** Answer here**