To our teachers:

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Name: *______________________________

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

Center for Renewable Energy Advanced Technological Education

SOLAR PV: THE I-V CURVE
Part Two, Producing I-V Curves in the Lab & The Effect of Irradiance

In **Part One** of your lesson, you plotted I-V and power curves representing the primary performance characteristics of a new solar PV module. It should now be easy for you to see that an I-V curve graphically represents the relationship between electrical potential (Volts) across a module and the current (Amps) flowing through it.

Producing an I-V curve is one of the most common ways to determine how an electrical device is performing in an electrical circuit. Key properties of any electronic device can be diagnosed from the shape and details of an I-V curve trace.

An I-V curve trace on a solar PV cell, module, or system will produce its own distinctive shape and details. The shape and details of an I-V curve trace provide important insights into the operation and performance of a solar PV device.

In **Part Two** of your lesson, you'll create three I-V curve traces from a classroom solar module. You'll employ different levels of light for each trace. To make your traces, you'll apply a series of electrical potentials (Volts) to your module. At each Volts measurement, the current (Amps) through your module will be measured. This will enable you to determine how Volts and Amps are affected by changes in irradiance.

You'll begin each trace in a condition where your module produces its maximum electrical potential (Volts) and has no current flow. This point on your graph is called **open-circuit voltage** and is labeled **Voc**. This condition occurs when an electrical circuit is disconnected—an open-circuit situation. Disconnected, no current can flow through an open circuit because its resistance = ∞ (infinity).

You'll finish each trace in an electrical condition where your module produces its maximum current and has no electrical potential (Volts). This point on your graph is called **short-circuit current** and is labeled **Isc**. This condition occurs when an electrical circuit is connected and has no (or very low) resistance to current flow. Connected this way, the potential difference between two points is zero and there is no electrical potential (Volts).

Between these two extremes of resistance, you'll measure and plot a large number of I-V operating points to approximate an I-V curve for your module. The point at which you find your module delivers its maximum power and operates most efficiently is called its **maximum power point**. It is labeled **Pmax**. The electrical potential measurement at maximum power is called **maximum power voltage** and it is labeled **Vmp**. The electrical current measurement at maximum power is called **maximum power current** and it is labeled **Imp**.

Before you begin, become thoroughly acquainted with your lab materials and the procedure you'll follow to ensure your success in making quality I-V curve traces.

Materials:

- Student computing device
- LED floodlight
- Wood blocks
- 2 precut neutral density filter films
- Multimeter to measure DC Amps
- Classroom solar PV module
- Lab workboard with alligator clip wires
- Daystar solar irradiance meter
- Multimeter to measure DC Volts
- Decade variable resistance box

Lab Procedure:

Light Setting 1

1. Your teacher will give you verbal and visual instructions on how to perform the lab. Ask questions until you're satisfied you know how to proceed. This is important to avoid mistakes that may require you to start over.

2. Arrange, wire, and connect your lab equipment according to your teacher's illustrations and instructions.

3. If you haven't already done so, turn the front of your LED floodlight down so it faces your table. Adjust it so it's parallel to your table surface. Arrange the blocks under the face of your light so you can set your module on top of them. Set your module face up on your blocks. Adjust your module and blocks so the module is directly in the center of the face of your floodlight.

4. Open the Microsoft Excel spreadsheet titled **I-V Curve Part 2 Blank Data Tables and Graphs**. You'll be entering the data you acquire during the lab into blank data tables in this file. As you enter your data, I-V and Power Curves will automatically assemble themselves for you.

5. Turn on your Daystar meter. Place it along the edge of your module with the sensor facing the floodlight. You may need to move your blocks to accomplish this. After completing this step your module and Daystar meter should be directly under your floodlight. Turn on your LED floodlight.

6. Take the irradiance measurement and record it in your Excel spreadsheet under **Setting 1**. Remove your Daystar meter, carefully noting where you placed it for this measurement. It should be returned to the same place for subsequent readings.

7. Turn all four dials on your decade resistance box to 9 for maximum resistance (9,999 Ohms of resistance) if you haven't done so already.

8. If both wires are clamped to your decade box, unclamp one of them to establish an open circuit condition with your equipment.

9. If your multimeters are turned "on" turn them off. *Steps 9-11 are critical to complete so your multimeters don't turn off (time out) automatically in the middle of your readings for this light setting.*

10. Turn on the multimeter to your <u>left</u>. Set it up to read DC Volts within your expected range of use. If necessary, zero it (calibrate it to read zero). Arrange it in place so you don't have to move it for the rest of this part of the lab to take measurements or read the display.

11. Turn on the multimeter to your <u>right</u>. Set it up to read DC Amps within your expected range of use. If necessary, zero it. Arrange it in place so you don't have to move it for the rest of this part of the lab to take measurements or read the display.

12. Take your first Volts measurement from the multimeter. Enter it into your data table under **Setting 1,** Measurement 1. Take your first milliAmps measurement from your other multimeter. It should read zero in open circuit condition. Enter zero for your first milliAmps reading into the data table.

13. Connect the wire to your decade resistance box that was left unconnected (step 8) for your first set of closed circuit readings.

14. Take your second Volts measurement from the multimeter. Enter it into your data table under Volts, Measurement 2. Take your second milliAmps measurement from your other multimeter. Enter it into your data table.

15. Dial down the resistance on your decade resistance box starting at the X1000 dial. Change it from 9 to 8 (9999 → 8999).

16. Take your third Volts measurement from the multimeter. Enter it into your data table under Volts Measurement 3. Take your third milliAmps measurement from your other multimeter. Enter it into your data table.

17. Dial down the resistance on your decade resistance box at the X1000 dial again. Change it from 8 to 7 (8999 → 7999). Then take and record your fourth Volts measurement from the multimeter. Take and record your fourth milliAmps measurement from the other multimeter. Enter it into your data table.

18. As you enter your data, I-V and Power Curves will automatically assemble themselves for you. As this happens, check to make sure your I-V and Power Curves closely resemble those you produced in **Part One** of this lesson. If they do not, get assistance from your teacher.

19. Continue dialing down your resistance, step by step in this manner. Take Volts and milliamps measurements each time. You will have to move to the next dial down from time to time. Ask your instructor for guidance if you don't know how to dial down your resistance in this way. You'll take over thirty more measurements before reaching 0001 on your resistance box dials.

20. For your final measurement turn all the dials on your decade box to zero. At this setting, you will be as close to a short circuit condition as we can achieve with this equipment. Take your last Volts and milliAmps readings and enter them into your data table.

21. Turn your LED floodlight off. Examine the graph plots you produced. Do they resemble your graph plots from **Part One** of this Lab?

Light Setting 2

22. Decrease the irradiance to 50% of your original light. Do this by placing a pre-cut piece of 50% neutral density filter film over the entire face of your module and Daystar meter. This film, usually used for photography, filters out light of all wavelengths by approximately 50%

23. Return to step 6 of the procedure for **Light Setting 1**. Follow all steps as before, except enter your data into your Excel spreadsheet under **Setting 2**. *Steps 9-11 are critical to complete so your multimeter and amp clamp don't turn off (time out) automatically in the middle of your readings for this light setting.*

Light Setting 3

24. Decrease the irradiance to 25% of your original light. Do this by layering a second piece of 50% neutral density filter film over the first piece of film, the entire face of your module, and your Daystar meter.

25. Return to step 6 of the procedure for **Light Setting 1**. Follow all steps as before, except enter your data into your Excel spreadsheet under **Setting 3**. *Steps 9-11 are critical to complete so your multimeter and amp clamp don't turn off (time out) automatically in the middle of your readings for this light setting.*

26. Turn off your floodlight. Follow directions from your teacher for takedown and cleanup of your lab equipment.

Show What You Know, Part Two

1. You should be familiar with the five solar PV module nameplate values from **Part One** of this activity. Determine the same five values from the I-V curves you produced for **Settings 1, 2, and 3** in your lab spreadsheet. Enter them into **Table 1** below, along with the irradiance measurement for each setting.

Table 1.

Setting:	One	Two	Three
Irradiance:	* **W/m^2**	* **W/m^2**	* **W/m^2**
Pmax	* **W**	* **W**	* **W**
Vmp	* **V**	* **V**	* **V**
Imp	* **mA**	* **mA**	* **mA**
Voc	* **V**	* **V**	* **V**
Isc	* **mA**	* **mA**	* **mA**

2. Open the Microsoft Excel spreadsheet titled **I-V Curve Part 2 - Blank Voc's and Isc's by Setting**. Into that spreadsheet, enter Irradiance, Voc, and Isc measurements from **Table 1** above where indicated. Examine the results from the data tables and graphs you produce.

Which variable, Electrical Potential (Volts) or Current (Amps) is impacted the most as light (irradiance) is decreased? Give your answer choice. Then explain how you made your choice by referring to the graphs you just produced.

*** Answer Choice**

*** Explanation**

Take a snip or screenshot of your two completed graphs. Paste them into this document, below. Arrange your snip so it's not split between two pages.

*** Paste your graphs here ▼**

3. Confirm what you just learned and from the previous question in a different way. Go back to look at the **Setting 1, 2,** and **3** graphs you produced in the Microsoft Excel spreadsheet titled **I-V Curve Part 2 - Blank Data Tables and Graphs**.

Which variable, Electrical Potential (Volts) or Current (Amps) is impacted the most as light is decreased? Give your answer choice. <u>Then explain how you made your choice by referring to the **Setting 1, 2,** and **3** graphs you produced during the lab</u>. [This is the same question asked in number 2, but refers you to different graphs for an explanation.]

* **Answer Choice**

* **Explanation**

Take snips or screen shots of your three completed graphs. Paste them into this document, below. Arrange your photos so none of them are split between two pages.

* **Paste your graphs here ▼**

4. Compare your **Setting One** measurements from Post-lab question number 1, **Table 1,** to your module's nameplate values at STC shown in **Table 2**, below.

Table 2.

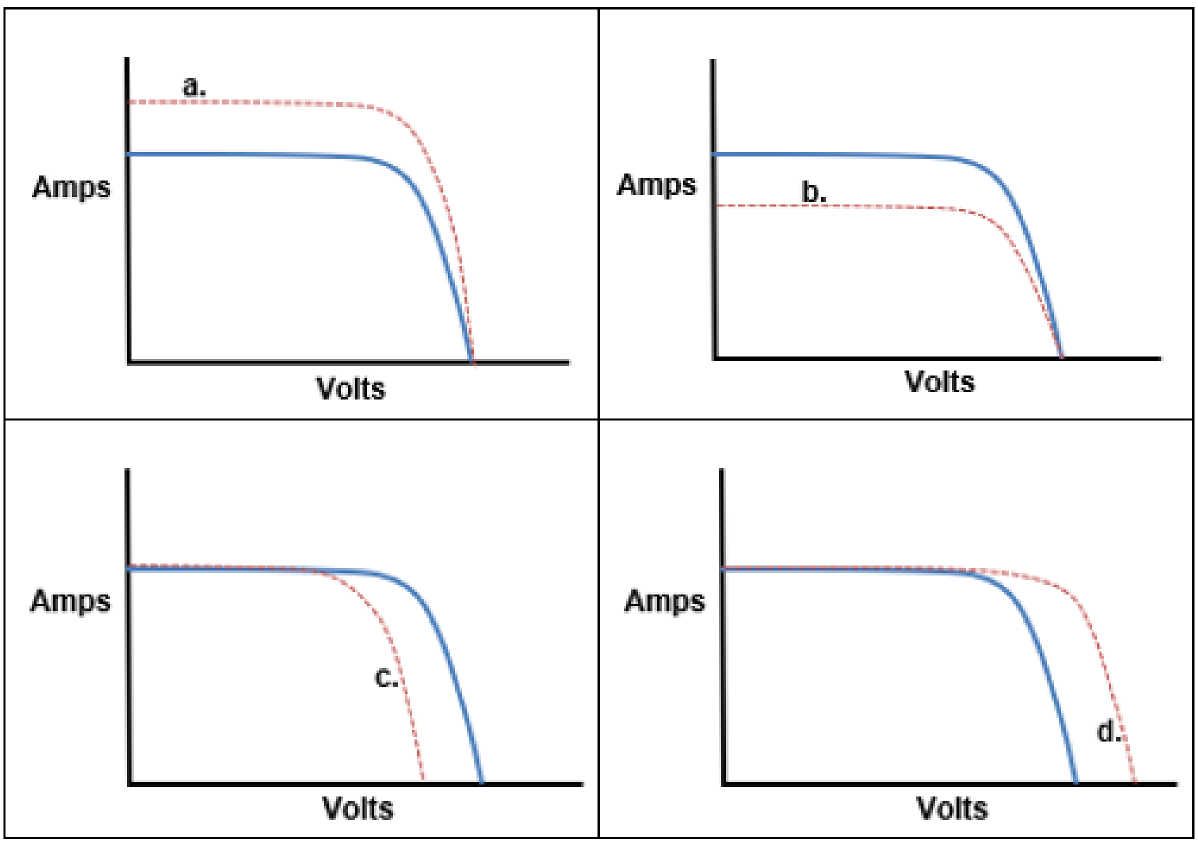
Specification	Your module at STC
Pmax	**1.2** W
Vmp	**6.0** V
Imp	**200** mA
Voc	**7.2** V
Isc	**210** mA

Plainly, your lab measurements from **Setting One** don't match the nameplate values for your classroom module. Provide at least two different reasons why these values don't match.

4a. * Answer

4b. * Answer

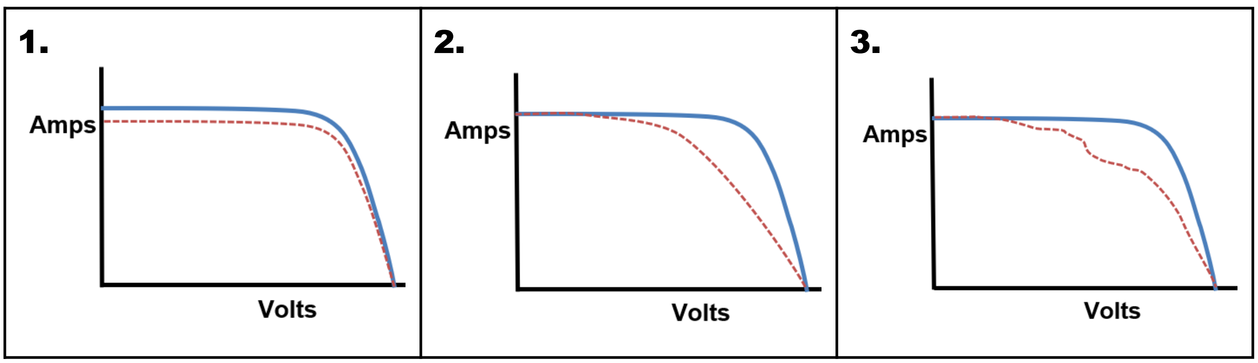
5. Each of the solid, blue I-V curves shown below are identical. They represent an I-V curve trace from a solar array in Madison, Wisconsin. The other I-V curves (shown in dashed, brown) represent four different locations from around the United States.



Assume all factors other than location are exactly the same. Which location choice, a, b, c, or d, shows how the very same system would usually perform in Phoenix, AZ? Give your answer choice. Then explain how you made your choice and why it makes sense.

*** Answer**

6. Each of the blue I-V curves shown below are identical. They show an I-V curve trace from a solar array in Green Bay, Wisconsin upon installation. The I-V curves shown in dashed brown represent situations that might occur over time in contrast to the original, solid, blue curve traces. Match each of the three pairs of graphs (numbered) to the description that best fits each one, below. Each number choice is used once.



6a. Over time, the solar array becomes uniformly covered in dust and dirt.

*

6b. Over time, trees grow up and the solar array becomes partially shaded.

*

6c. The modules in the solar array age after many years.

*

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.

*** Answer**