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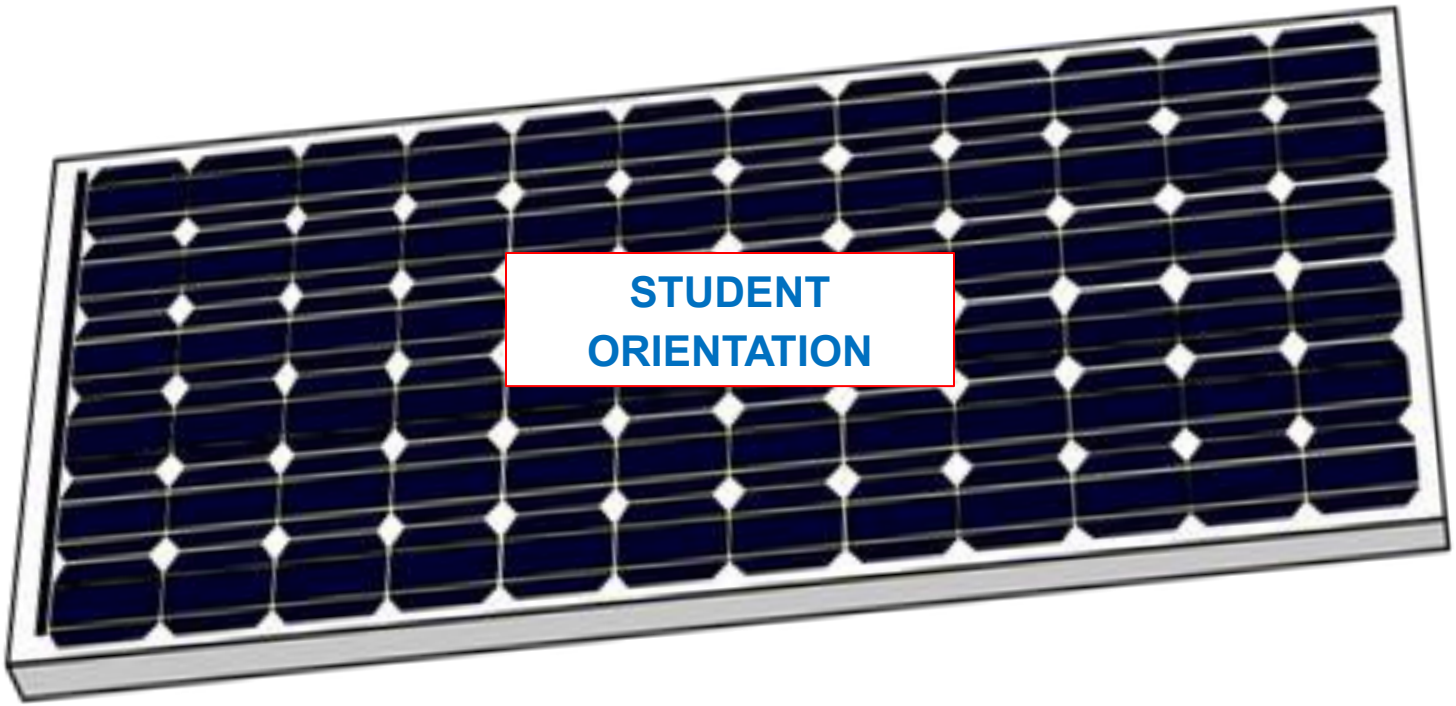
CREATE	Center for Renewable Energy Advanced Technological Education	Name: _____ Date: ____ / ____ / ____ Class Hour: ____

SOLAR PV:
MODULE PERFORMANCE



STUDENT ORIENTATION

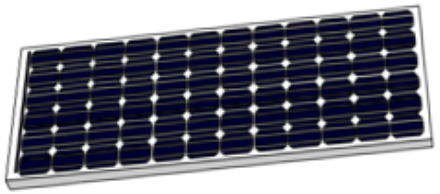
CREATE	Center for Renewable Energy Advanced Technological Education	Name: _____ Date: ____ / ____ / ____ Class Hour: ____

SOLAR PV:
MODULE PERFORMANCE

Introduction

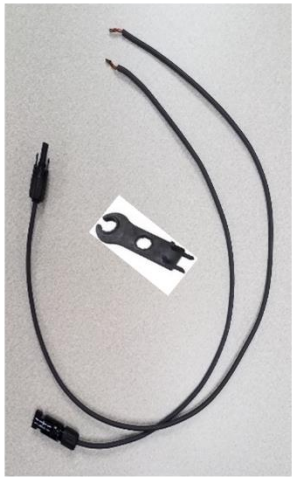
Like most people, you probably understand that a solar PV module works best in lots of sunlight. But do you know how an array of solar PV modules should be positioned to get maximum sunlight in the first place? What about shading? Sometimes a small amount of shading on a PV array is unavoidable. But 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)

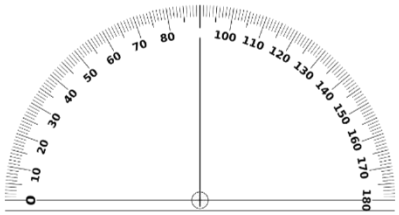
By the conclusion of the lesson you'll know the most important factors affecting solar PV module performance, and the critical relationships between them.

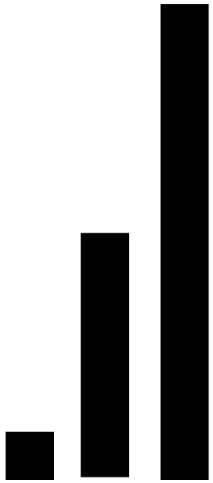




Materials

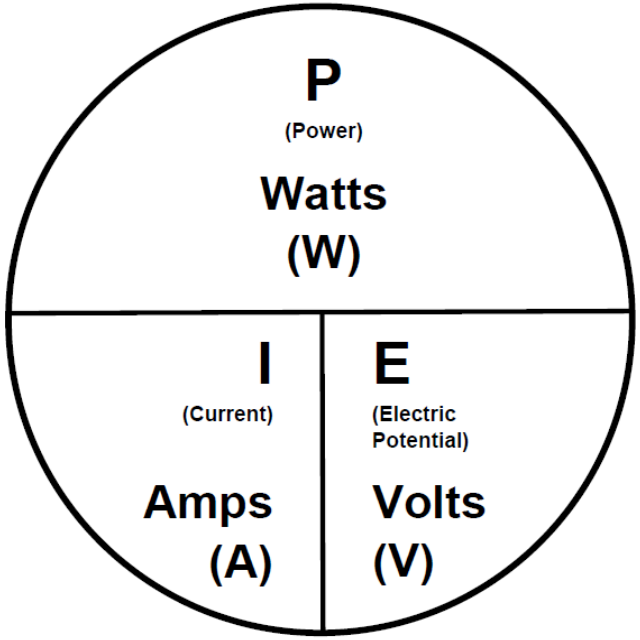
- Solar PV Module
- Multimeter with alligator leads
- Pyranometer
- Module stand
- Pre-cut module shading materials
- Sacrificial leads (with disconnect tool)
- Amp clamp
- Infrared thermometer
- Protractor
- High intensity LED Lamp (optional)



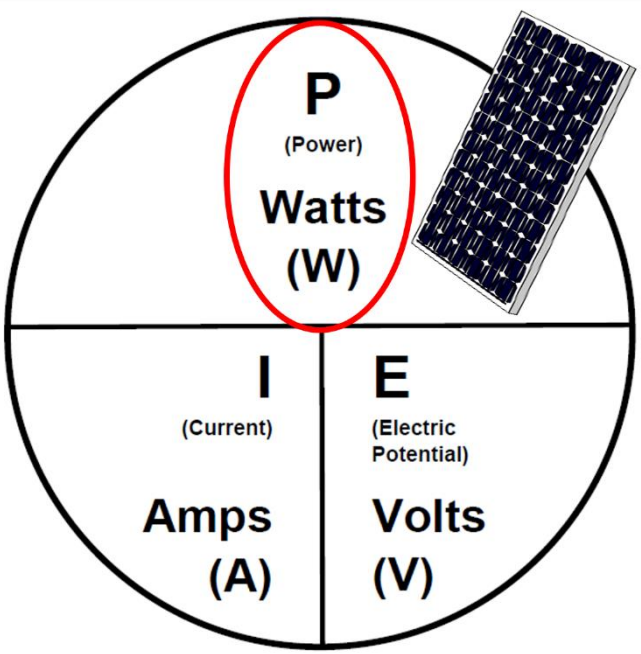





Electrical Measurements & Using A Multimeter (1)

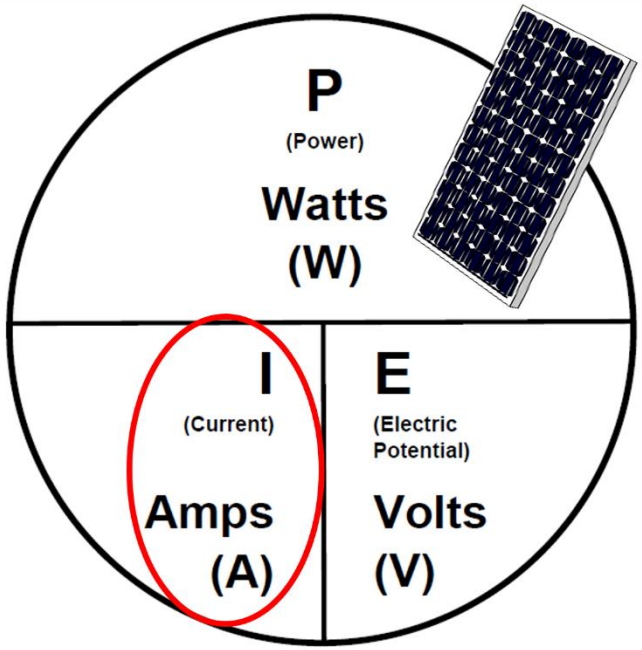


Electrical Measurements & Using A Multimeter (2)



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.

Electrical Measurements & Using A Multimeter (3)



Electrical Potential (measured in volts) defined. Many people use the word "voltage" instead of electric potential.

Electrical potential is a measurement of the difference in volts between two points.

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.
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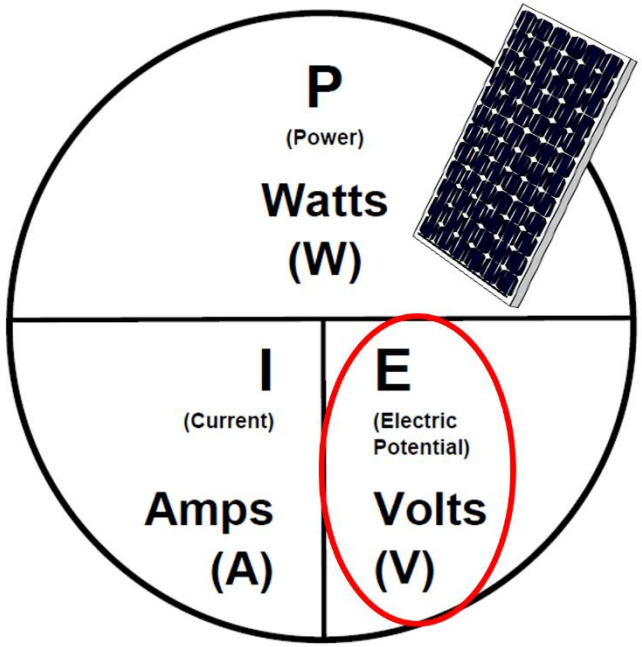
Electrical Measurements & Using A Multimeter (4)



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.
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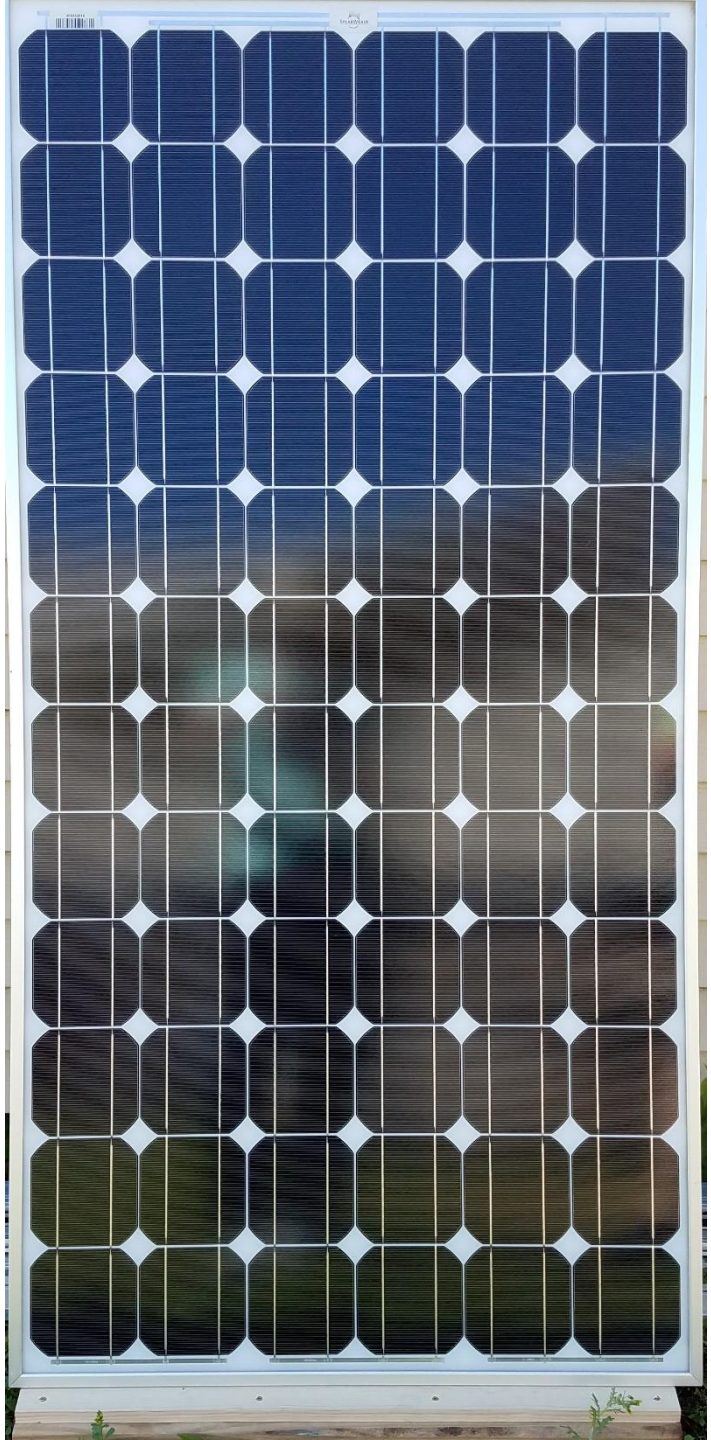
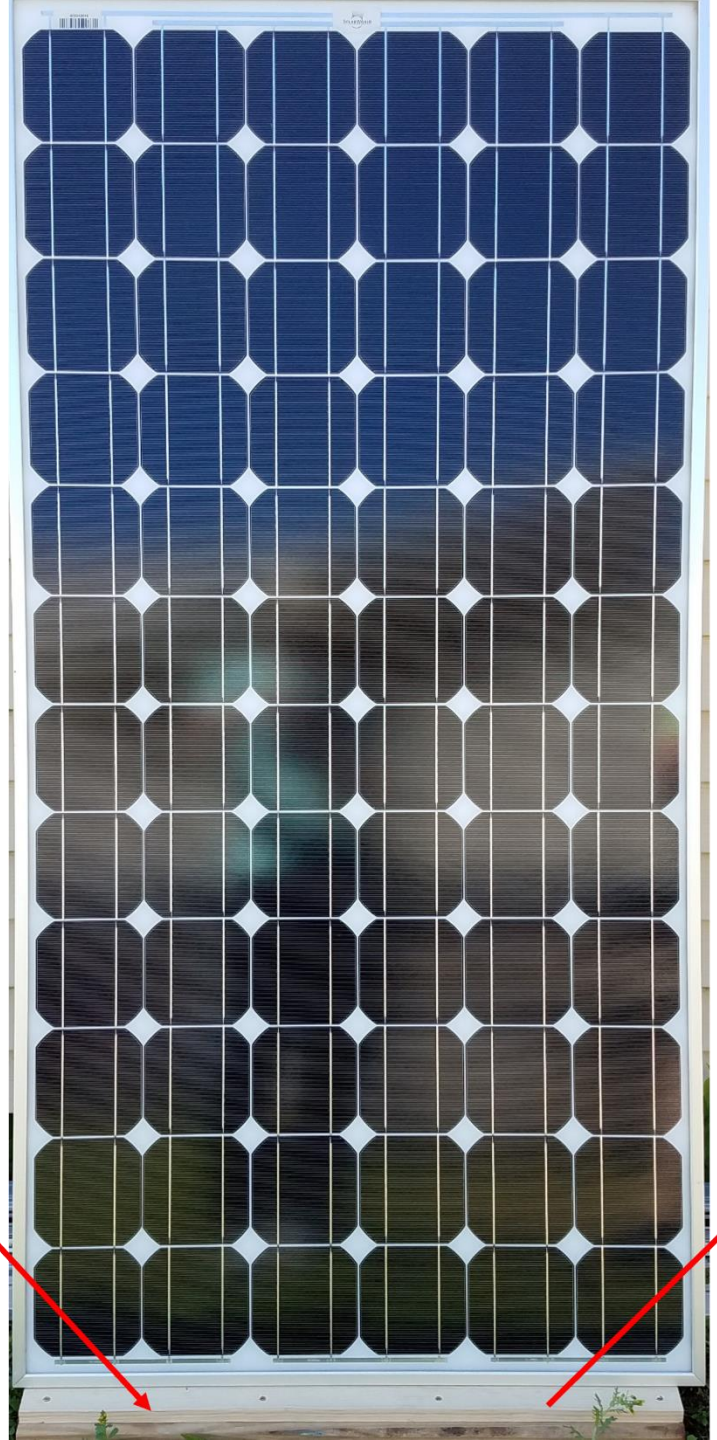
Your Solar PV Module (1)



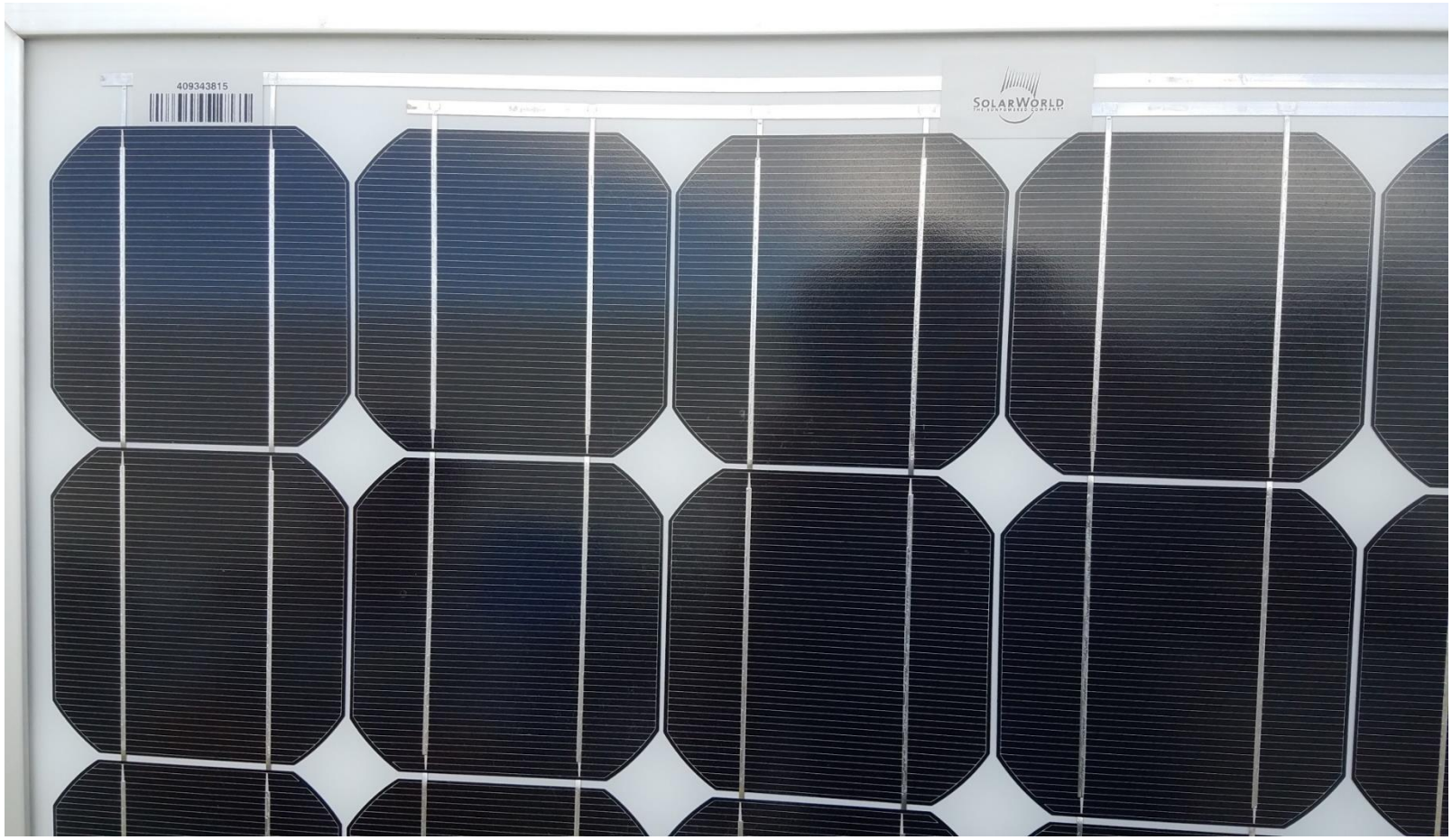
Your Solar PV Module (2)



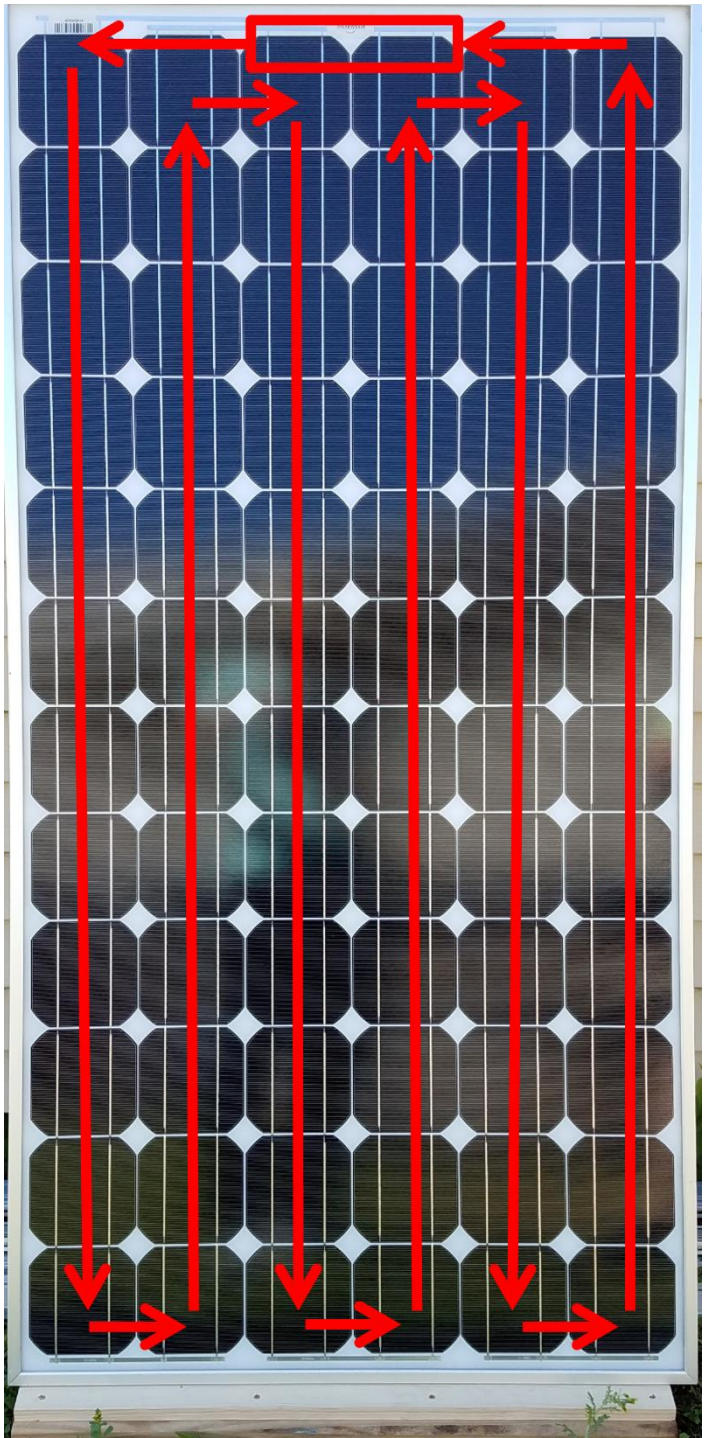
Note module sitting in our module stand.

Your Solar PV Module (3)

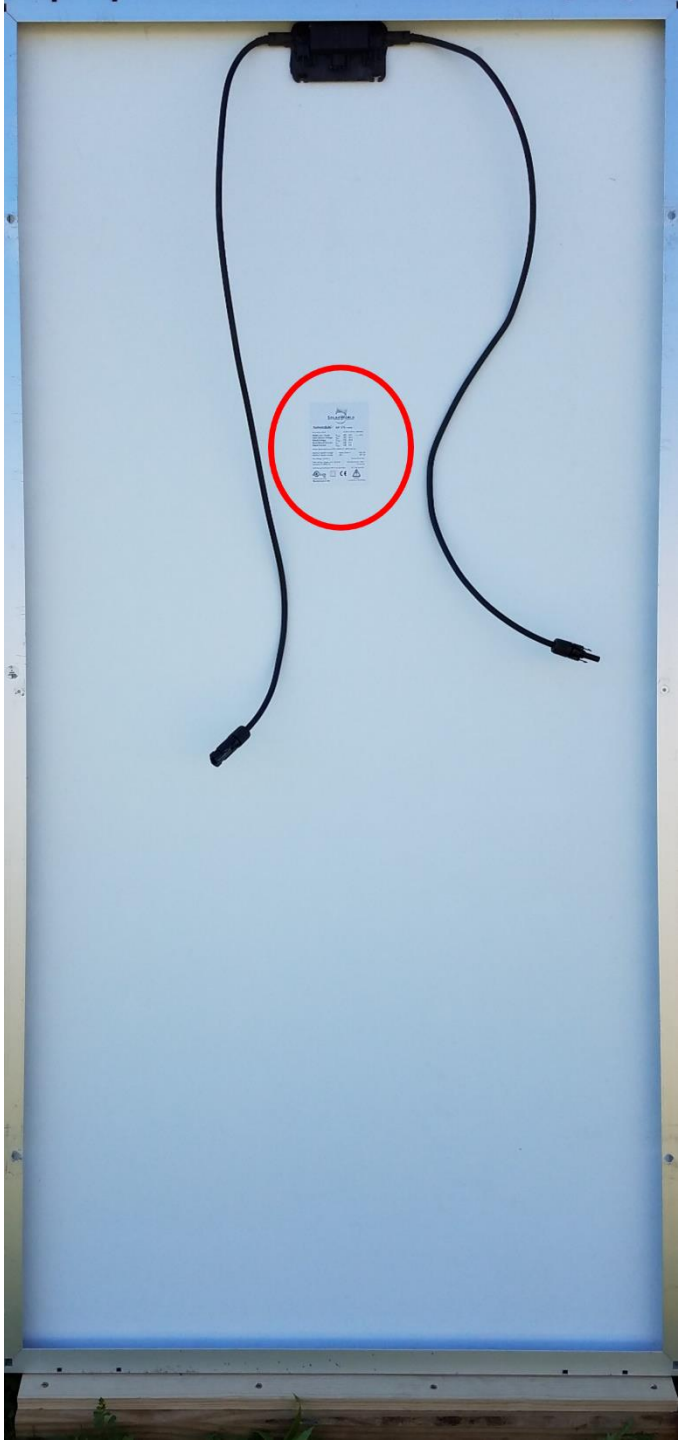
Your Solar PV Module (4)



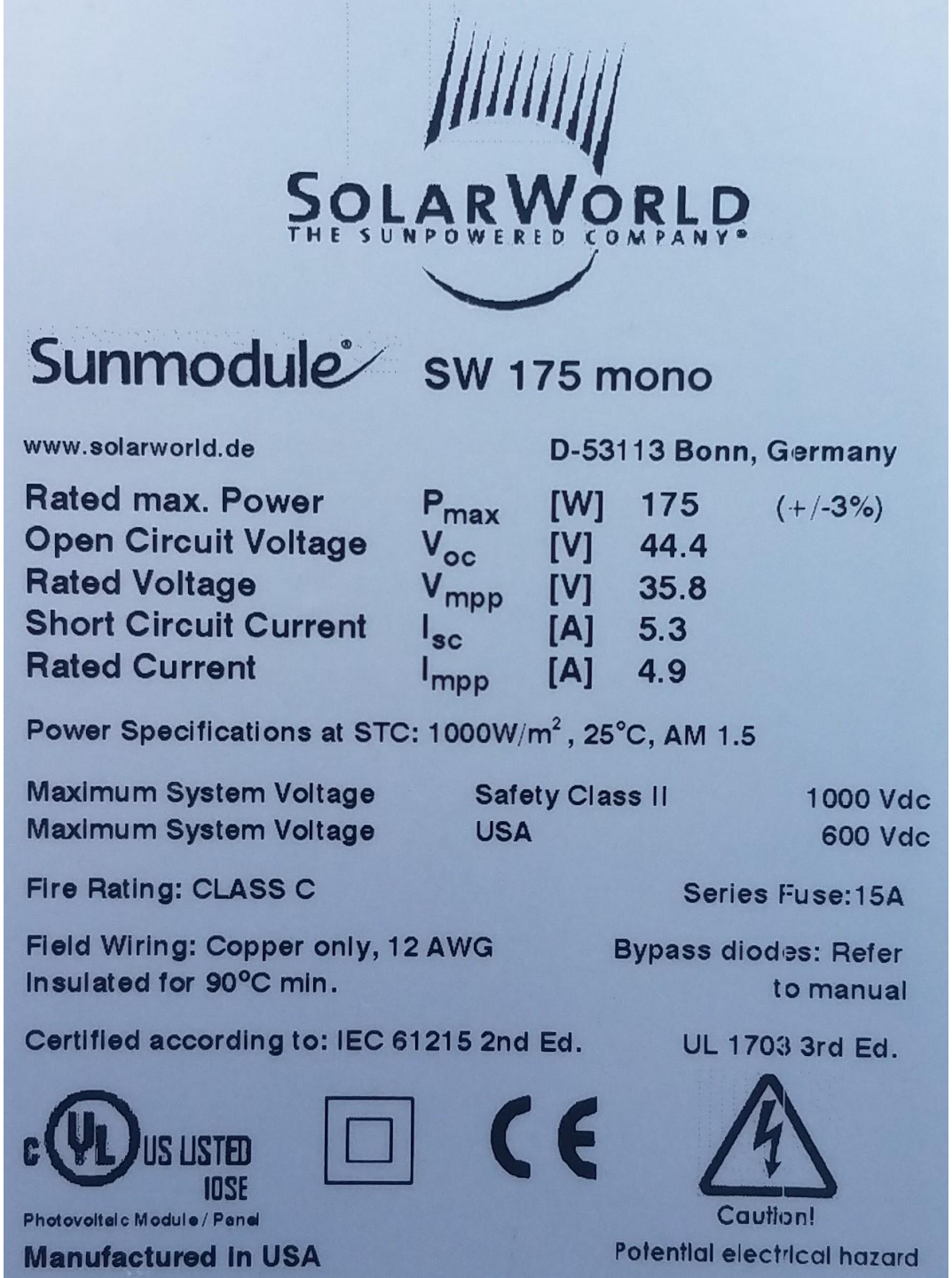
Your Solar PV Module (5)



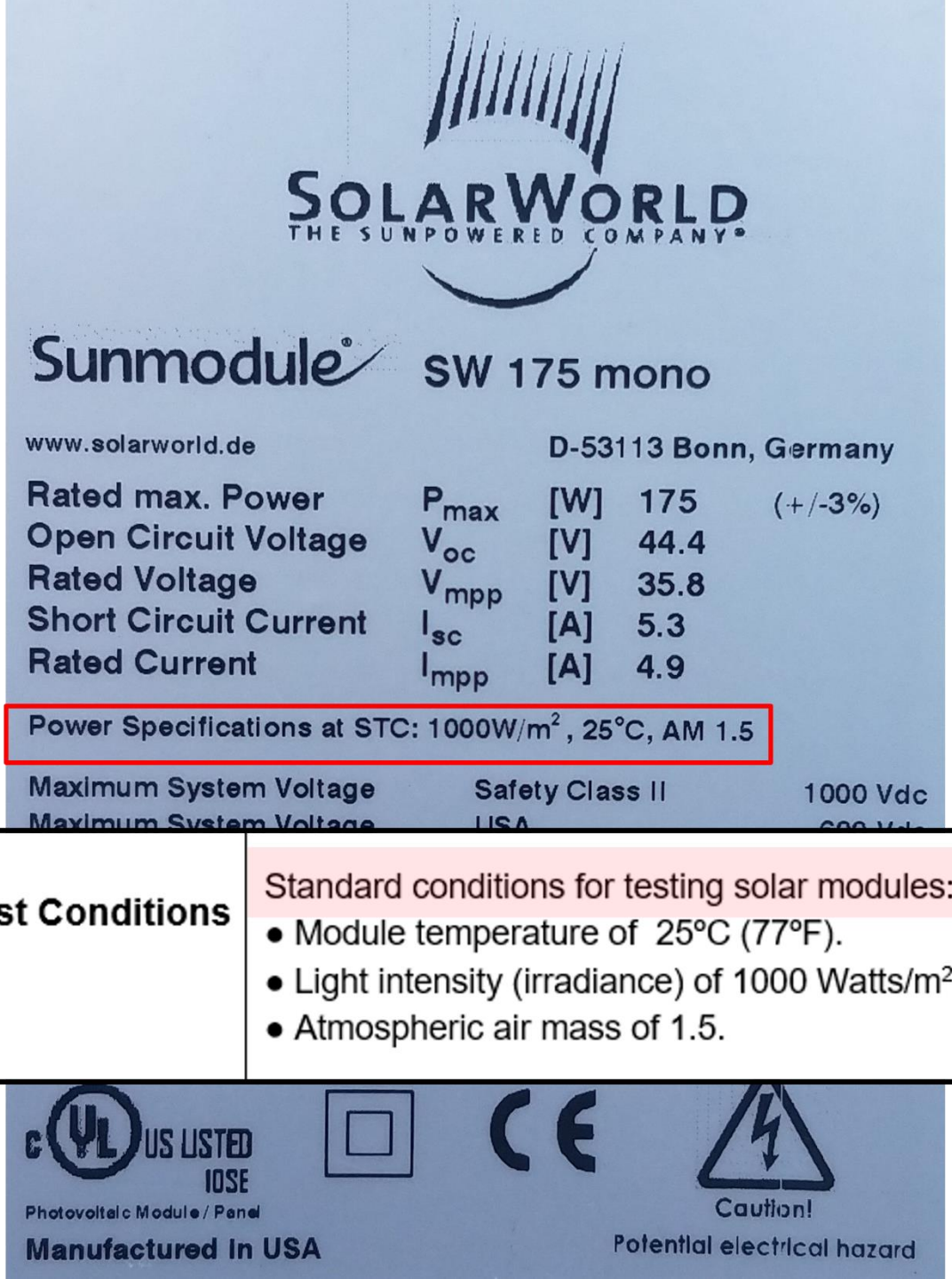
Your Solar PV Module (6)



Your Solar PV Module (7)

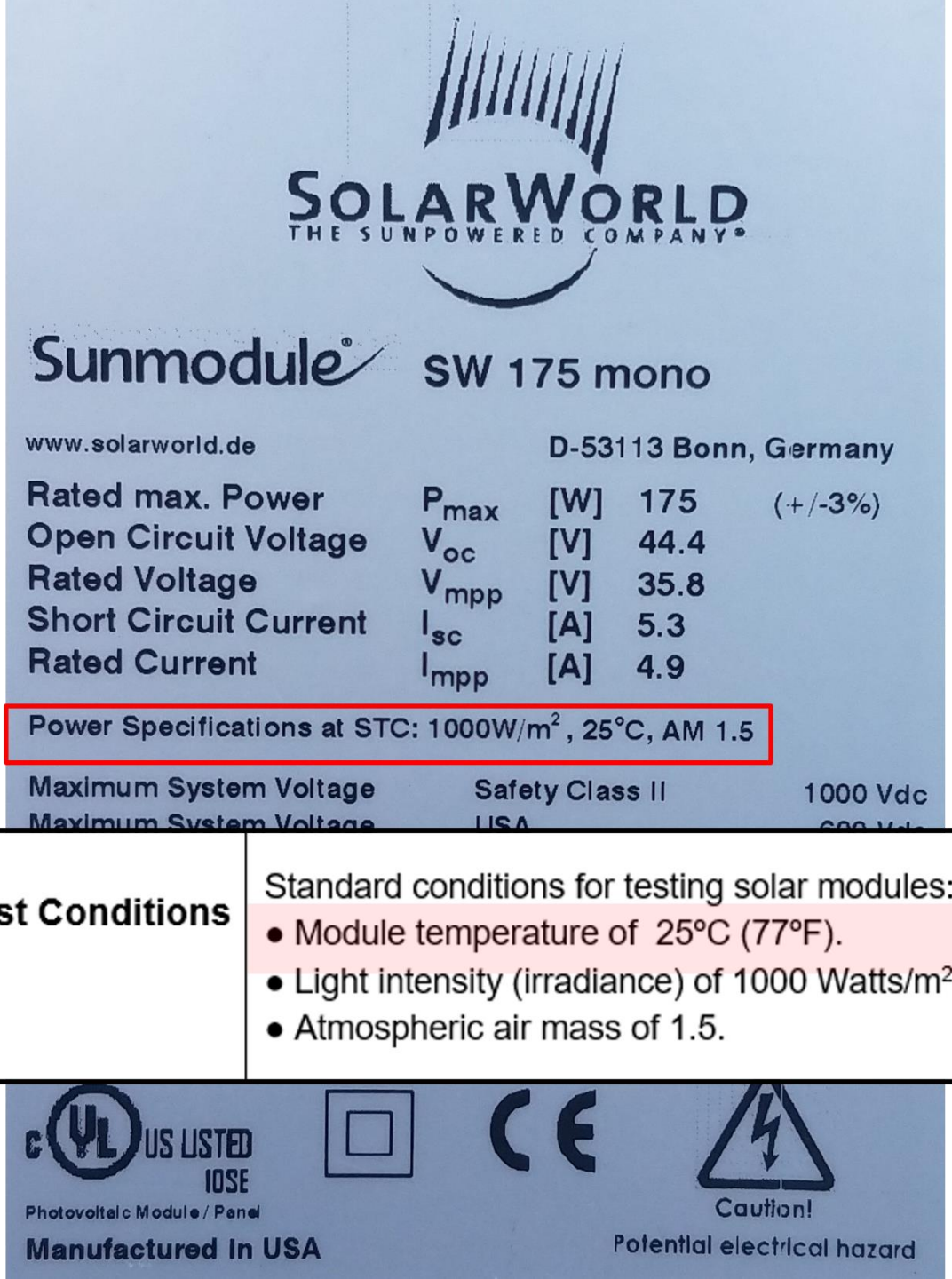


Your Solar PV Module (8)



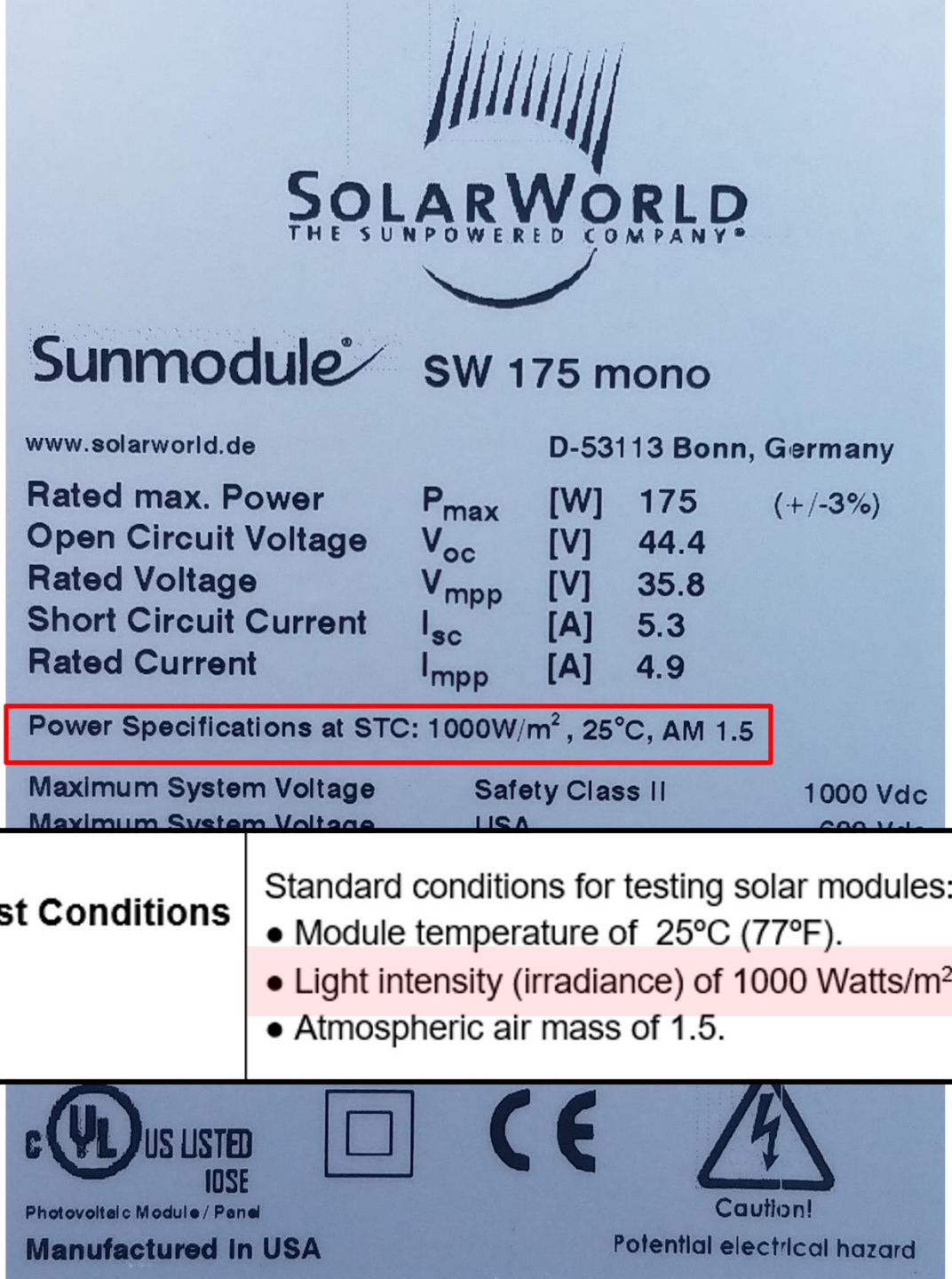
Standard Test Conditions STC	Standard conditions for testing solar modules: • Module temperature of 25°C (77°F). • Light intensity (irradiance) of 1000 Watts/m². • Atmospheric air mass of 1.5.

Your Solar PV Module (9)



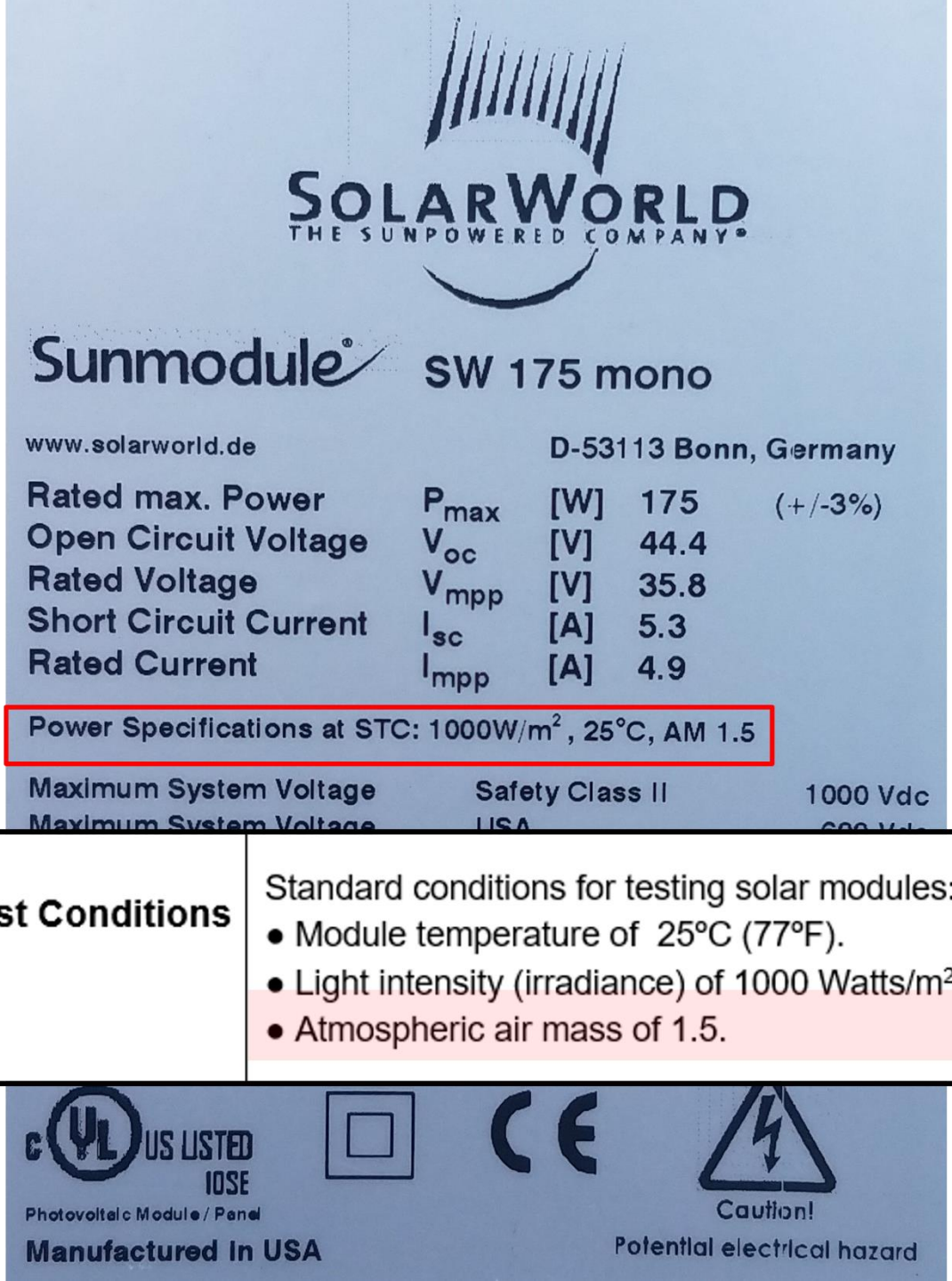
Standard Test Conditions STC	Standard conditions for testing solar modules: • Module temperature of 25°C (77°F). • Light intensity (irradiance) of 1000 Watts/m². • Atmospheric air mass of 1.5.

Your Solar PV Module (10)



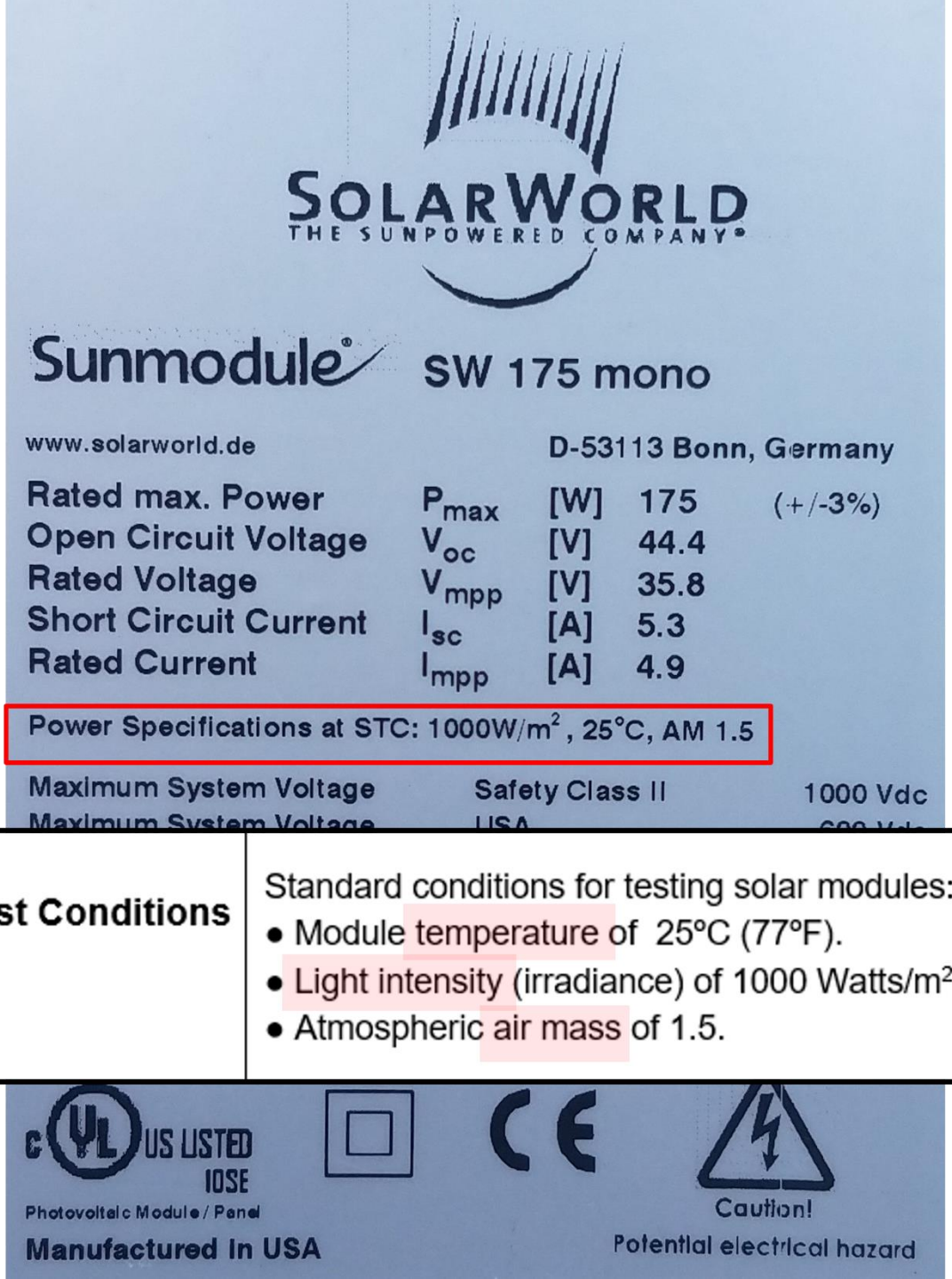
Standard Test Conditions STC	Standard conditions for testing solar modules: • Module temperature of 25°C (77°F). • Light intensity (irradiance) of 1000 Watts/m². • Atmospheric air mass of 1.5.

Your Solar PV Module (11)



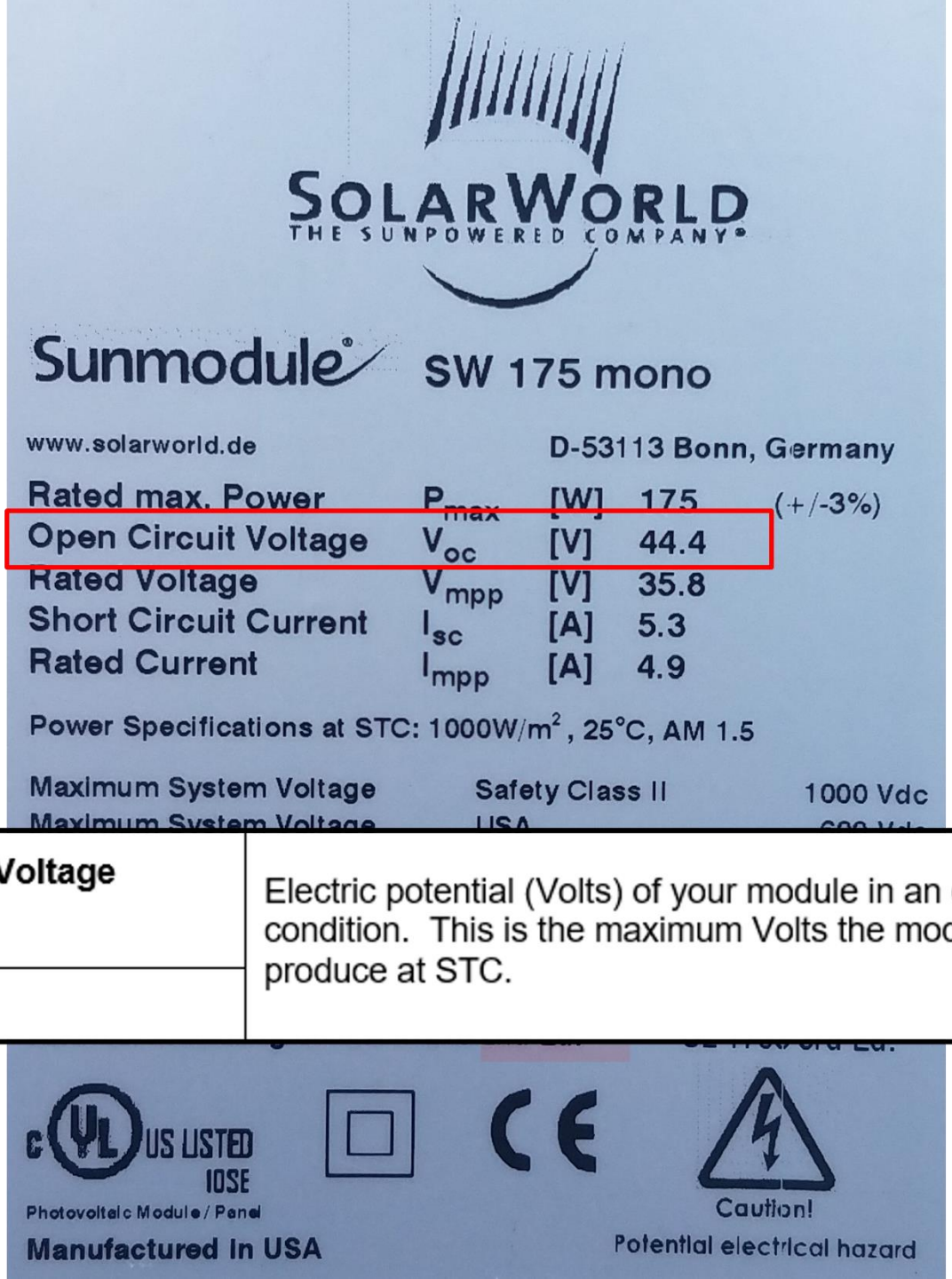
Standard Test Conditions STC	Standard conditions for testing solar modules: • Module temperature of 25°C (77°F). • Light intensity (irradiance) of 1000 Watts/m². • Atmospheric air mass of 1.5.

Your Solar PV Module (12)



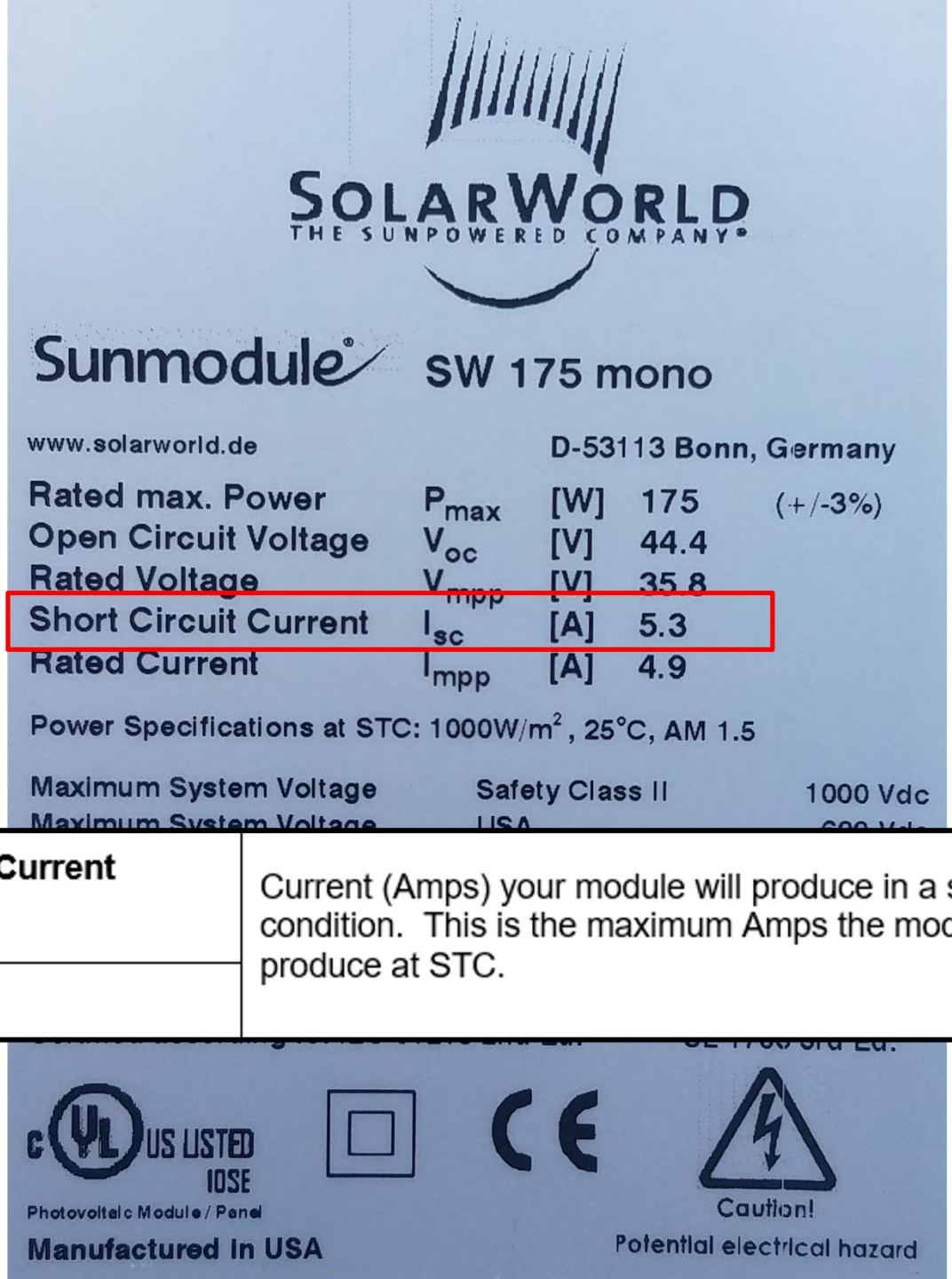
Standard Test Conditions STC	Standard conditions for testing solar modules: • Module temperature of 25°C (77°F). • Light intensity (irradiance) of 1000 Watts/m². • Atmospheric air mass of 1.5.

Your Solar PV Module (13)



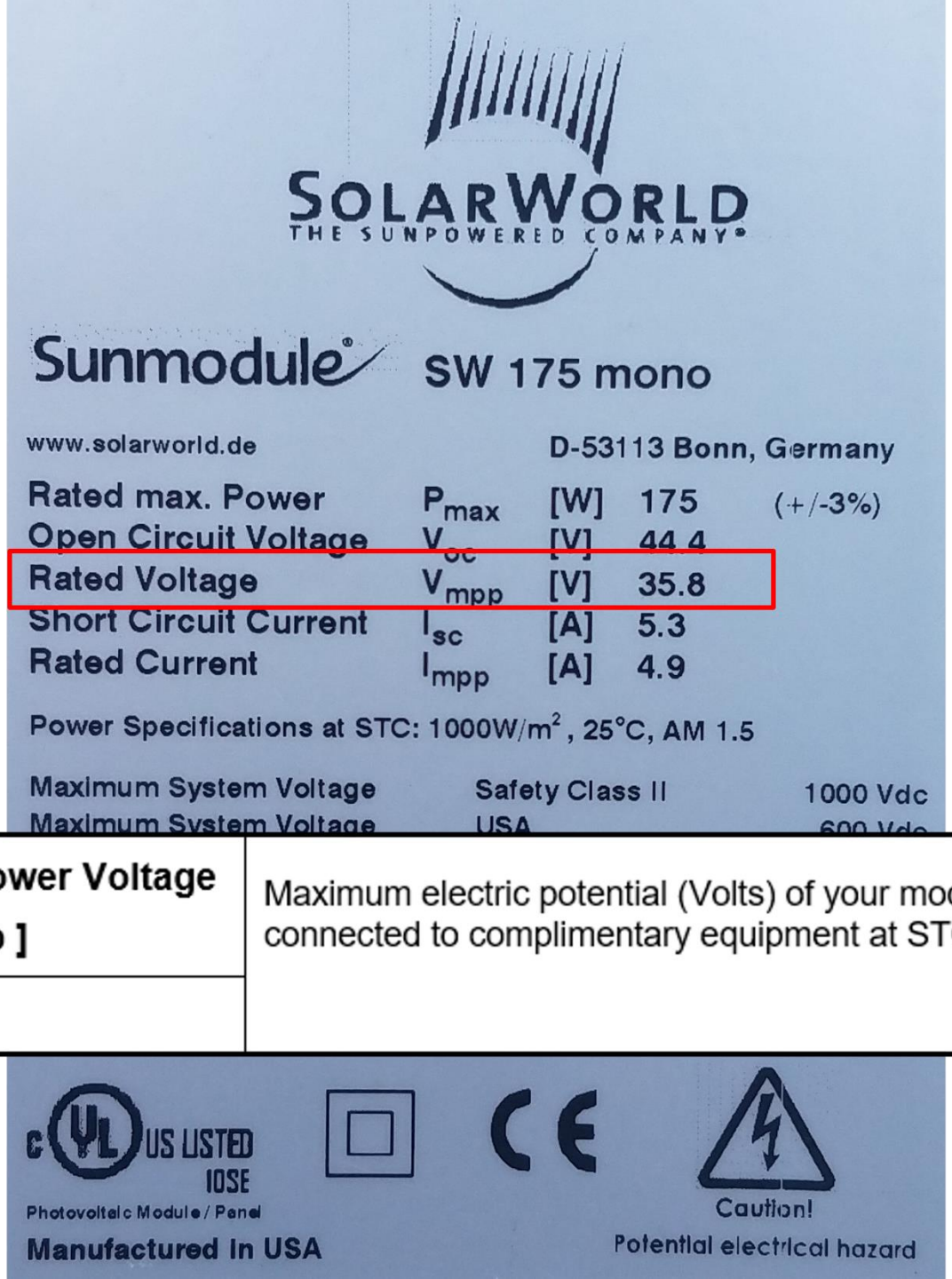
Open Circuit Voltage **Voc**	Electric potential (Volts) of your module in an open circuit condition. This is the maximum Volts the module can produce at STC.
*	

Your Solar PV Module (14)



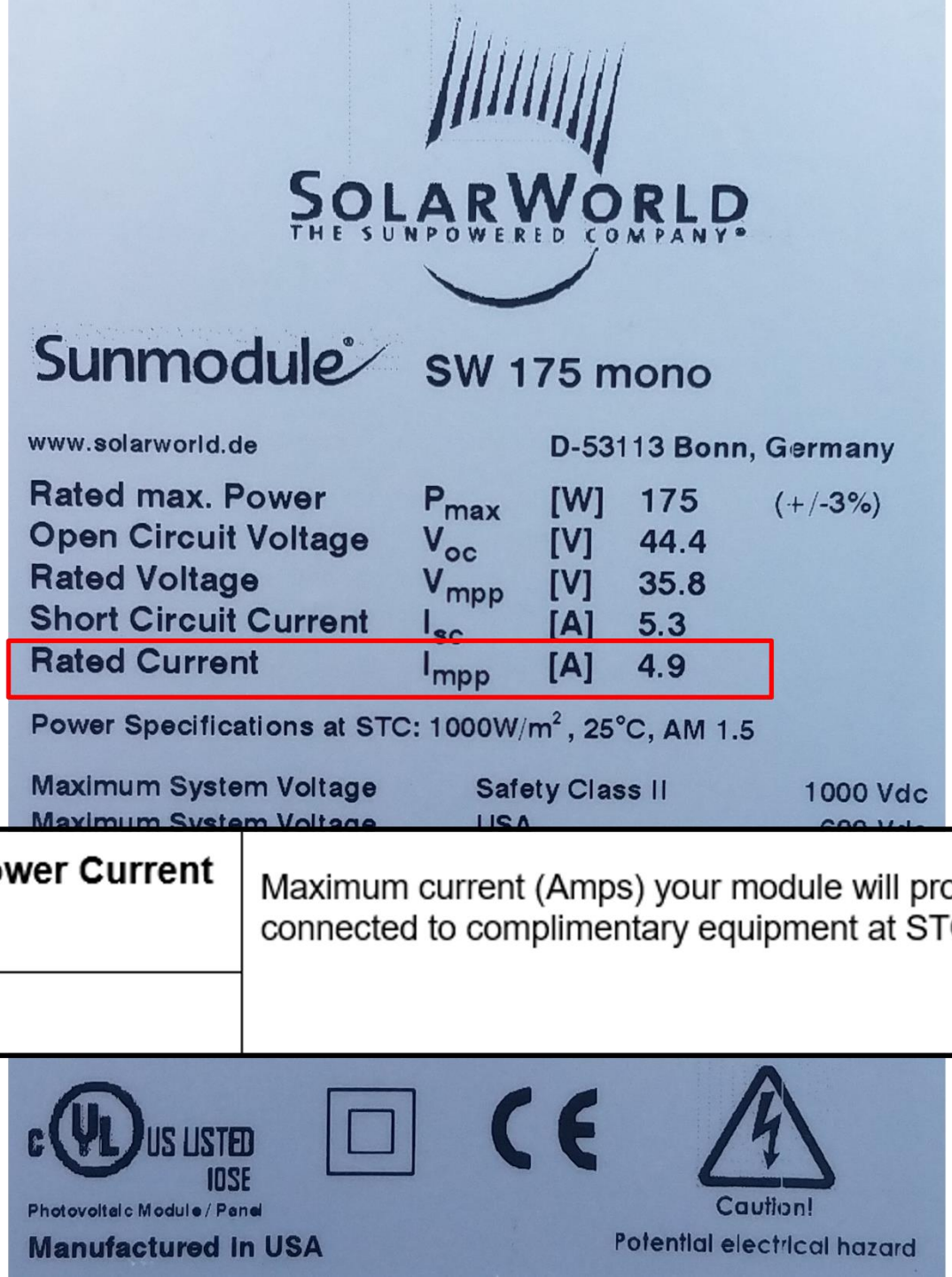
Short Circuit Current **Isc**	Current (Amps) your module will produce in a short circuit condition. This is the maximum Amps the module can produce at STC.
*	

Your Solar PV Module (15)



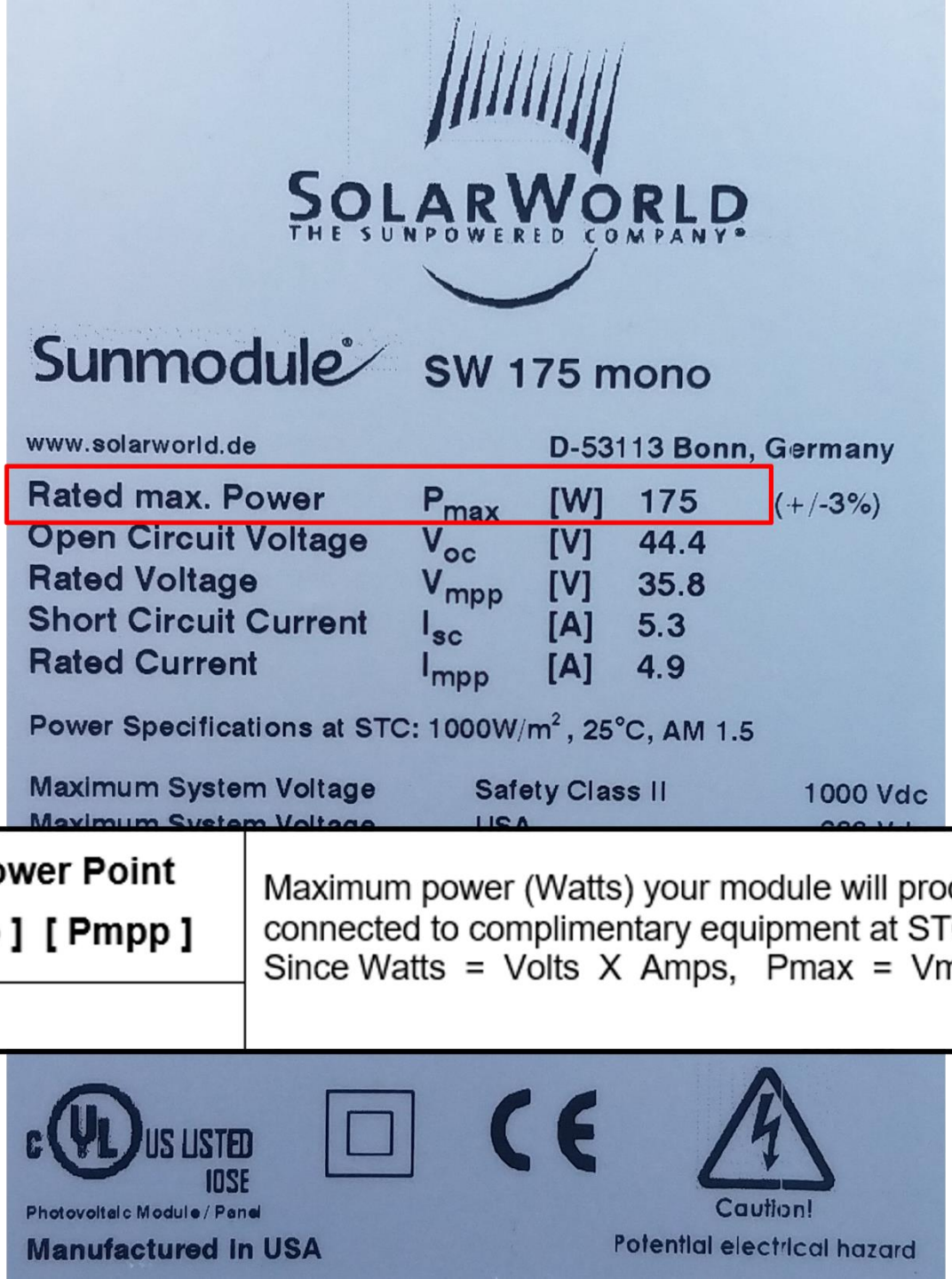
Maximum Power Voltage Vmp [Vmpp]	Maximum electric potential (Volts) of your module when connected to complimentary equipment at STC.
*	

Your Solar PV Module (16)



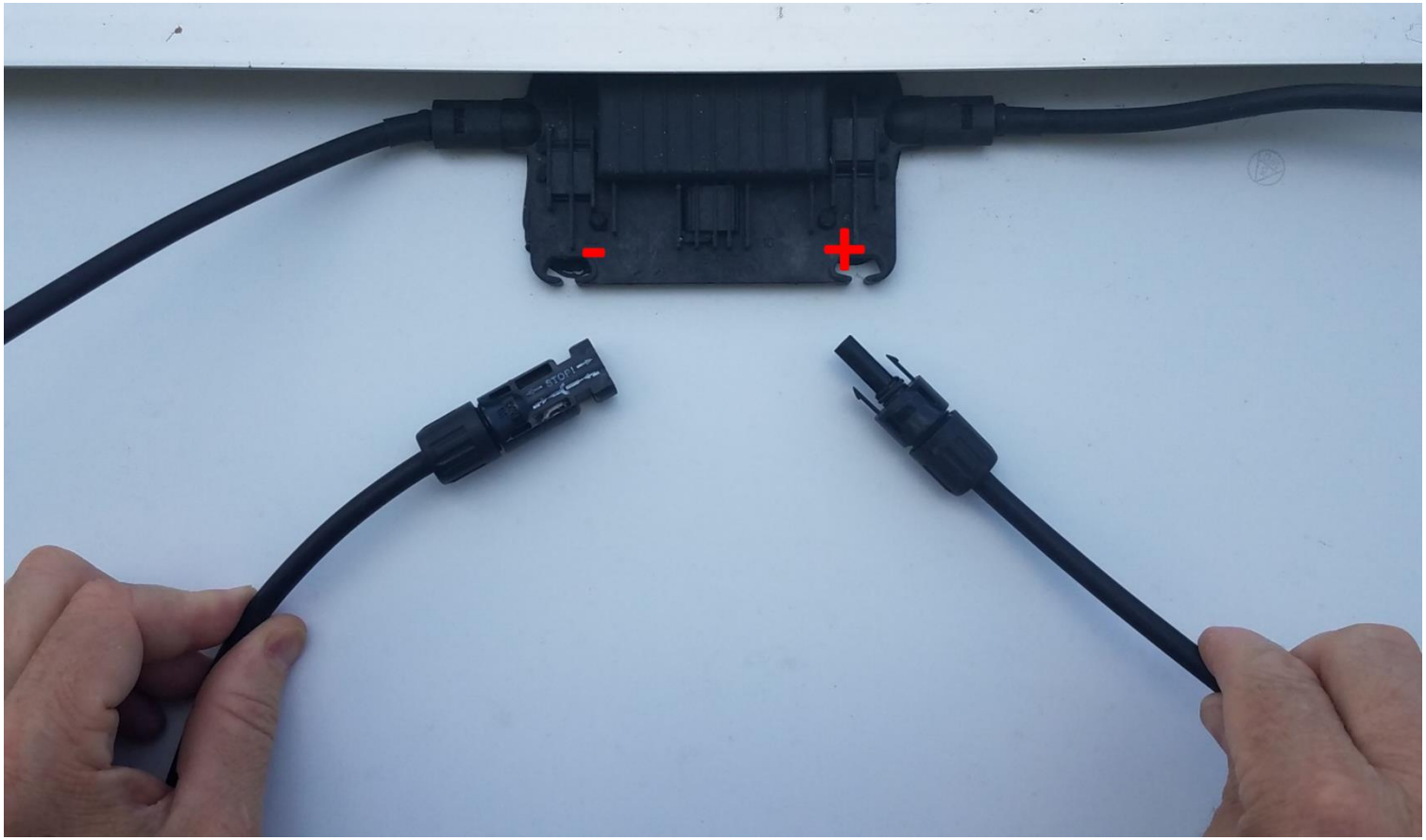
Maximum Power Current Imp [Impp]	Maximum current (Amps) your module will produce when connected to complimentary equipment at STC.
*	

Your Solar PV Module (17)

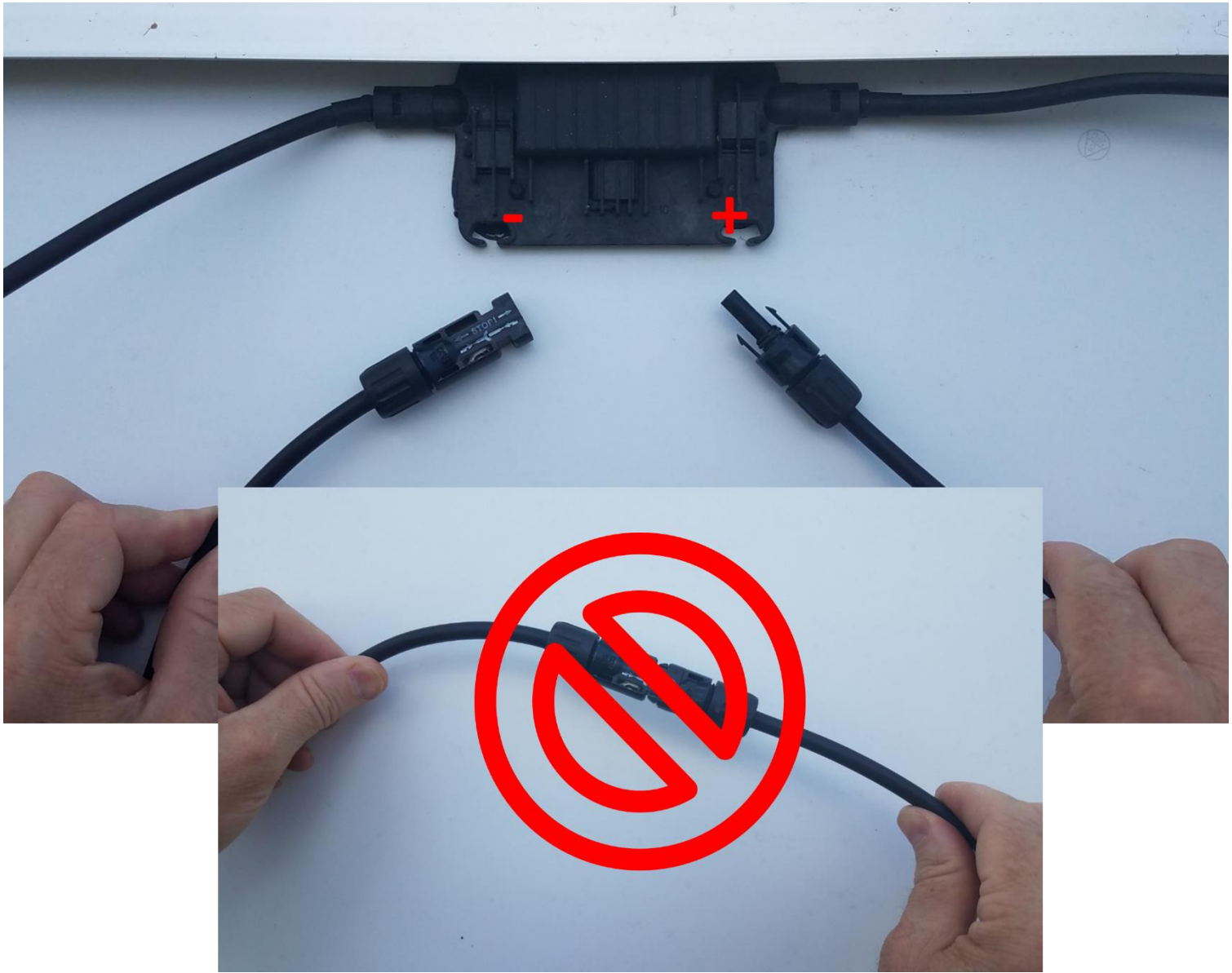


Maximum Power Point **Pmax [Pmp] [Pmpp]**	Maximum power (Watts) your module will produce when connected to complimentary equipment at STC. Since Watts = Volts X Amps, Pmax = Vmp X Imp.
*	

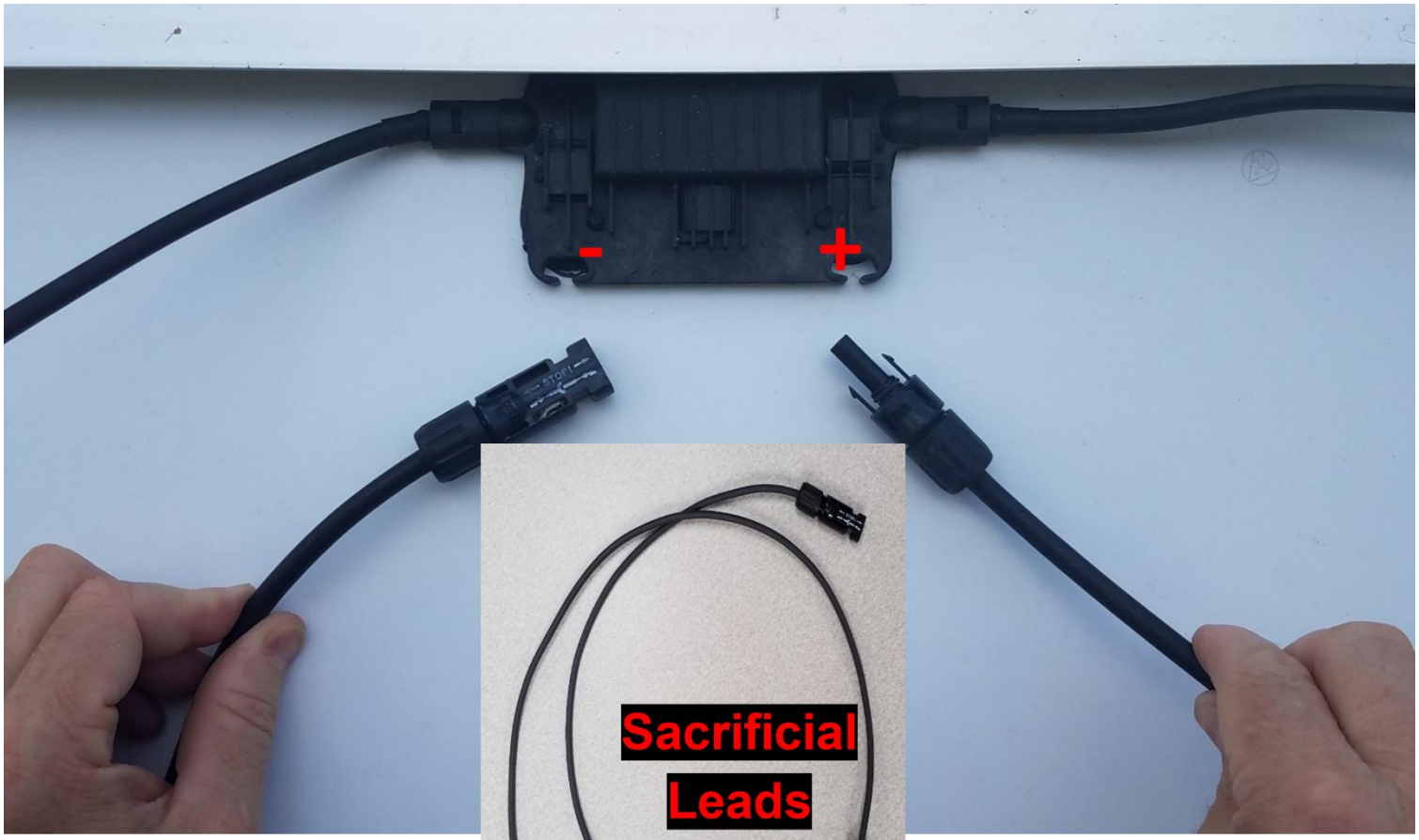
Your Solar PV Module (18)



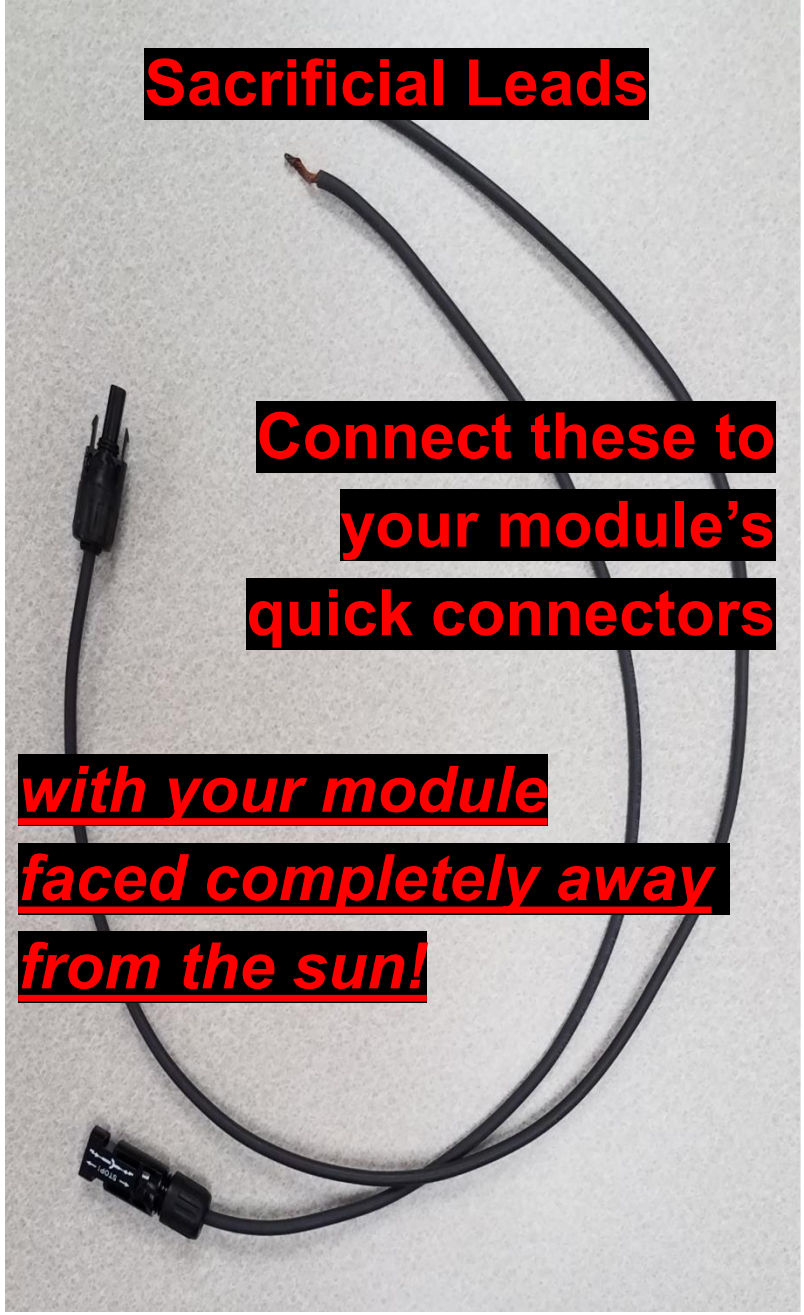
Your Solar PV Module (19)

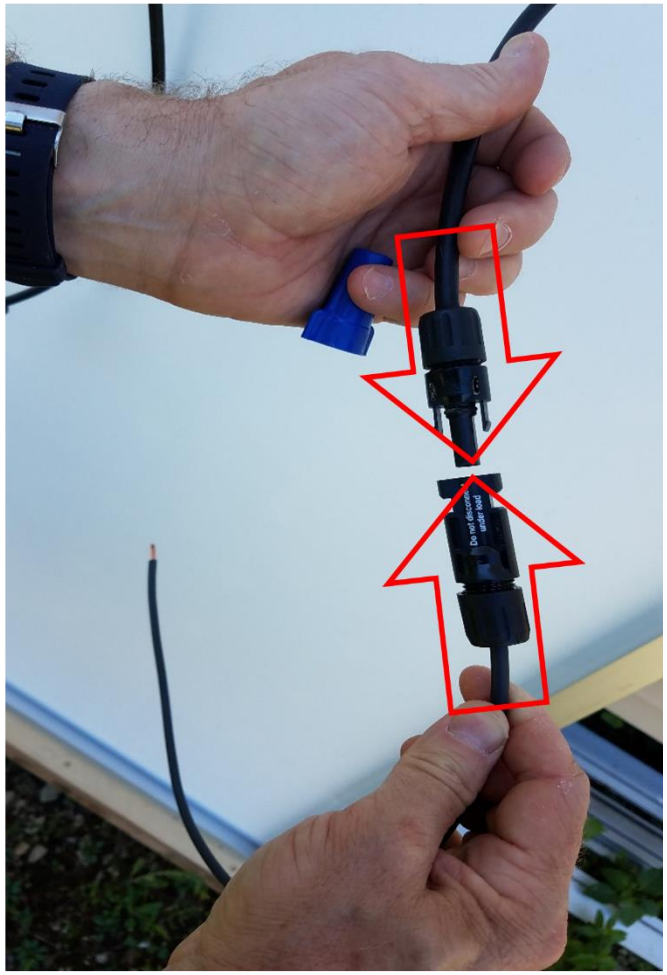


Your Solar PV Module (20)

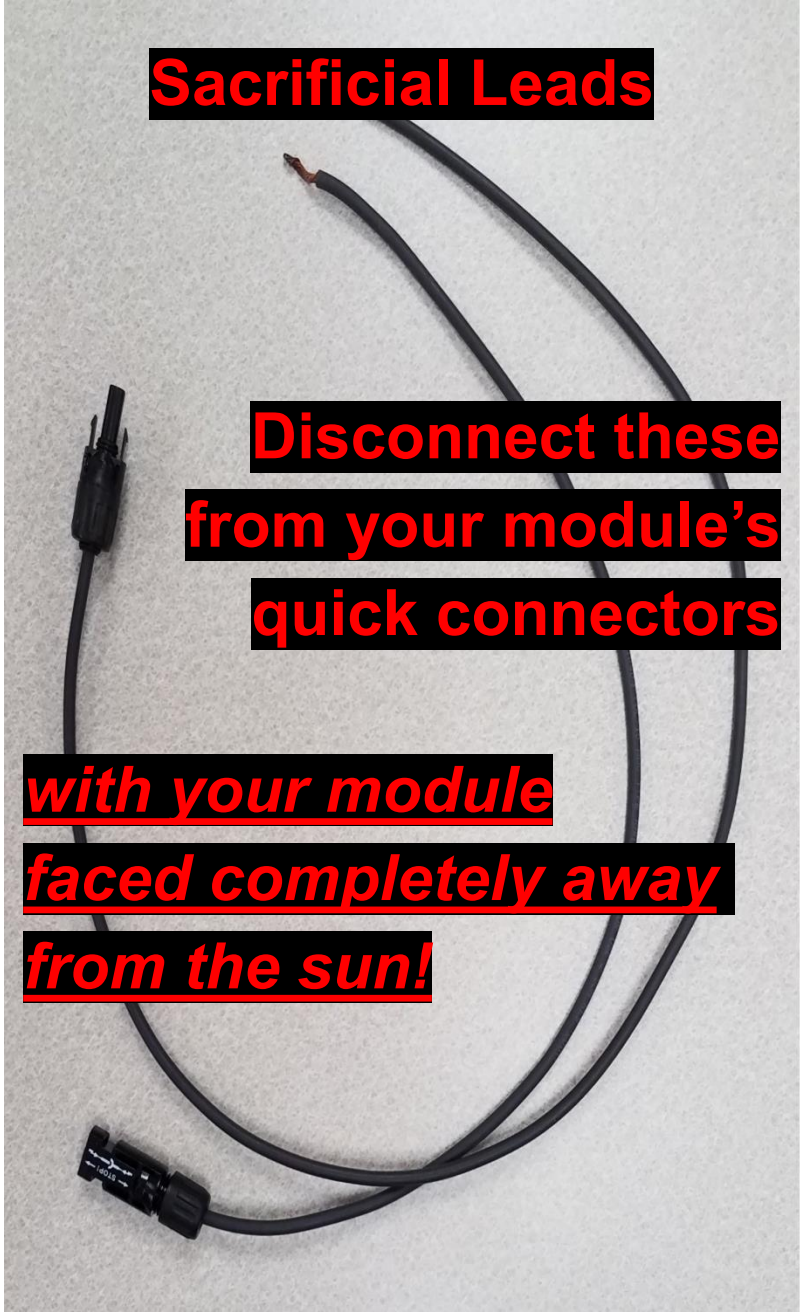


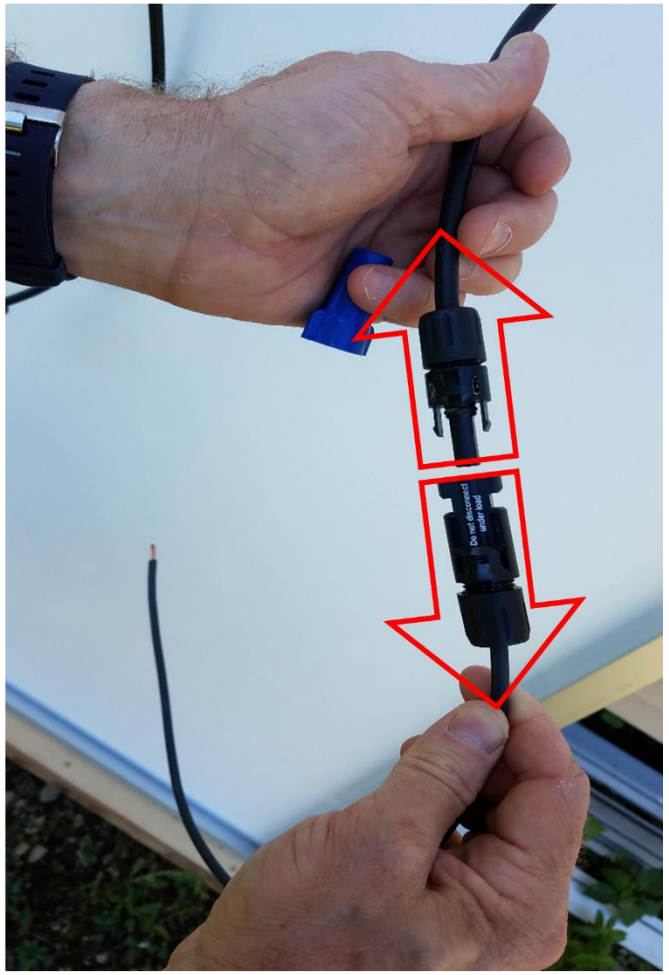
Your Solar PV Module (21)



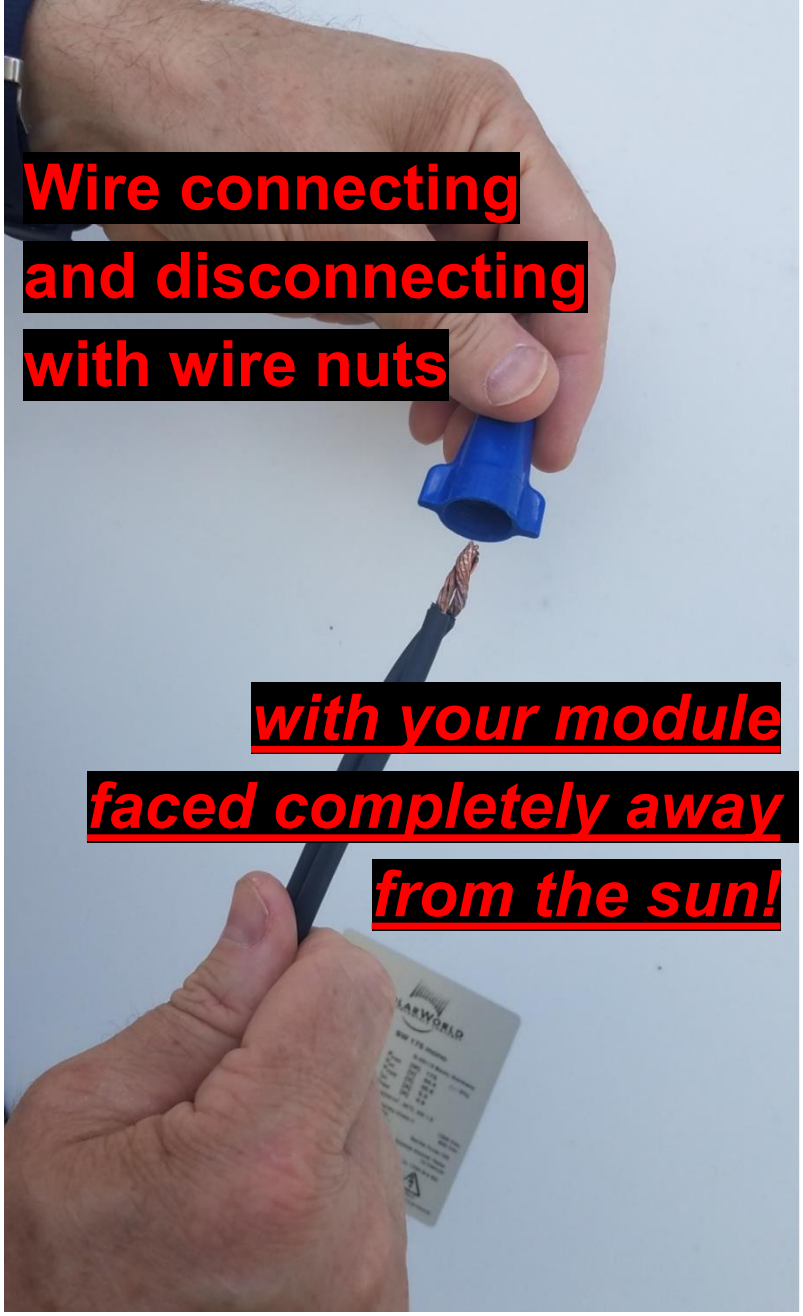


Your Solar PV Module (22)





Your Solar PV Module (23)



Your Solar PV Module (24)

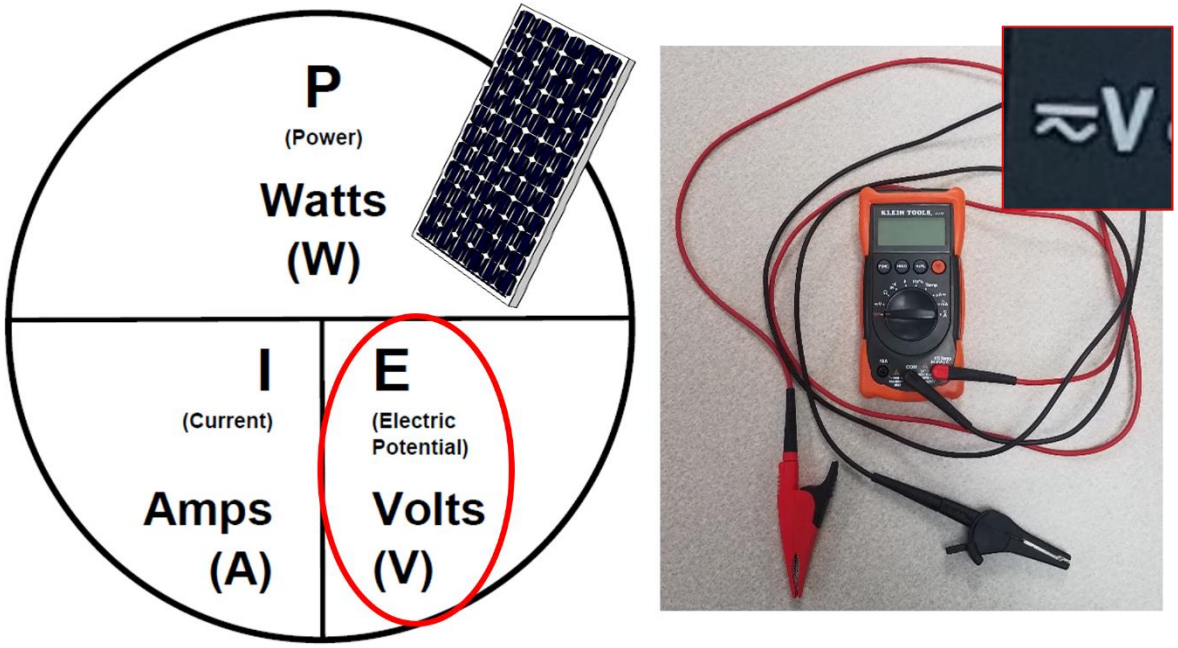
Never touch these two leads together with the module faced toward *the sun.* (click here)

Your Solar PV Module (25)

Table 1.	a.	b.	c.	d.
				
Module position or orientation ▼	Irradiance **W/m²**	Temperature **°C**	Electric Potential (Volts) open circuit condition **Voc**	Current (Amps) short circuit condition **Isc**

Your Solar PV Module (26)

Your Solar PV Module (27)



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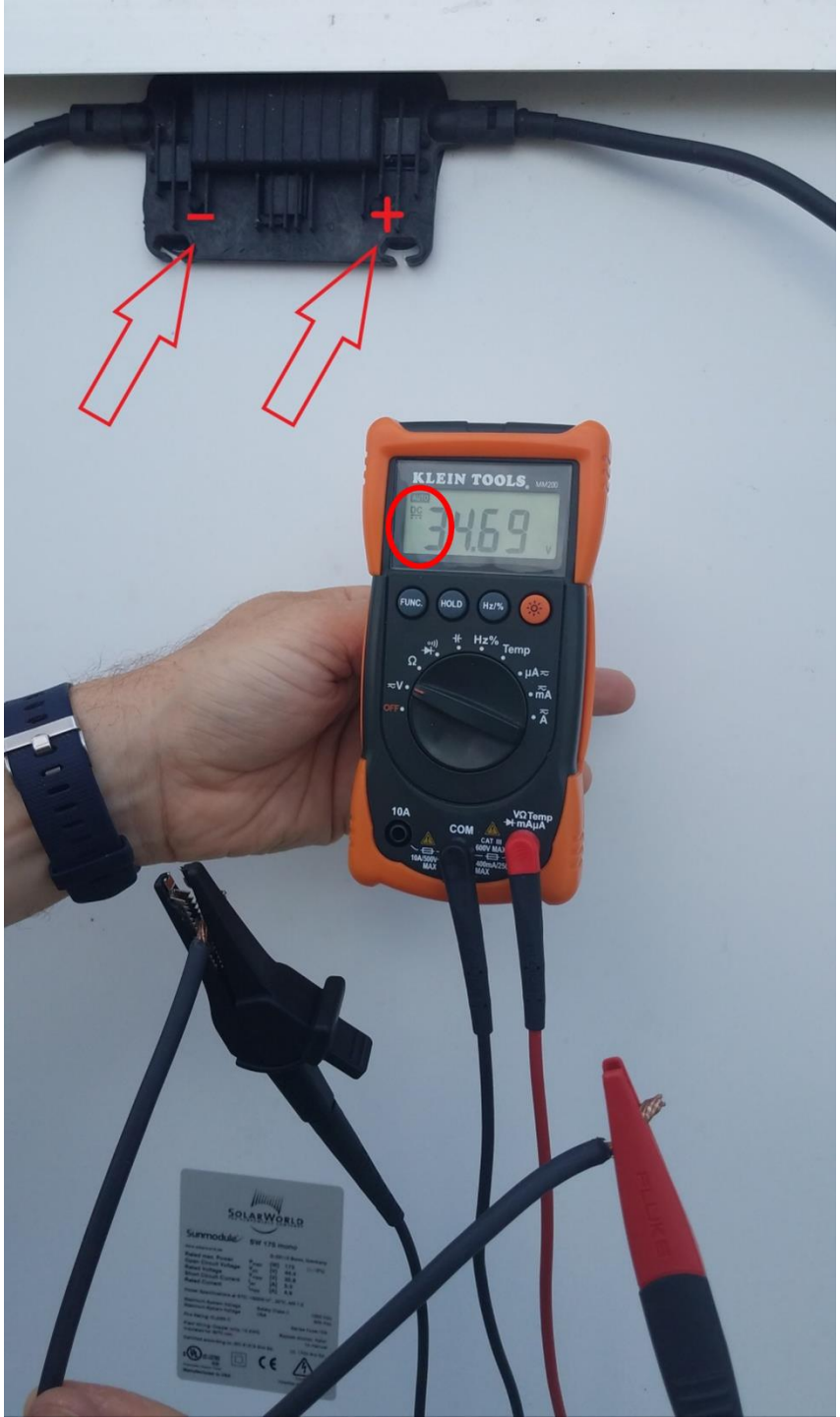
Your Solar PV Module (28)



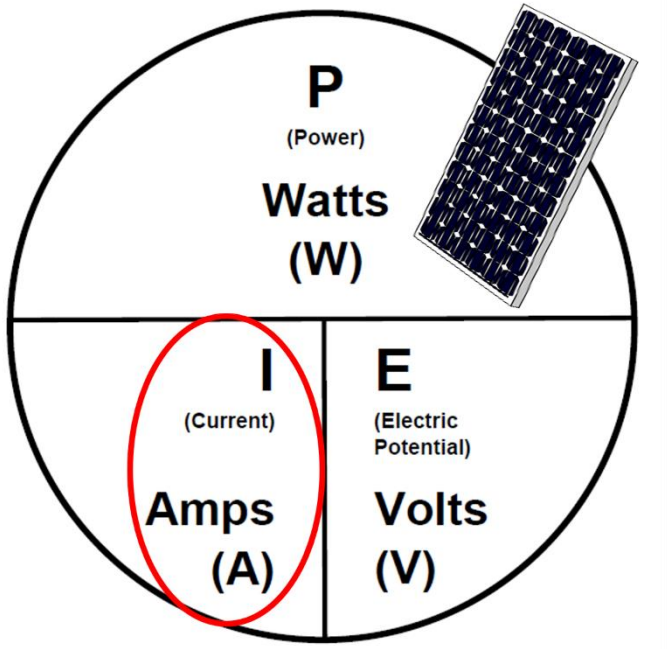
Your Solar PV Module (29)

Your Solar PV Module (30)

Table 1.	a.	b.	c.	d.
				
Module position or orientation ▼	Irradiance **W/m²**	Temperature **°C**	Electric Potential (Volts) open circuit condition **Voc**	Current (Amps) short circuit condition **Isc**

Your Solar PV Module (31)

Your Solar PV Module (32)



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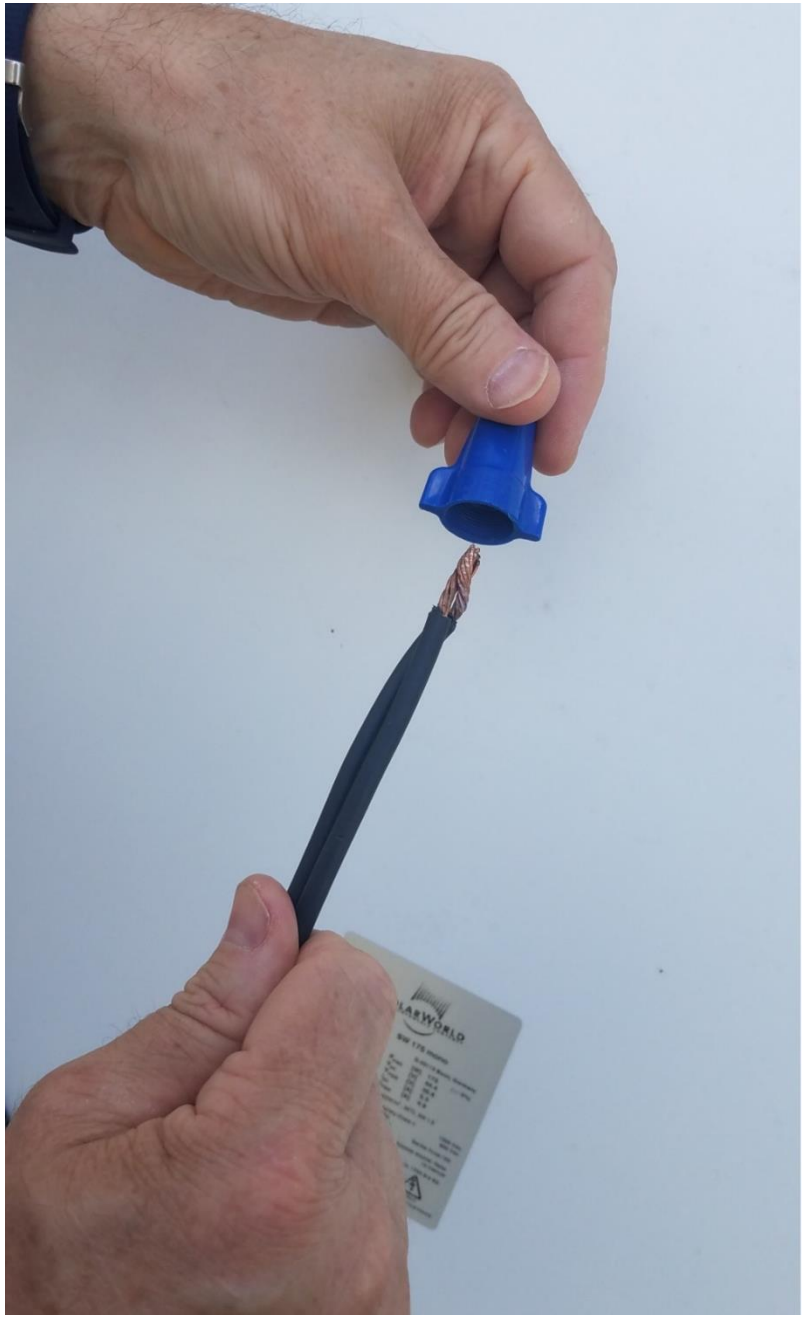
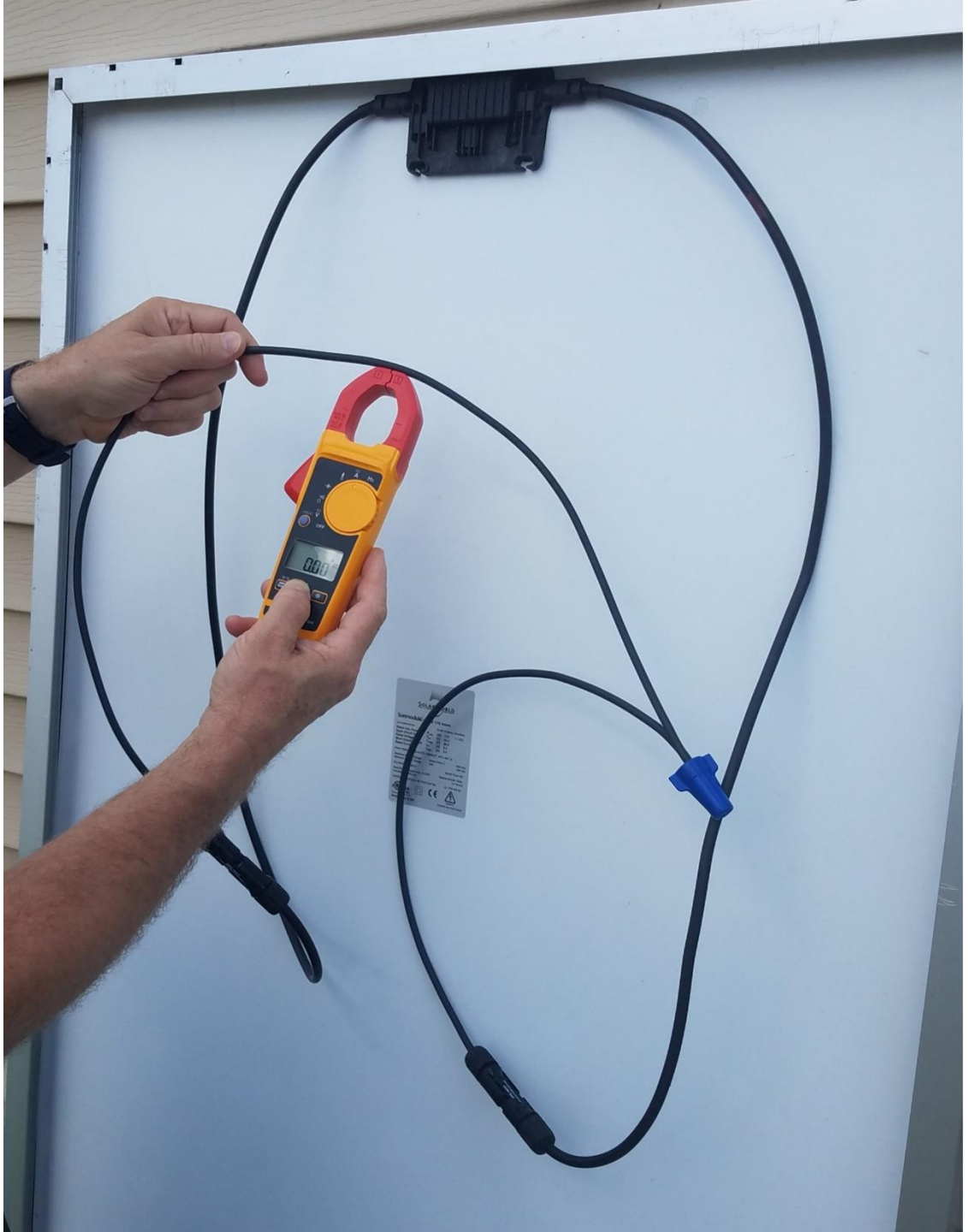
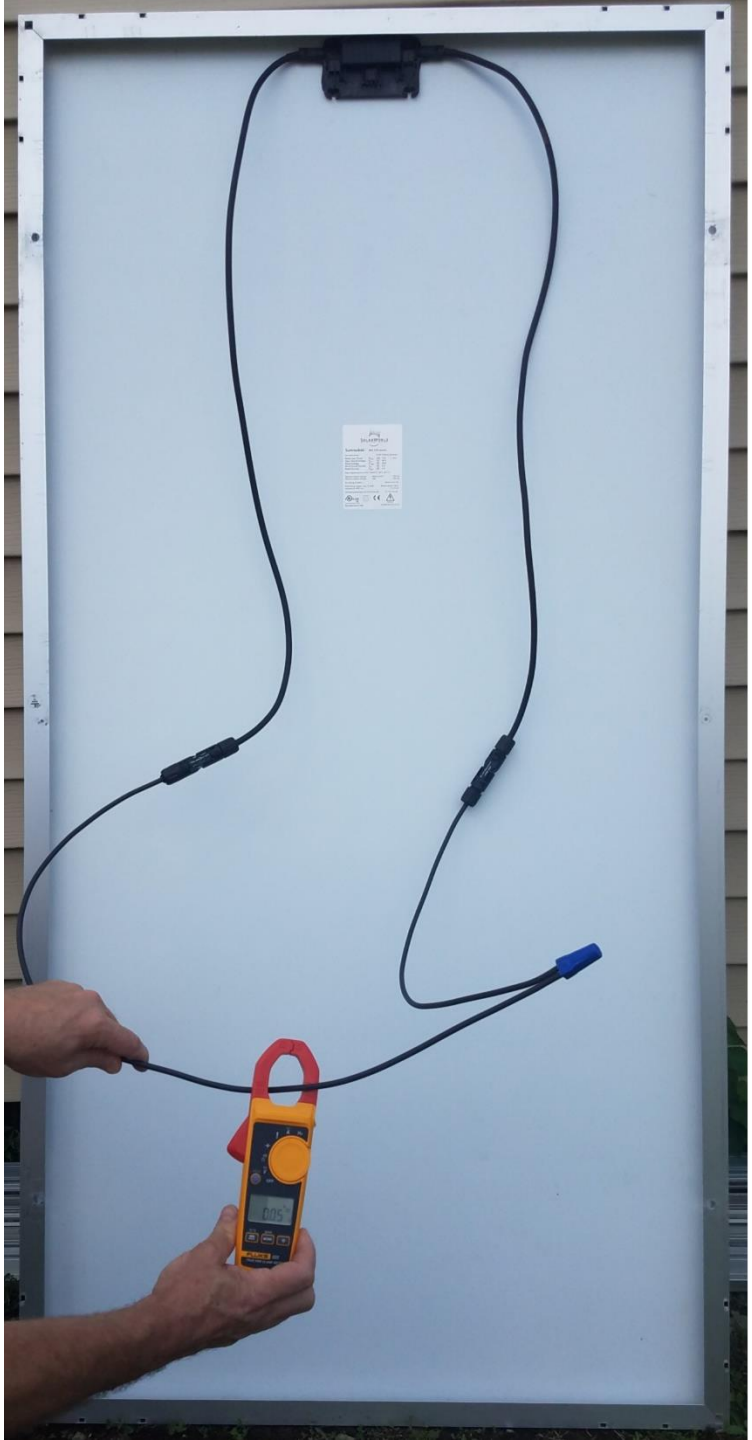
Your Solar PV Module (33)



Your Solar PV Module (34)



Your Solar PV Module (35)



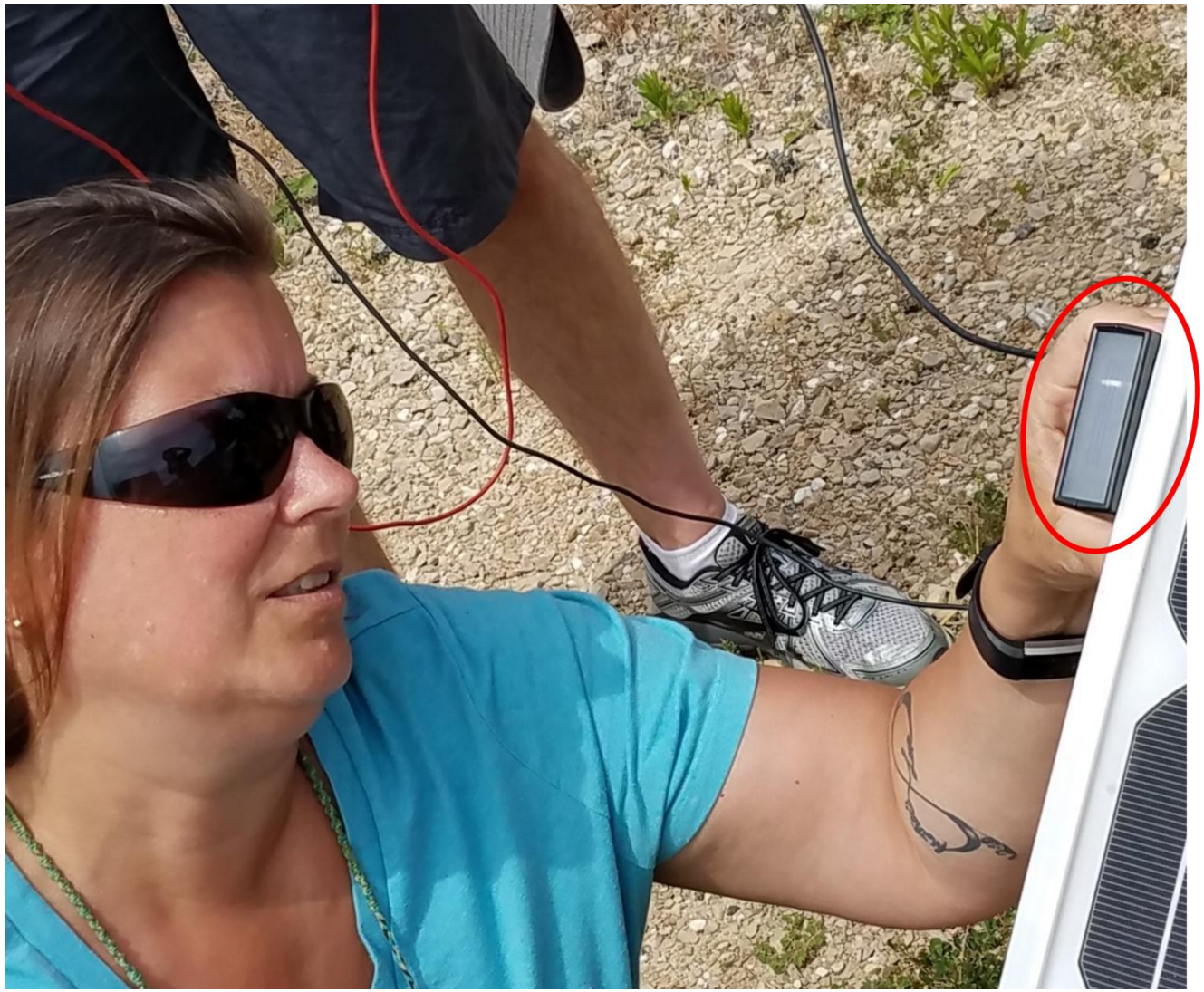
Your Solar PV Module (36)

Using a Pyranometer (1)

Table 1.	a.	b.	c.	d.
				
Module position or orientation ▼	Irradiance **W/m²**	Temperature **°C**	Electric Potential (Volts) open circuit condition **Voc**	Current (Amps) short circuit condition **Isc**

Using a Pyranometer (2)

Using a Pyranometer (3)



Using an Infrared Thermometer (1)

Table 1.	a.	b.	c.	d.
				
Module position or orientation ▼	Irradiance **W/m²**	Temperature **°C**	Electric Potential (Volts) open circuit condition **Voc**	Current (Amps) short circuit condition **Isc**

Using an Infrared Thermometer (2)

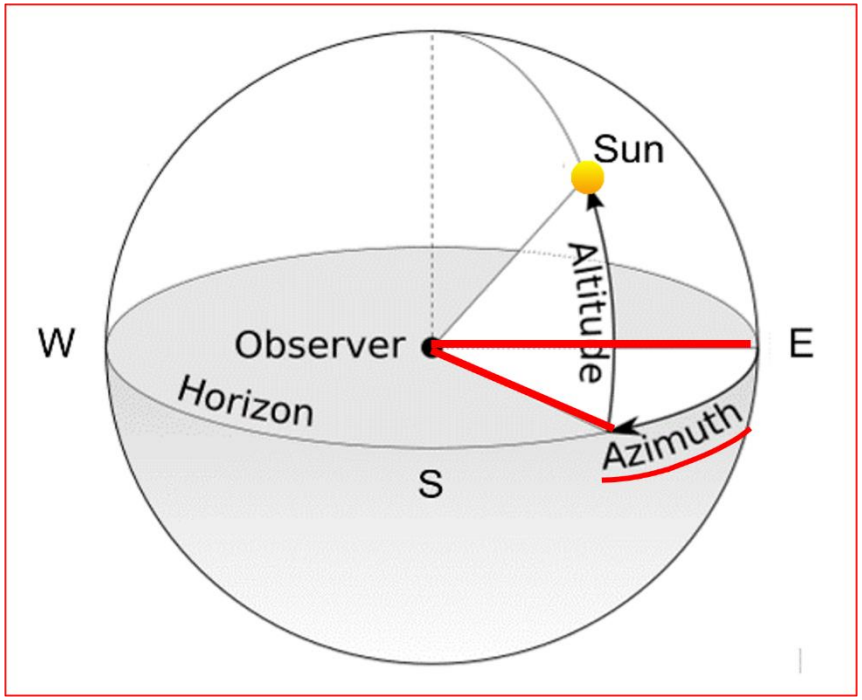
Module Positioning (1)

Table 1. **Module position or orientation** ▼	**a.**  Irradiance **W/m²**	**b.**  Temperature **°C**	**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 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Module Positioning (2)

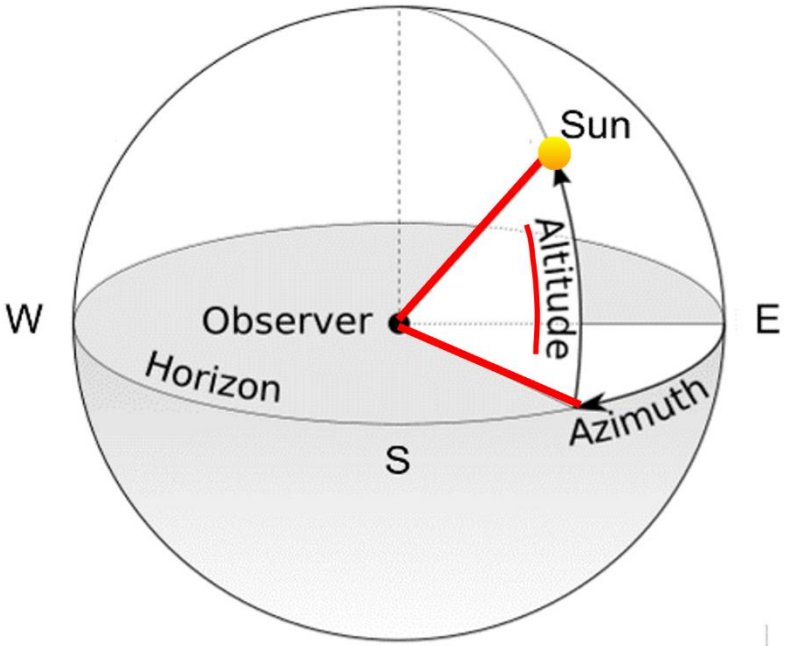
Table 1. **Module position or orientation** ▼	**a.**  Irradiance **W/m²**	**b.**  Temperature **°C**	**c.**  Electric Potential (Volts) open circuit condition **Voc**	**d.**  Current (Amps) short circuit condition **Isc**
1. Ideal direction and **ideal tilt angle**, **module cool** *Ideal azimuth and ideal tilt angle*	*	*	*	*
2. Ideal direction and **Vertical** (module upright at 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Module Positioning (3)



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)	The Ideal Tilt Angle we'll use for this lab is 90° - current Solar Altitude.
*	

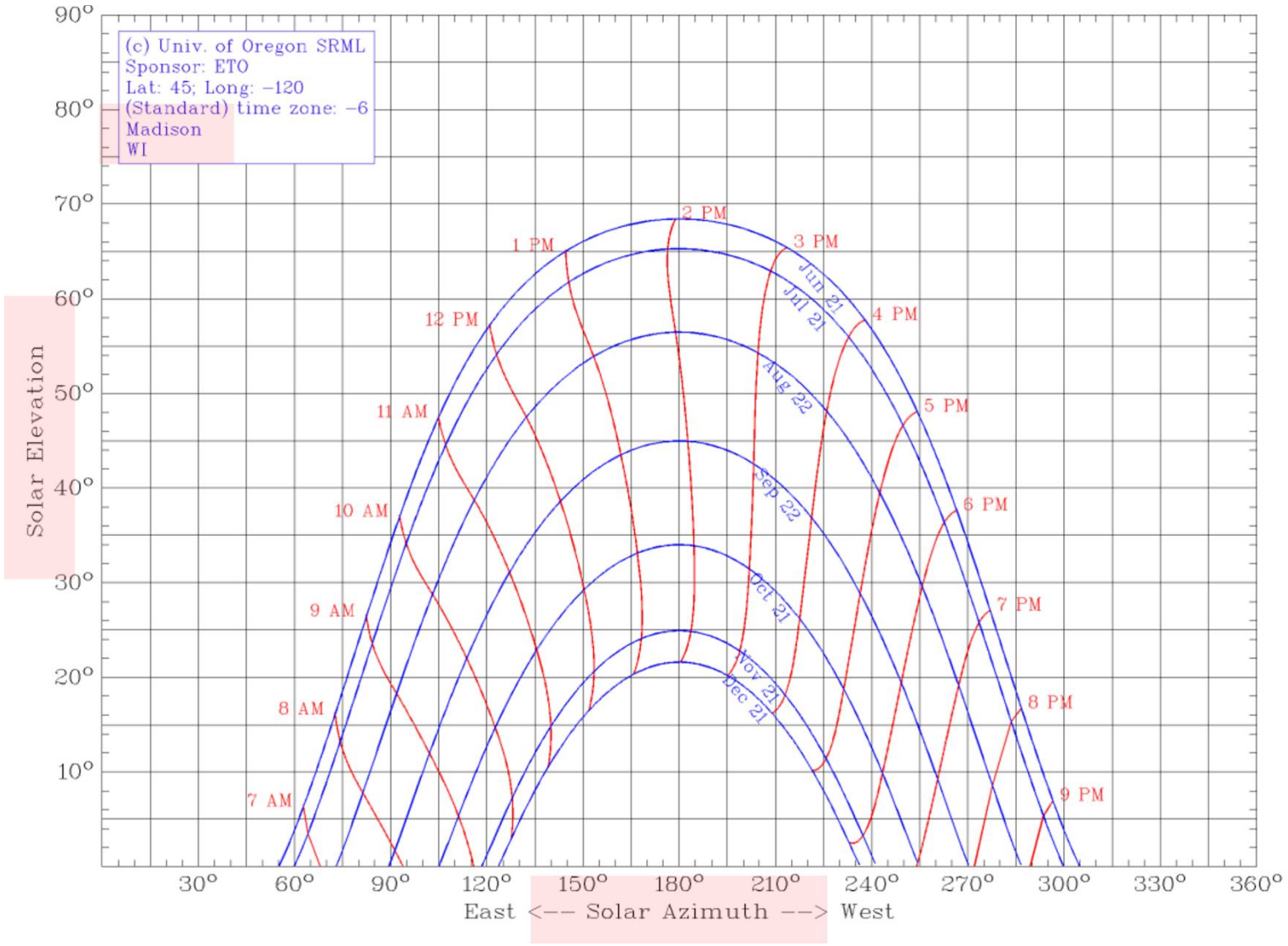
Module Positioning (4)



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)	The Ideal Tilt Angle we'll use for this lab is 90° - current Solar Altitude.
*	

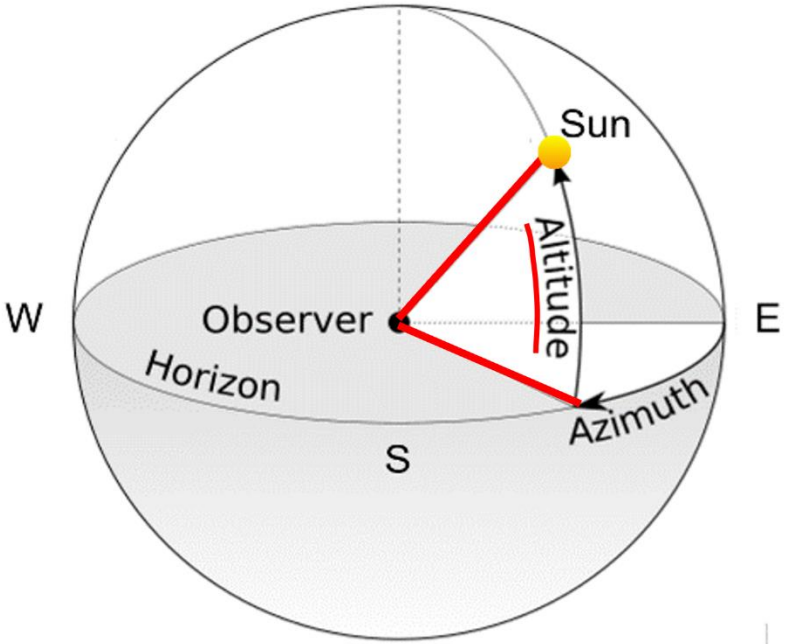
Module Positioning (5)

Module Positioning (6)



University of Oregon Sun Path Chart Program (click here)

Module Positioning (7)



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)	The Ideal Tilt Angle we'll use for this lab is 90° - current Solar Altitude.
*	

Module Positioning (8)

Table 1. **Module position or orientation** ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	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 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Module Positioning (9)

Table 1. **Module position or orientation** ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	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 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Module Positioning (10)

Table 1. **Module position or orientation** ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	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 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Module Positioning (11)

Table 1. **Module position or orientation** ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	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 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Module Positioning (12)

Table 1. **Module position or orientation** ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	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 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Module Positioning (13)

Reminders and Pointers (1)

Table 1. Module position or orientation ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	c.  Electric Potential (Volts) open circuit condition **Voc**	d.  Current (Amps) short circuit condition **Isc**
1. Ideal direction and **ideal tilt** *Ideal azi* *and idea*	▲	▲	▲	▲
2. Ideal (module *Ideal azi* *and 90°*				
3. Horiz flat on th *Azimuth* *and 0° ti*				
4. Facir (no sunli *0° azimu* *and 90°*				
5. Ideal **ideal tilt** *Ideal azi* *and idea*				

Before performing the lab, you'll practice taking each of these measurements in the shade…

…out of the sun with the module cool.

Reminders and Pointers (2)

Table 1. Module position or orientation ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	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 90°) *Ideal azimuth and 90° tilt angle*				
3. Horizontal (face up, flat on the ground) *Azimuth doesn't matter and 0° tilt angle*				
4. Facing north and **vertical** (no sunlight hitting module front) *0° azimuth and 90° tilt angle*				
5. Ideal direction and **ideal tilt angle**, **module warm** *Ideal azimuth and ideal tilt angle*	*	*	*	*

◄ To begin the lab, move your module into position in the sun and take your measurements as quickly as possible while the module is still cool.

Reminders and Pointers (3)

Perform lab activity position by position (L to R, top to bottom)

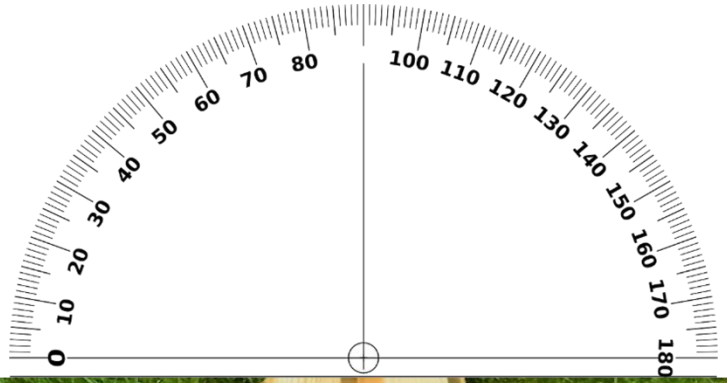
Table 1. **Module position or orientation** ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	c.  Electric Potential (Volts) open circuit condition **Voc**	d.  Current (Amps) short circuit condition **Isc**
1. Ideal direction and **ideal tilt angle**, **module cool** *Ideal azimuth and ideal tilt angle*	*	*	*	*
2. Ideal direction and **Vertical** (module upright at 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Reminders and Pointers (4)

Keep these two positions as identical as possible

Table 1. Module position or orientation ▼	a.  Irradiance **W/m²**	b.  Temperature **°C**	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 90°) *Ideal azimuth and 90° 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 0° 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) *0° azimuth and 90° 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*	*	*	*	*

Reminders
and
Pointers (5)



Module stand to set and keep your azimuth.

Protractor to help you find your tilt angles.

Reminders and Pointers (6)

Table 1.

Ideal azimuth and ideal tilt angle

a.  Irradiance **W/m²**	b.  Temperature **°C**	c.  Electric Potential (Volts) open circuit condition **Voc**	d.  Current (Amps) short circuit condition **Isc**
*	*	*	*
*	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.	*
*	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.	*
*	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.	*
*	*	*	*

Lesson Part Two: Experimenting With Module Shading (1)

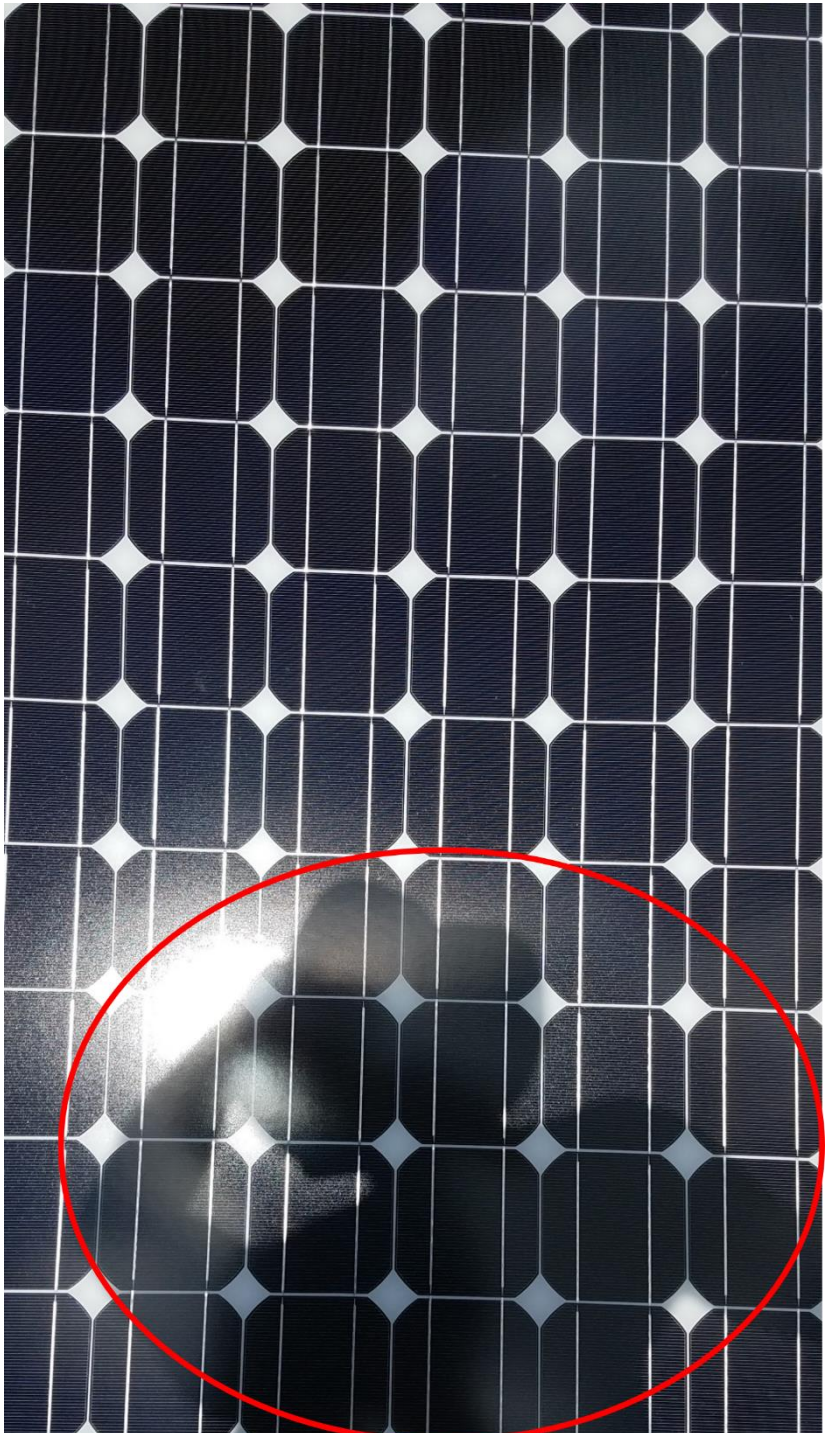
Table 2. Module position or orientation ▼	a.  Irradi-ance **W/m²**	b.  Temper-ature **°C**	c.  Electric Potential (Volts) open circuit condition **Voc**	d.  Current (Amps) short circuit condition **Isc**	
6. Ideal direction (azimuth), **ideal tilt angle**, and **one cell shaded**	*	*	*	*	*
7. Ideal direction (azimuth), **ideal tilt angle**, and **one row shaded**	*	*	*	*	*
8. Ideal direction (azimuth), **ideal tilt angle**, and **one column shaded**	*	*	*	*	*

Lesson Part Two: Experimenting With Module Shading (2)

Reminders and Pointers (7)

Reminders and Pointers (8)

Easy to accidentally make this mistake



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