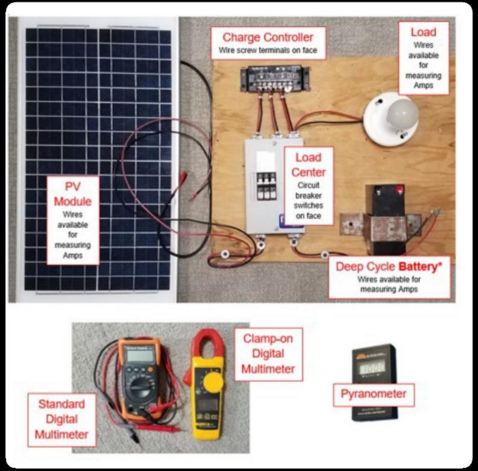
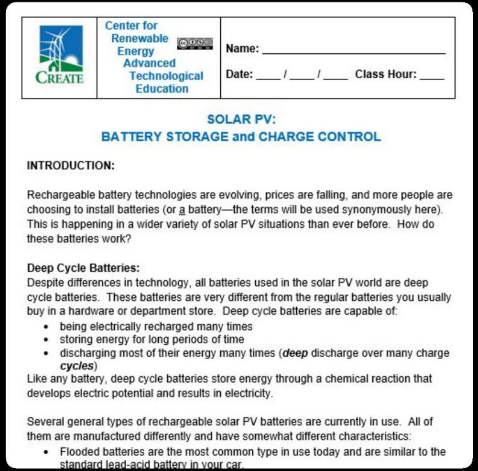
SOLAR PV: BATTERY STORAGE AND CHARGE CONTROL





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SOLAR PV:
BATTERY STORAGE and CHARGE CONTROL

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Several general types of rechargeable solar PV batteries are currently in use. All of them are manufactured differently and have somewhat different characteristics:

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CREATE Energy Storage Project

The goal of the CREATE Energy Storage Project is to advance the field of renewable energy by integrating energy storage technology into existing two-year college programs.

Disclaimer: this work was supported by the National Science Foundation award # 1800893 through the Advanced Technological Education program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Your Presenters

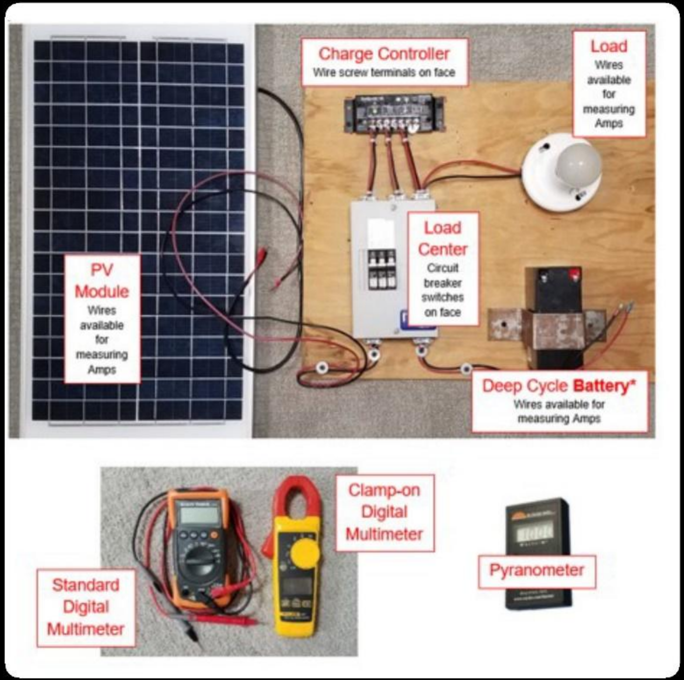
Scott Liddicoat

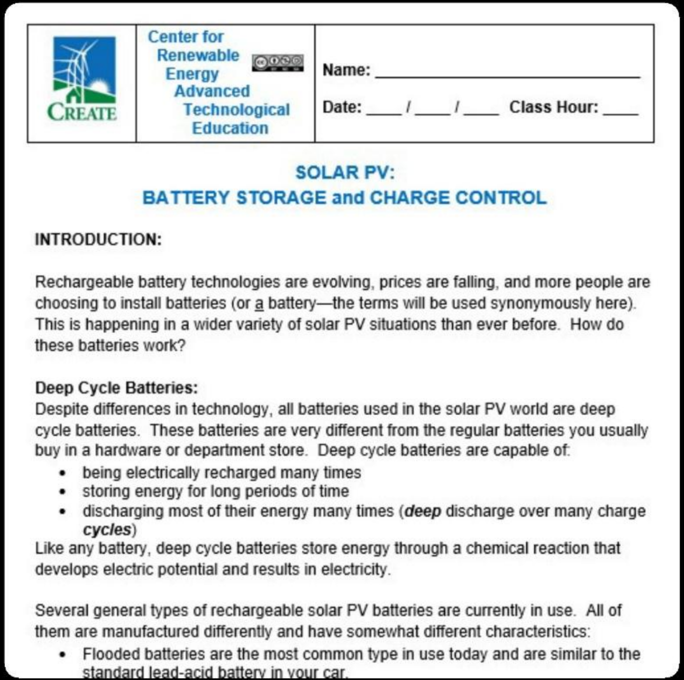
Green Bay Southwest High School

Joel Shoemaker

Madison College

SOLAR PV:
BATTERY STORAGE
AND CHARGE CONTROL





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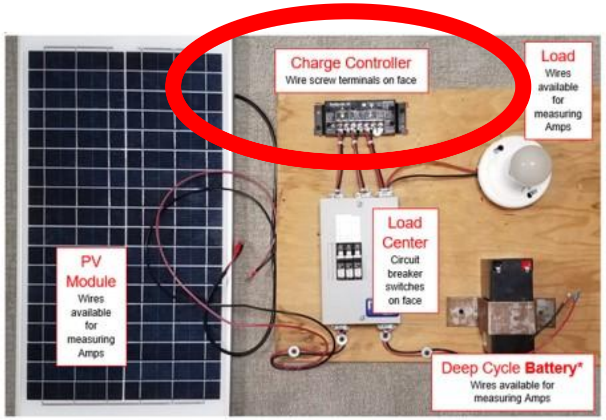
- **Understand the function of the charge controller in governing current flow in a renewable energy battery storage system.**



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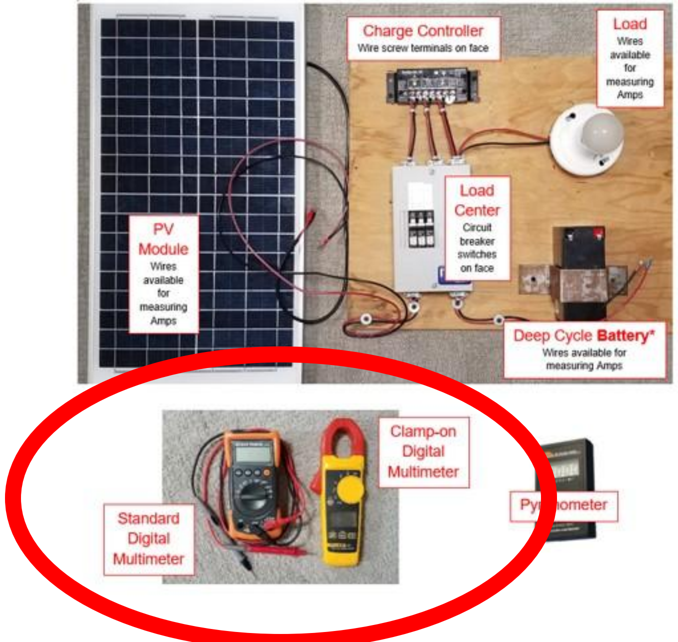
- Understand the function of the charge controller in governing current flow in a renewable energy battery storage system.
- Predict, measure, and explain electric potential (volts) and current (amps) in a variety of dynamic settings.



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- Understand the function of the charge controller in governing current flow in a renewable energy battery storage system.
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- Understand how to access this lesson (and others) on the CREATE website.
- **Understand the features available within this lesson for ease of teacher and student classroom use.**

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Joel **Scott**

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Have you attended a previous CREATE workshop? *

- ○ Yes
- ○ No

Grade level taught (check all that apply) *

- ☐ Middle School
- ☐ High School

CREATE

Center For Renewable Energy Advanced Technological Education

Teaching Materials

Solar Instructional Materials

The following instructional materials were developed as part of the CREATE Solar PV Institute faculty professional development workshops.

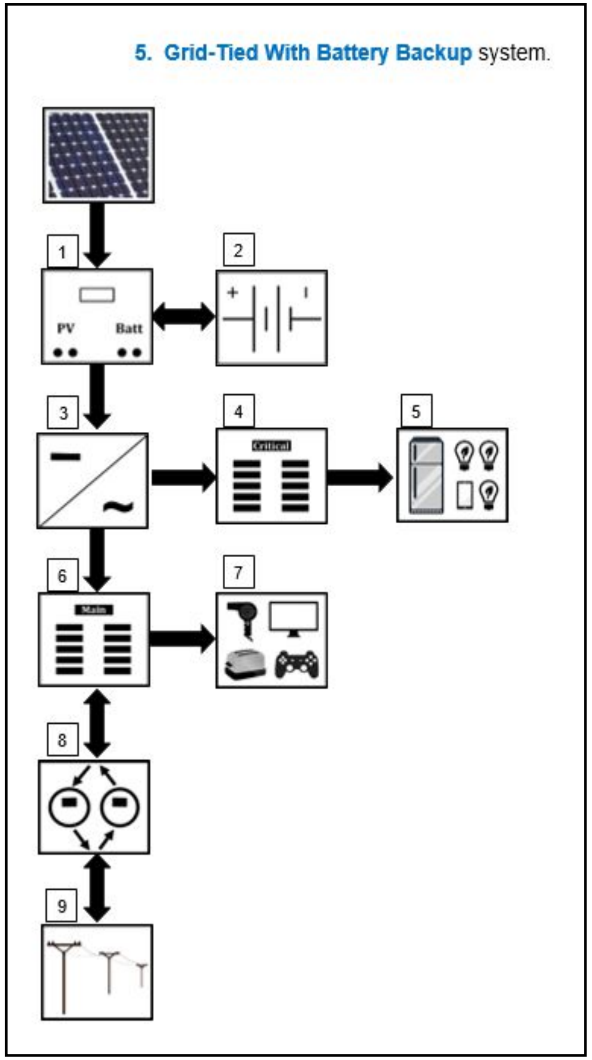
The documents below include teacher lesson plans, student handouts, answer keys, and resources for each of the lessons explored in the Solar Institutes. Documentation is also provided for each lesson referencing the US DOE Energy Literacy Standards (ELS) and the Next Generation Science Standards (NGSS).

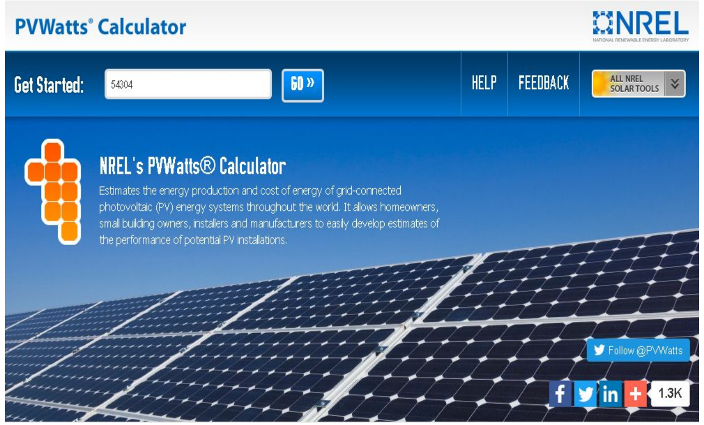
Documents are provided in .pdf format to preserve original formatting, and also in a .docx format that can be edited and customized by teachers for their specific application.

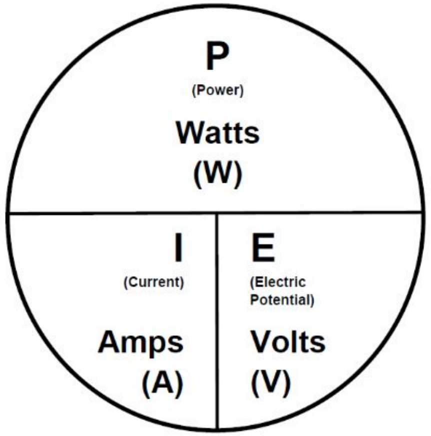
1a. Measuring Sunlight The Pyranometer Instructors Guide & Answer Key
.PDF | .DOCX

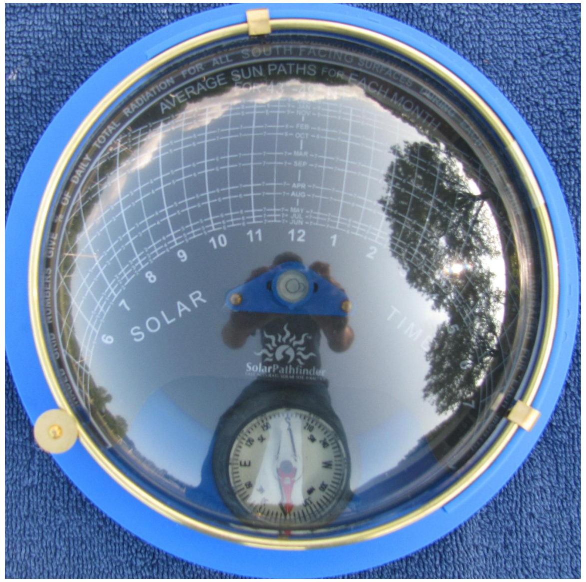
1b. Measuring Sunlight The Pyranometer Student Lesson & Response Guide

Six Teaching Activities Already Available









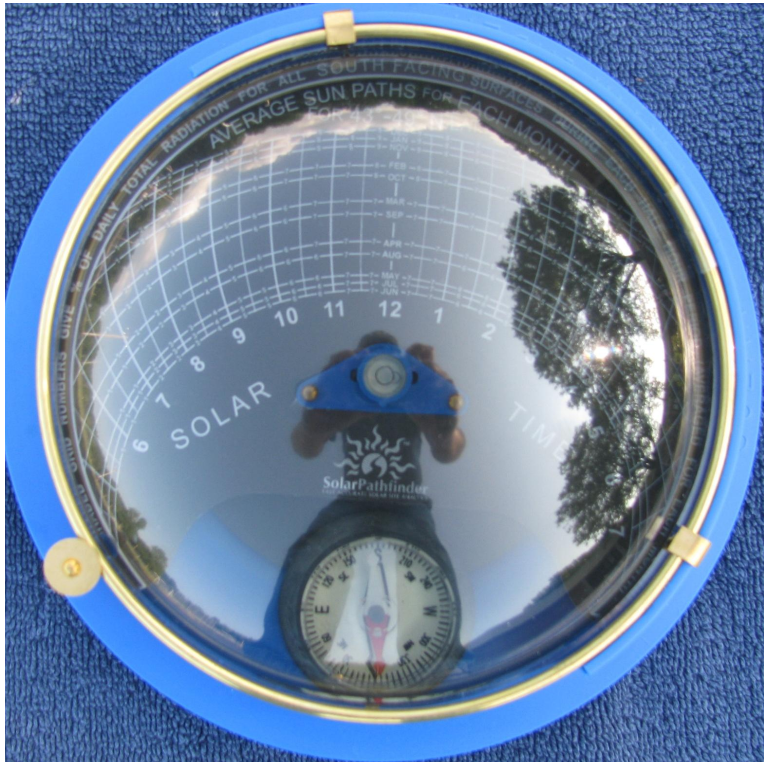
Six Teaching Activities Already Available

1. Measuring Sunlight: The Pyranometer

Six Teaching Activities Already Available

1. Measuring Sunlight: The Pyranometer

2. Solar Site Analysis: The Solar Pathfinder



Six Teaching Activities Already Available

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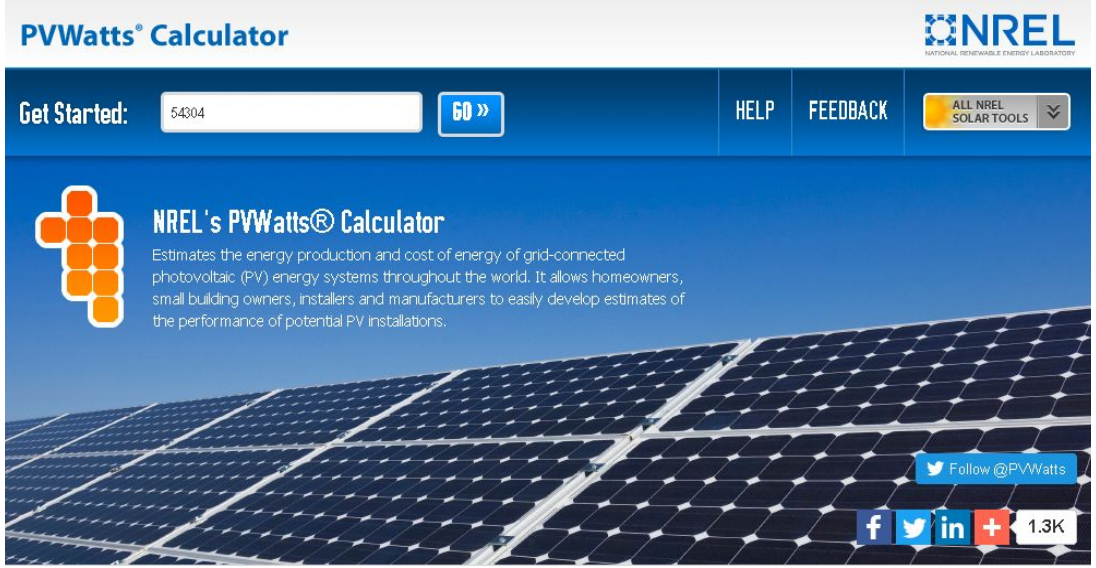
2. Solar Site Analysis: The Solar Pathfinder

3. Solar Location Analysis: The PVWatts Calculator



Six Teaching Activities Already Available

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2. Solar Site Analysis: The Solar Pathfinder

3. Solar Location Analysis: The PVWatts Calculator

4. Solar PV: Silicon

Six Teaching Activities Already Available

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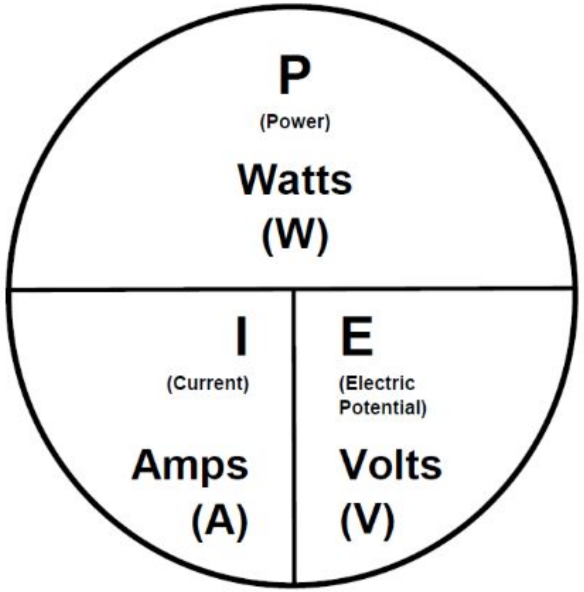
3. Solar Location Analysis: The PVWatts Calculator
4. Solar PV: Silicon
5. Solar PV: Watts From The Sun



Six Teaching Activities Already Available

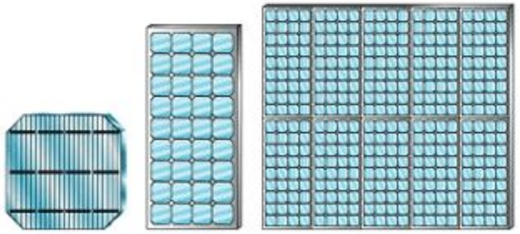
1. Measuring Sunlight: The Pyranometer

2. Solar Site Analysis: The Solar Pathfinder

3. Solar Location Analysis: The PVWatts Calculator

4. Solar PV: Silicon

5. Solar PV: Watts From The Sun (Volts and Amps)



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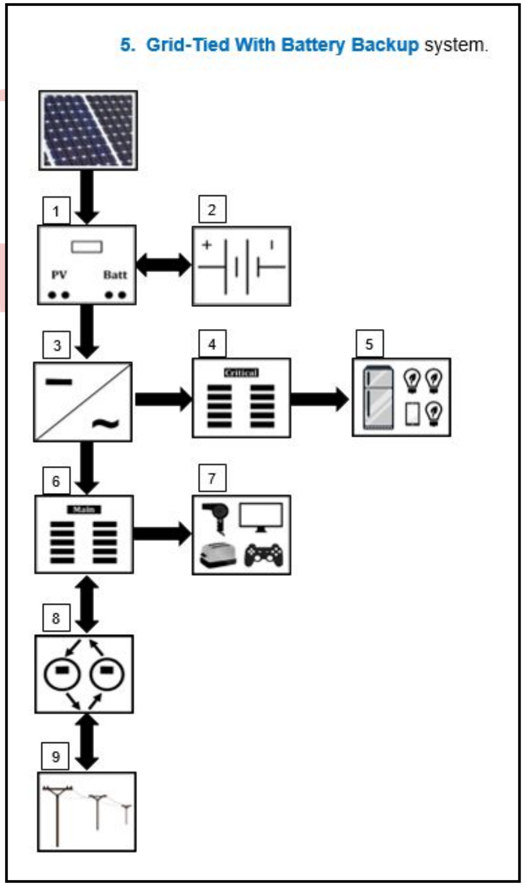
5. Solar PV: Watts From The Sun
6. Solar PV: Balance Of System And System Design



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6b. (Still in production)

6c. (Still in production)

7a.Solar PV Battery and Charge Controller Student Lesson and Response Guide
.PDF | .DOCX

7b. Solar PV Battery and Charge Controller Teacher Answer Key
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7c. (Still in production)

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Now it's time for you to see how a deep cycle battery and charge controller function under normal operating conditions. In this lab you will:

- Predict, measure, and explain electric potential (volts) and current (amps) in a variety of dynamic settings.
- Understand the function of the charge controller in governing current flow in a renewable energy battery storage system

PROCEDURE:

This lab assumes you are outdoors, and your PV module is in full sun. As you begin the lab, you are plainly starting in sunny, daytime conditions.

1. Check to ensure all three circuit breakers at the load center are switched off. Switched off at the load center, the circuits from the PV module, the battery, and the load are all open circuits.

2. Connect the PV module to the wires from the load center. Then connect the battery to the wires from the load center.

3. Before you measure the electric potential on the battery:

- * What do you expect this measurement to be?

4. Measure the electric potential *on the* <u>*wires* from the battery</u> in DC volts.

- * What is your actual measurement?

Q2. Before going further, explain how you knew what the actual measure would be (or how you could or should have known).

*** Answer**

5. Before you measure the electric potential on the PV module:

- * What do you expect this measurement to be?

6. Measure the electric potential *on the* <u>*wires* from the PV module</u> in DC volts.

- * What is your actual measurement?

Q3. Before going further, explain how you knew what the actual measure would be (or how you could or should have known).

*** Answer**

7. Before you measure the electric potential on the load:

- * What do you expect this this measurement to be?

8. Measure the electric potential *on the* <u>*terminals* of the charge controller from the load</u> in DC volts.

- * What is your actual measurement?

Q4. Before going further, explain how you knew what the actual measure would be (or how you could or should have known).

*** Answer**

Facing pages are strategically arranged

25. Turn off the switch for the PV module at the load center. Doing this opens the circuit from the PV module to the charge controller, preventing the module from producing current. Even though your PV module is still in the sun, you are now essentially, simulating nighttime conditions.

26. Before completing the measurements indicated in the following table (**Table 3.**), what do you expect your measurements to be? Write them into **Table 3**.

27. Now complete **Table 3.** by writing your actual measurements into the table.

Table 3. Device:	Electric potential in **Volts** (measured at the charge controller terminals)		Current in **Amps** (measured on the wires for each device)	
	Expected	Actual	Expected	Actual
Load	*	*	*	*
Battery	*	*	*	*

Q15. Why is the current on the load wire the same as the current on the battery wire?

* Answer

SHOW WHAT YOU KNOW:

Q16. A solar PV system with batteries is considerably more expensive than a grid-tied system. The owner of grid-tied only system sells the electricity they produce to their utility and buys what they can't produce from the utility. No battery storage is needed.

Despite the added expense, provide three good reasons why many people still choose to install a solar PV system with battery storage.

Read what's written next to all three blanks before writing about any one of them.

16-1. Provide a reason that is primarily place or location dependent.

*Answer

16-2. Provide a reason that is situation dependent, and different than your answer above.

Post lab questions

*Answer

16-3. Provide a third reason that is different from either of your previous answers.

* Answer

Q17. Naturally a system without batteries will not need a charge controller. A PV system of this kind is almost always connected to the local electricity grid. A PV system without batteries that is connected to the local energy utility grid is said to be "grid-tied."

Provide two good and different reasons why many people choose a grid-tied PV system over one with battery storage.

17-1. * Answer

17-2. * Answer

- **Energy Literacy Standards**

  and
- **Next Generation Science Standards (potentially) satisfied**

[posted soon]

2d. Standards Advanced ELS Pathfinder
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2e. Standards Advanced NGSS Pathfinder
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Other nice features:

Other nice features:

- **Teacher answer key on CREATE website.**

7b. Solar PV Battery and Charge Controller Teacher Answer Key
.PDF | .DOCX

Other nice features:

- **Teacher answer key on CREATE website.**
- **Available as PDF or MSWord document. This (along with our copyright) enables you to alter the document to your specific situation.**

7a.Solar PV Battery and Charge Controller Student Lesson and Response Guide
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Load	*	*	*	*
Battery	*	*	*	*

Q15. Why is the current on the load wire the same as the current on the battery wire?

* Answer

Madison College Materials List For This Lab:

- 12 Volt rechargeable battery [~$25]
  AGB (Absorbed Glass Mat), enclosed Lead/Acid
  7.2 Amp-Hour deep cycle solar
- Charge Controller [~$75]
  Morningstar Sun Saver 10L
  Rated 12 volts, up to 10 amps
- PV Module [~$100]
  Dasol DS-A18-30, 30 Watt module
- Load Center [~$50]
  4 circuit breaker openings available, of which we use 3
- 3 DC rated circuit breakers [~$10 each]
  Rated up to 250 volts, up to 10 amps
- Standard metal octagon electrical box
- Plastic keyless lamp holder
- 25 Watt, 12 Volt incandescent lamp [~$3]
- Clamp-on multimeter capable of measuring DC amps [~$150]
- Standard digital multimeter to measure DC volts [~$40]
- Pyranometer [~$170]
  Daystar
- Electrical wire, 8-10 feet
  Romex 14 AWG / 2 Conductors (cut bare ground off at open ends)
  Color white wire with permanent red marker at open ends
- Male and female wire spade connectors (appropriate crimping tool needed)
- 6 -1/2 inch Romex cable connectors
- Romex electrical wire staples
- 3/8 inch plywood board, roughly 18 inches X 24 inches

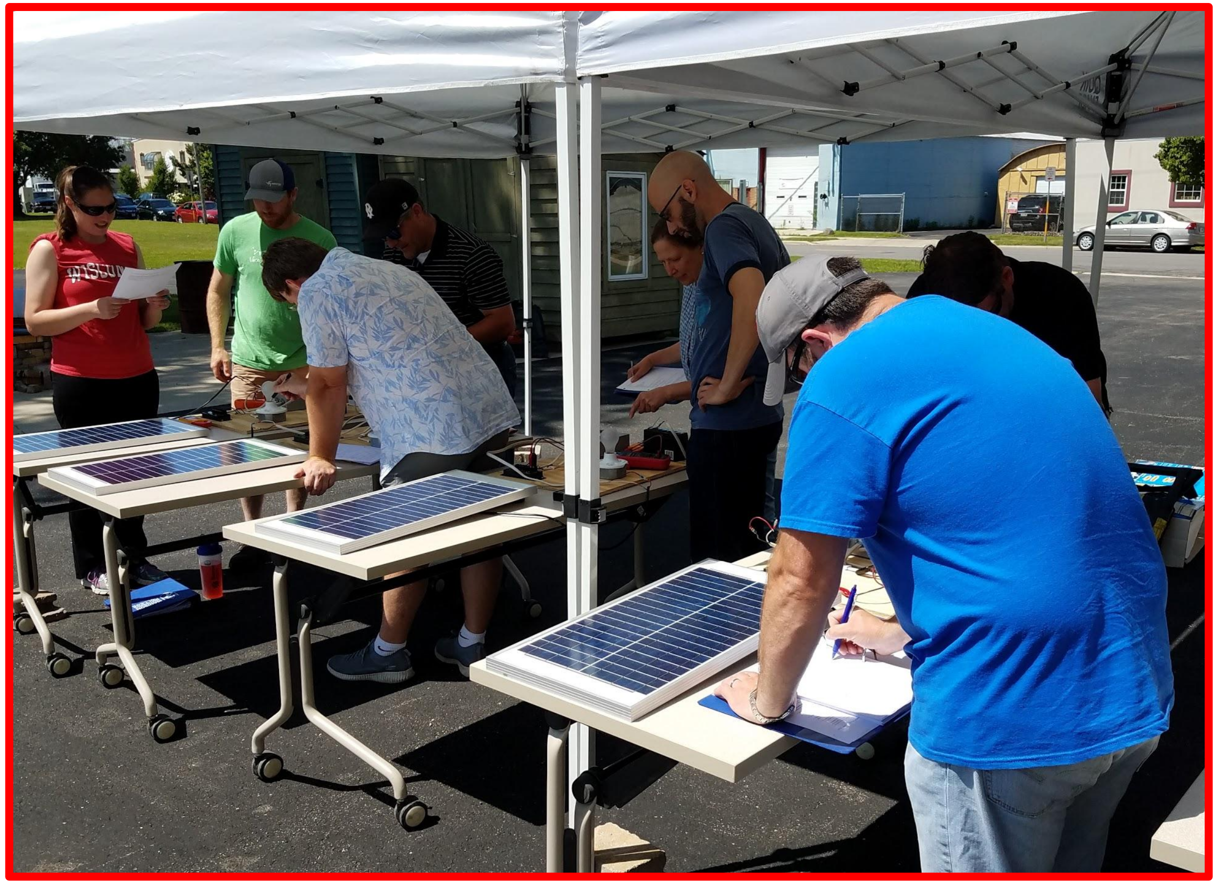
Batteries should be fully charged in preparation this lab.

Batteries should be slightly discharged just before students perform the lab.

Materials list included

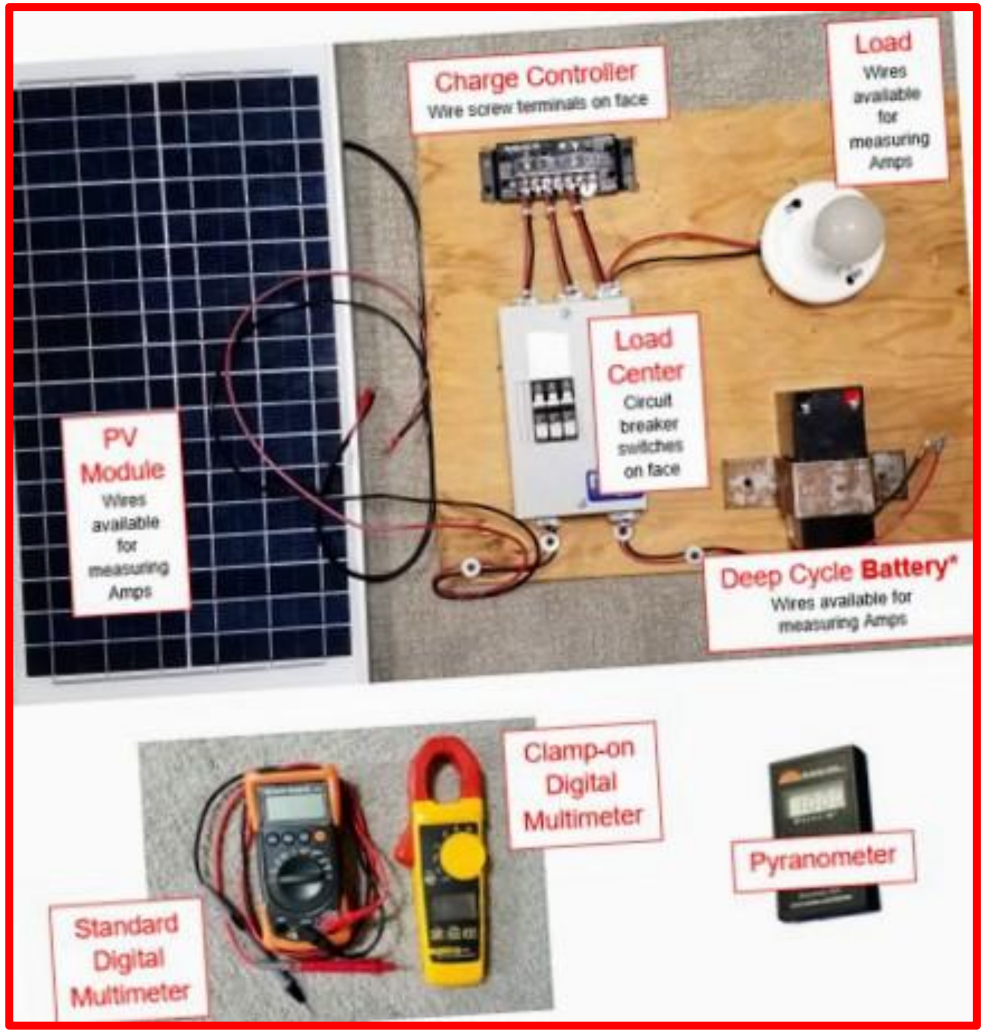
Lab Introductory Information:

- Deep Cycle Battery
- Charge Controller
- Think Like a Charge Controller Exercise
- Easy as PIE



Components of Lab:

- Deep Cycle Battery
- Solar PV Module
- Charge Controller
- Load Center and Circuit Breakers
- Incandescent Lighting Load
- Digital Multimeters
- Pyranometer



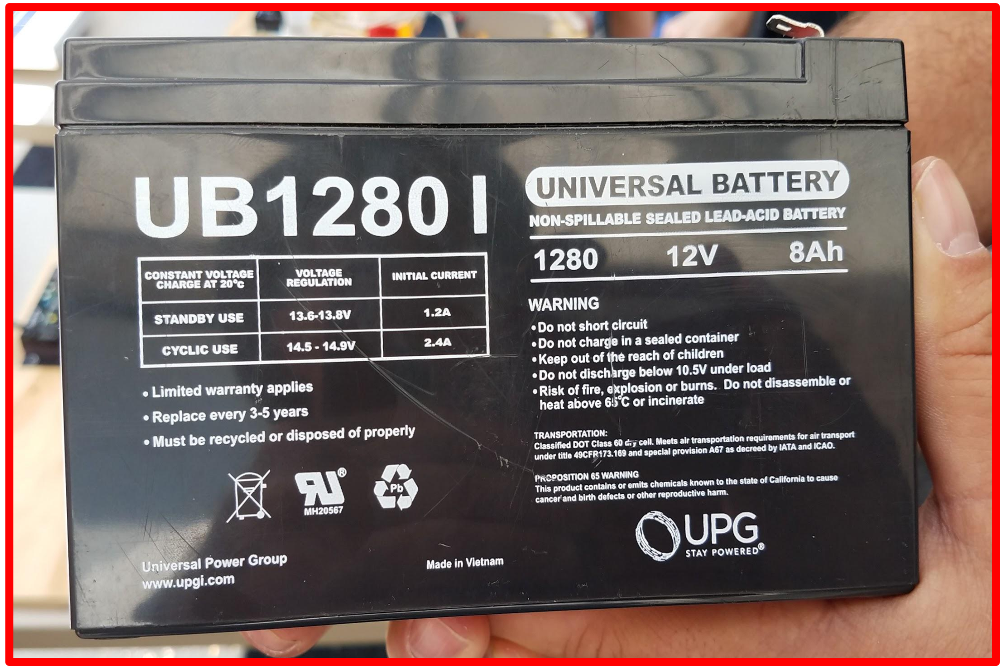
Components of Lab: Deep Cycle Battery

Purpose: Stores electrical energy

Type: nominal 12 volt, absorbed glass mat lead acid

Size: 8 amp-hours (sized to charge and discharge quickly so students can see results during lab)

Features: safe, available, durable, portable



Components of Lab: Solar Photovoltaic (PV) Module

Purpose: Produces electrical power

Type: nominal 12 volt, polycrystalline

Size: 30 watt (sized to charge battery quickly so students can see results during lab)

Features: safe, available, durable, portable

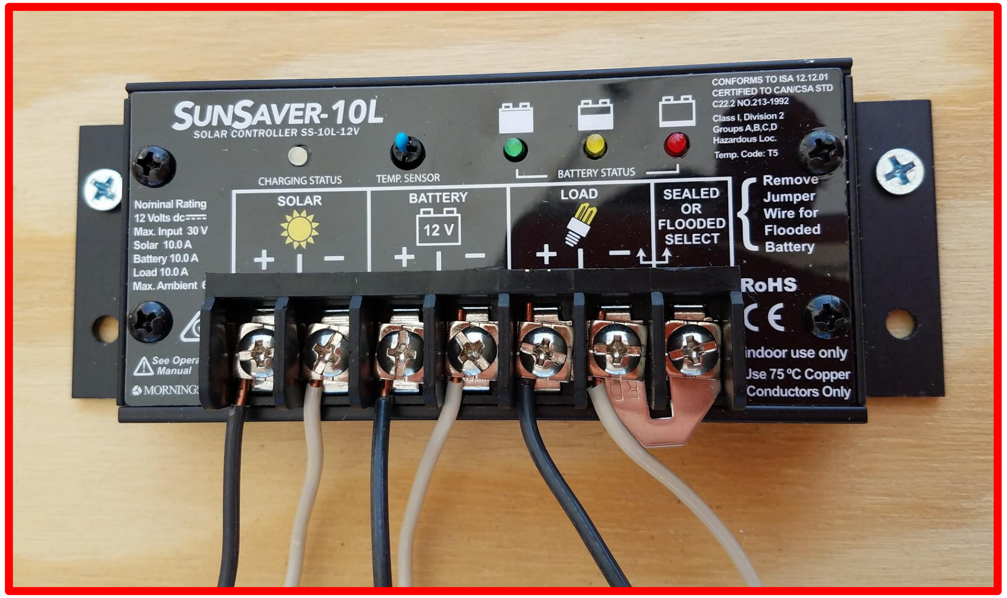
Components of Lab: Charge Controller

Purpose: Regulates charging and discharging of battery

Type: nominal 12 volt

Size: 10 amp

Features: safe, available, durable, portable, easy to use



Components of Lab: Incandescent Light Bulb (Load)

Purpose: Uses electrical energy

Type: nominal 12 volt

Size: 25 watt (sized to discharge the battery quickly so students can see results)

Features: safe, available, portable, easy to use, tolerant of electrical potential variations

Components of Lab: Load Center and Circuit Breakers (Switches)

Purpose: Controls connections between components

Type: DC rated, nominal 150 volt

Size: 10 amp

Features: safe, available, portable, easy to use, tolerant of electrical potential variations

Note: Load center and circuit breakers are typical of full-size solar photovoltaic systems and are not required for safety in this lab system

Components of Lab: Digital Multimeter (DMM)

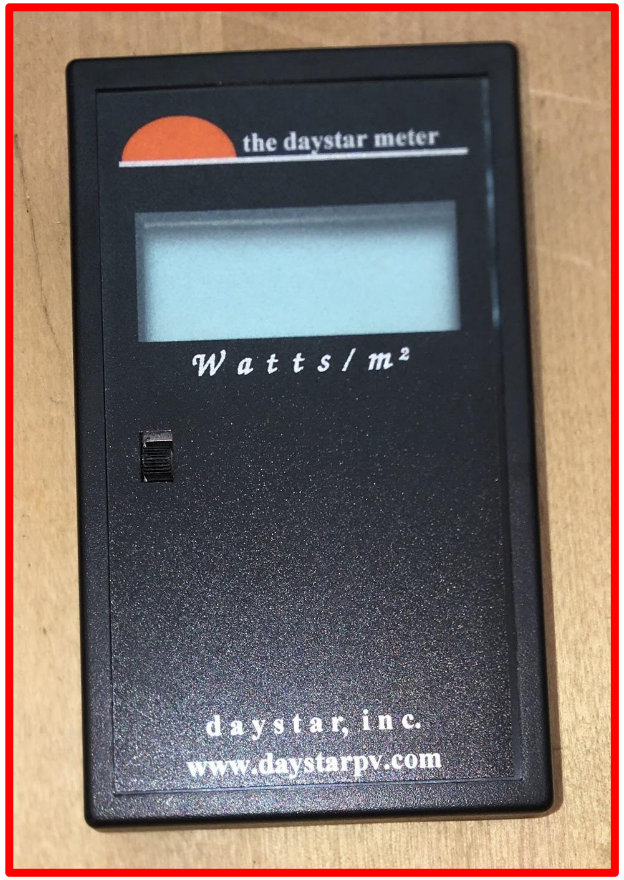
Purpose: Measure electrical quantities

Type: DC rated (Not all clamp-on DMMs measure DC current)

Components of Lab: Pyranometer (Daystar meter)

Purpose: Measure light

Type: Daystar meter is the easiest light meter to use for solar purposes - there is one switch to turn the meter on

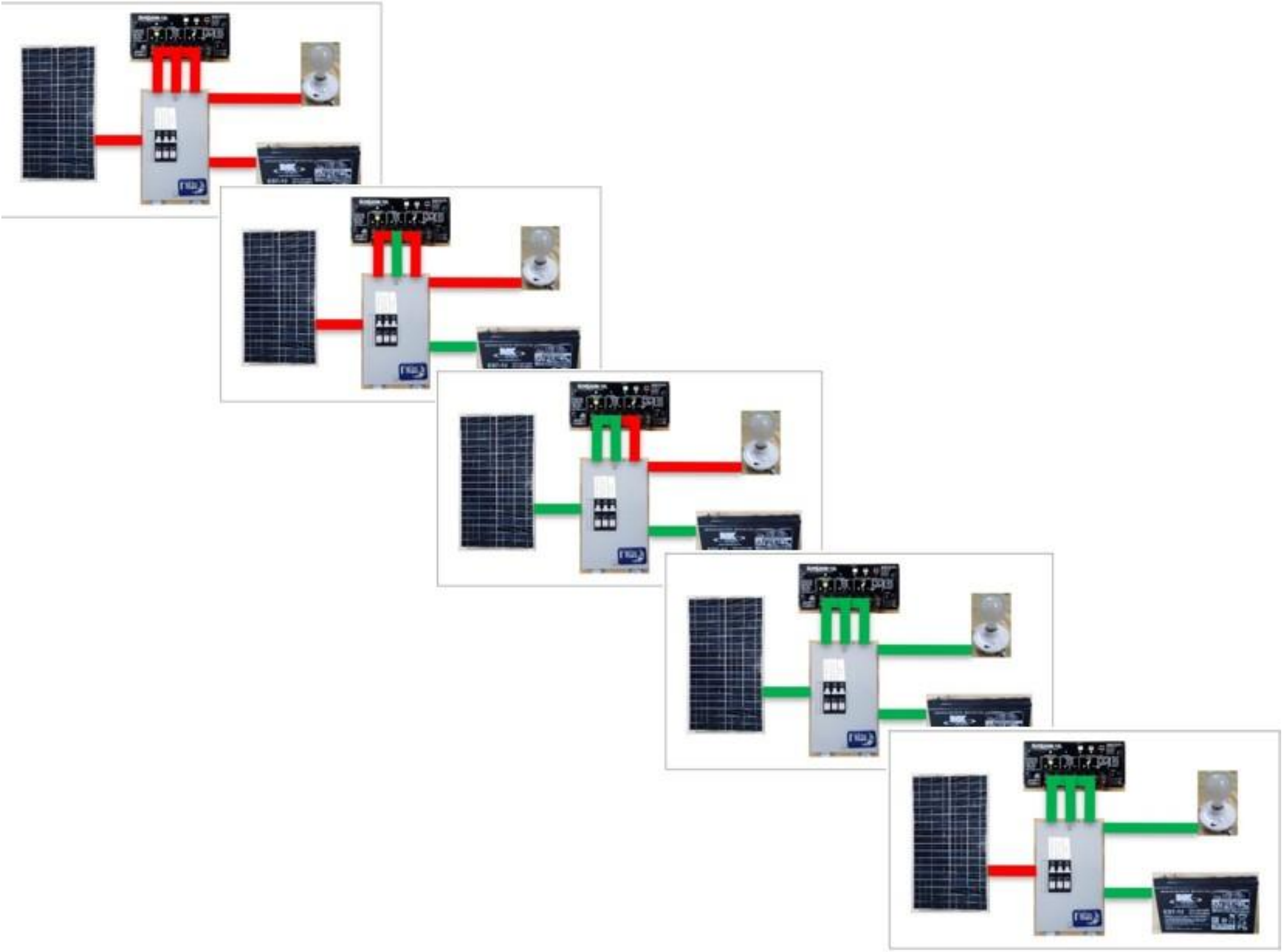


Best Practices

1. **Outdoors in full sun**
   - Hard to get enough light indoors
   - Intermittent clouds create the most difficult conditions for students to get consistent measurements
2. **Begin lab with batteries somewhat discharged**
   - Results may vary from those stated in the teacher answer key if lab begins with batteries fully charged or completely discharged

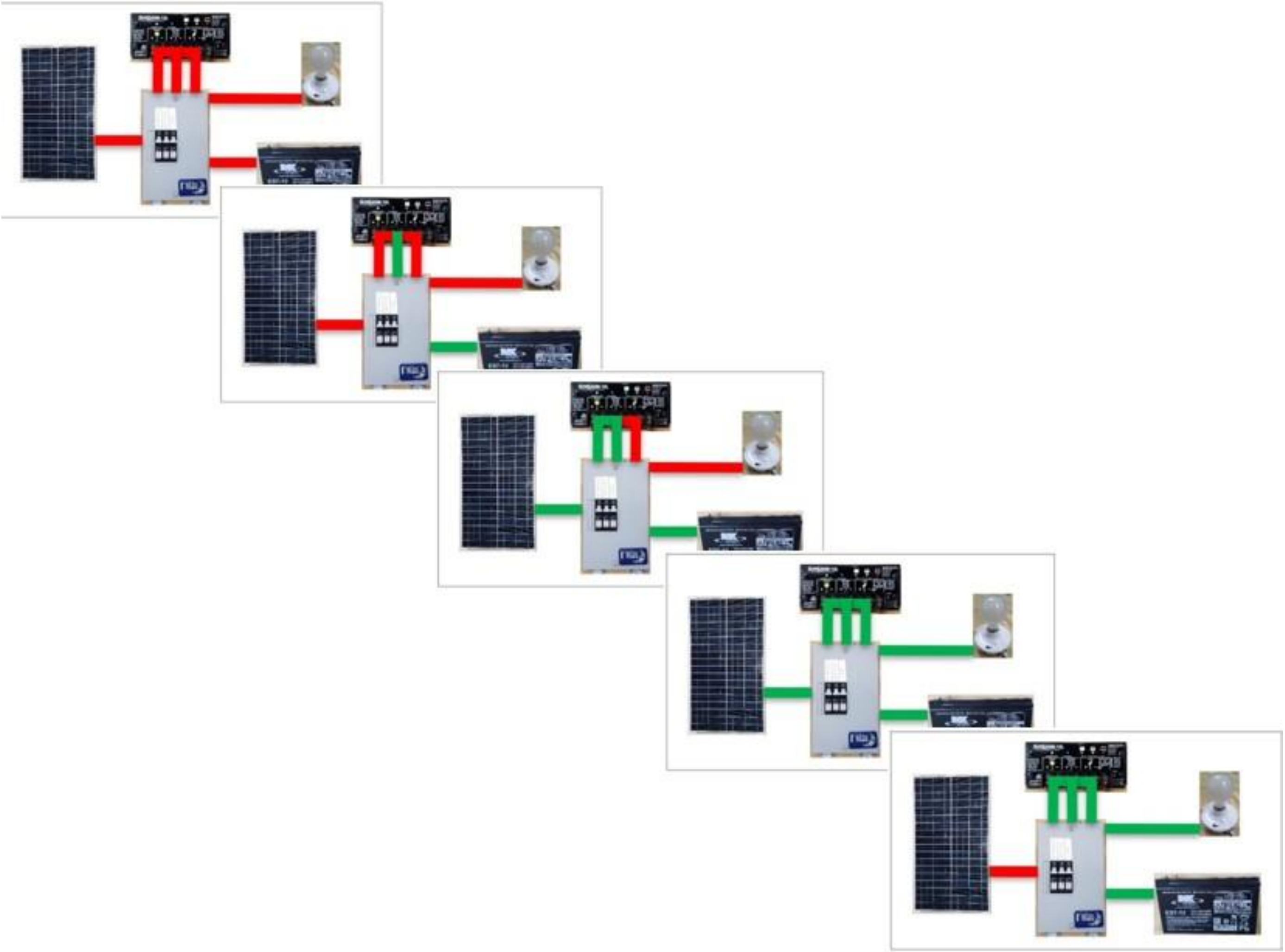
Lab Procedure

Five stages represent different conditions under which the solar PV system with batteries may be operating



Lab Procedure

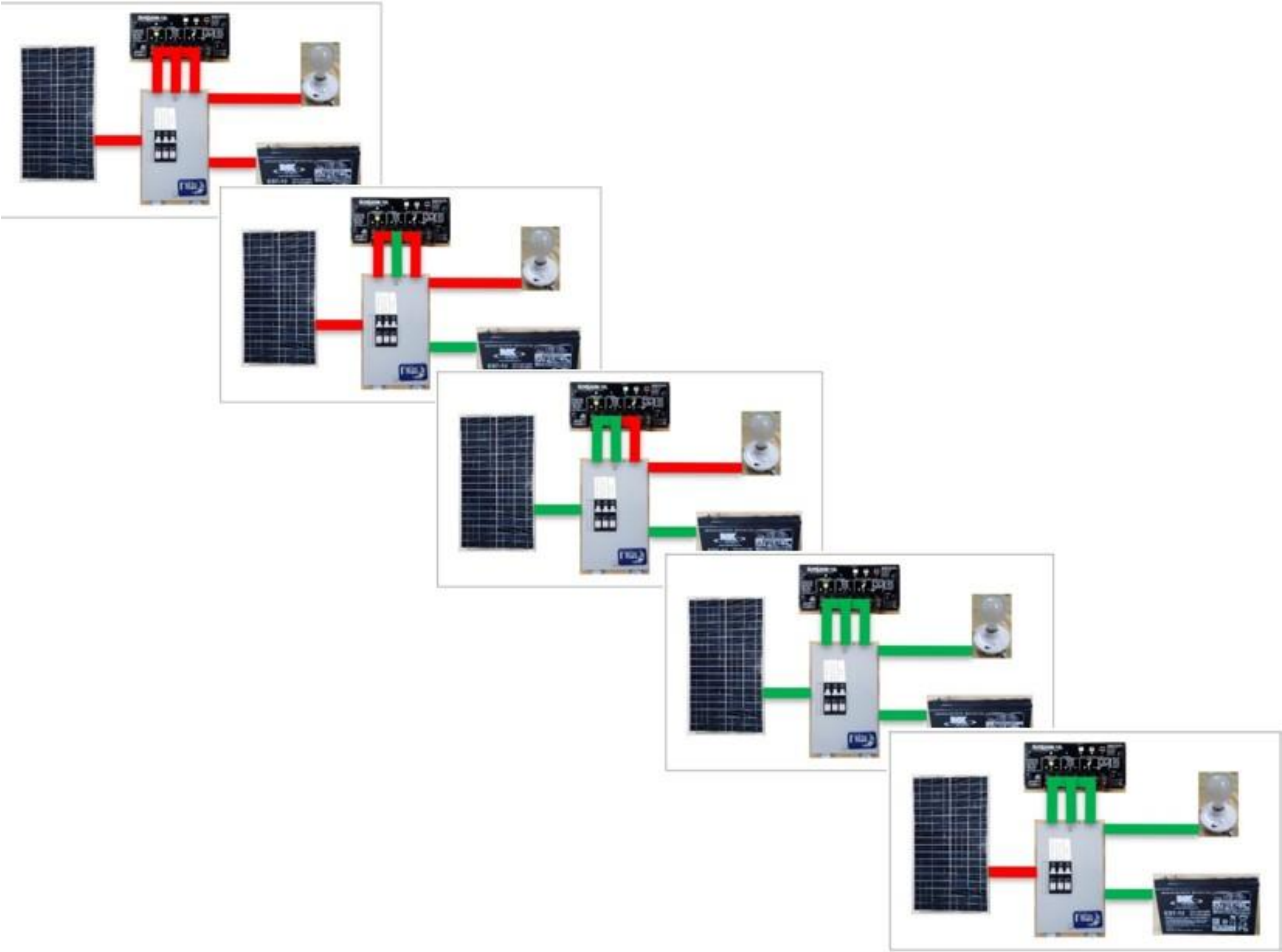
By taking measurements in these conditions, the students learn how the equipment operates to produce, store and consume electrical energy



Lab Procedure

The illustrations to the right in this slide indicate which components have been turned on in each of the stages.

These illustrations are used throughout the lab to orient students to the context in which they are taking measurements



Condition 1: All Switches Off - Baseline Measurements

- → All switches are off
- → All paths of the circuit are open

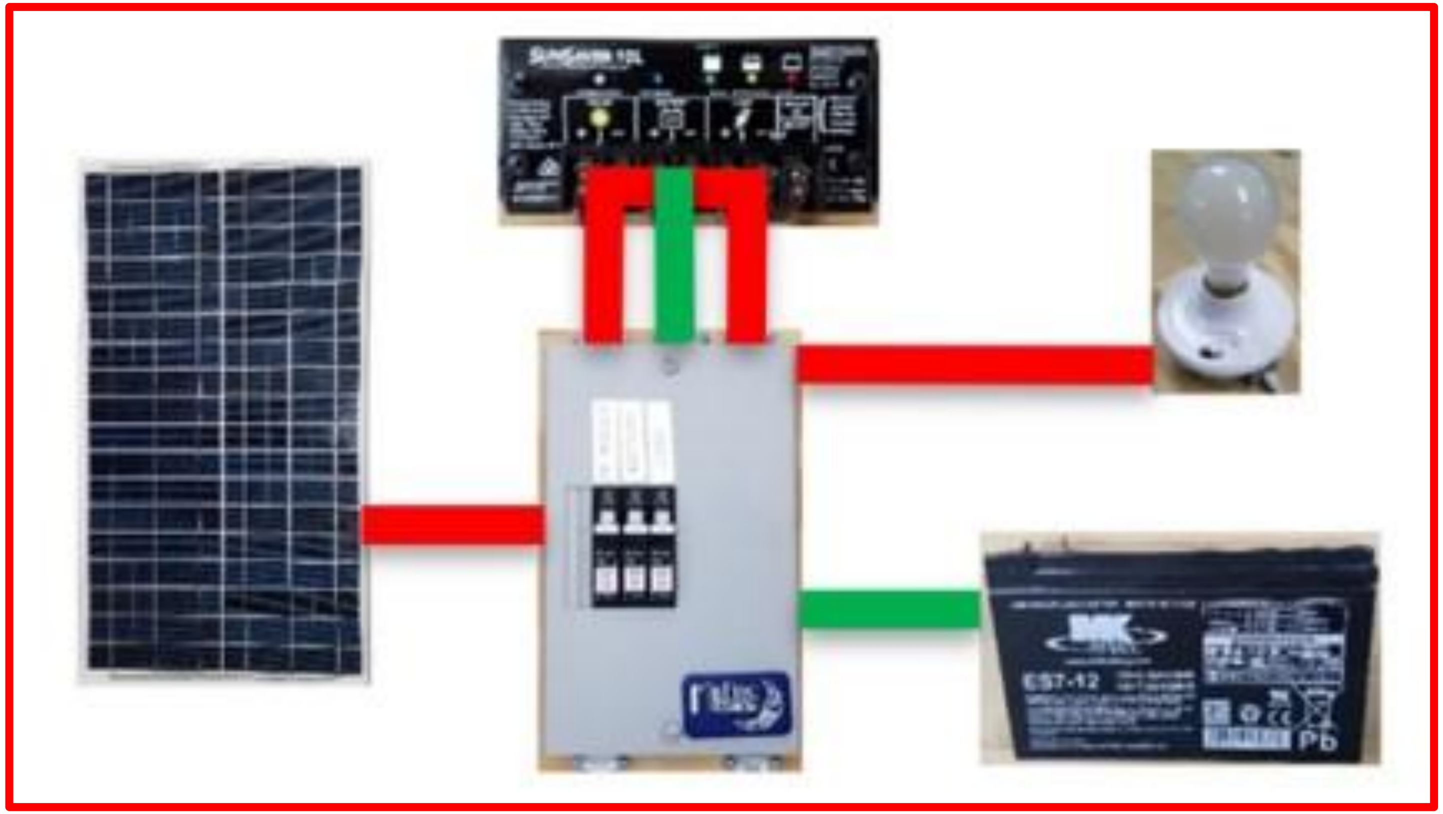
Condition 1: All Switches Off - Baseline Measurements

- What is electrical potential of battery, PV module and load?
- Students asked to predict value before measuring
- And to explain measured value
- Steps 2-8
- Questions 2-4

VOLTAGE	CHARGE %
12.6	100%
12.4	75%
12.2	50%
12.0	25%

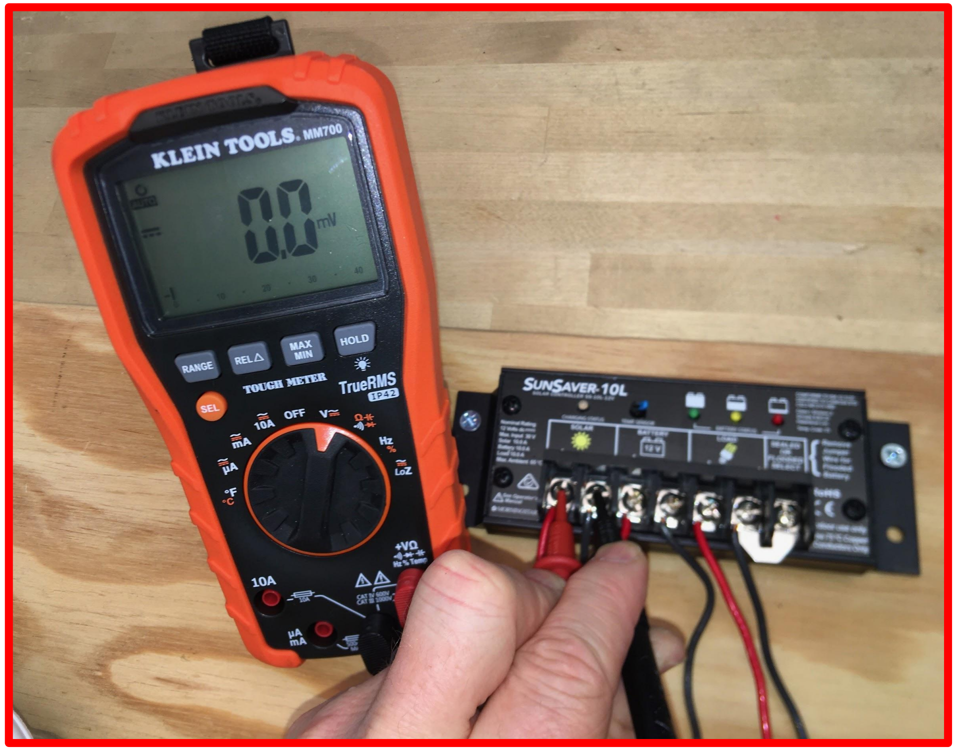
Condition 2: Nighttime with No Load

- Battery switch is on
- Solar PV switch is off representing no sunlight
- Light bulb switch is off representing all loads turned off



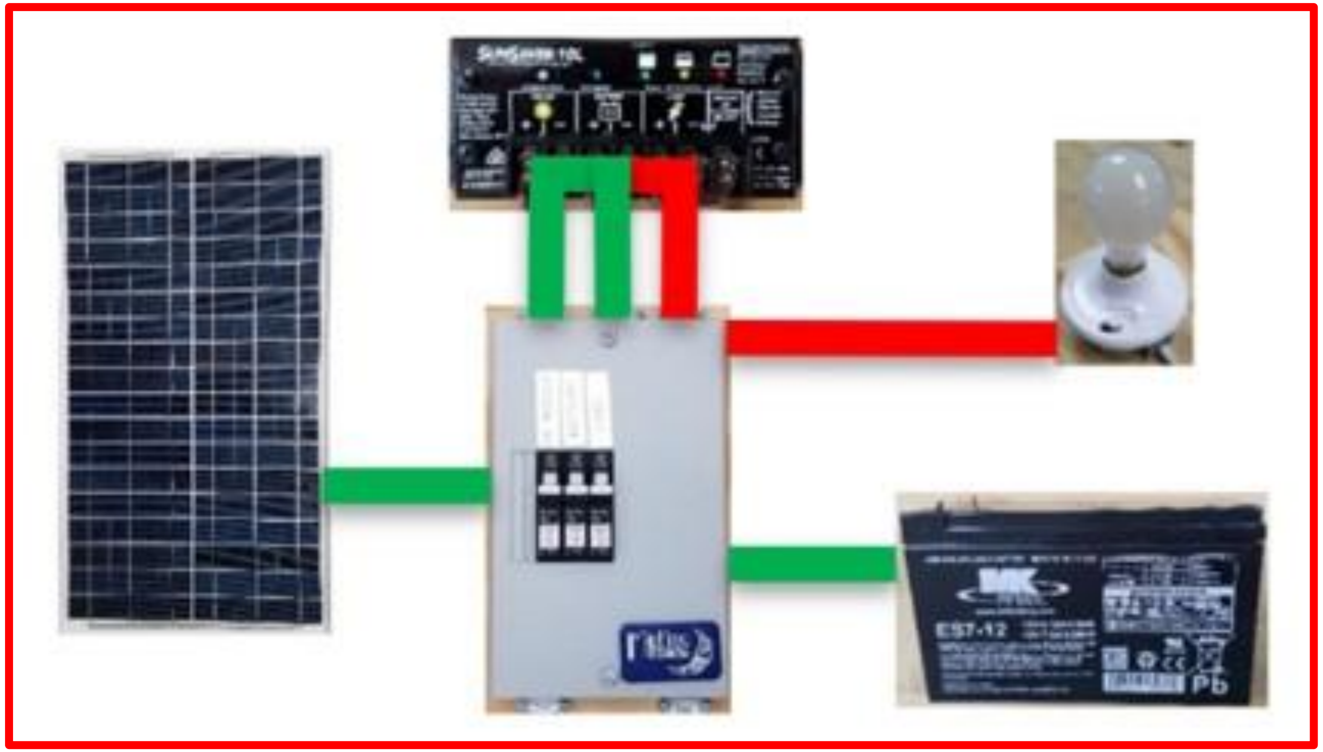
Condition 2: Nighttime with No Load

- Students predict, measure, then explain:
  - **electrical potential** of battery at charge controller terminals
  - **irradiance** at the PV module surface
  - **current** from the PV module
- Steps 9-15
- Questions 5-7



Condition 3: Daytime with No Load

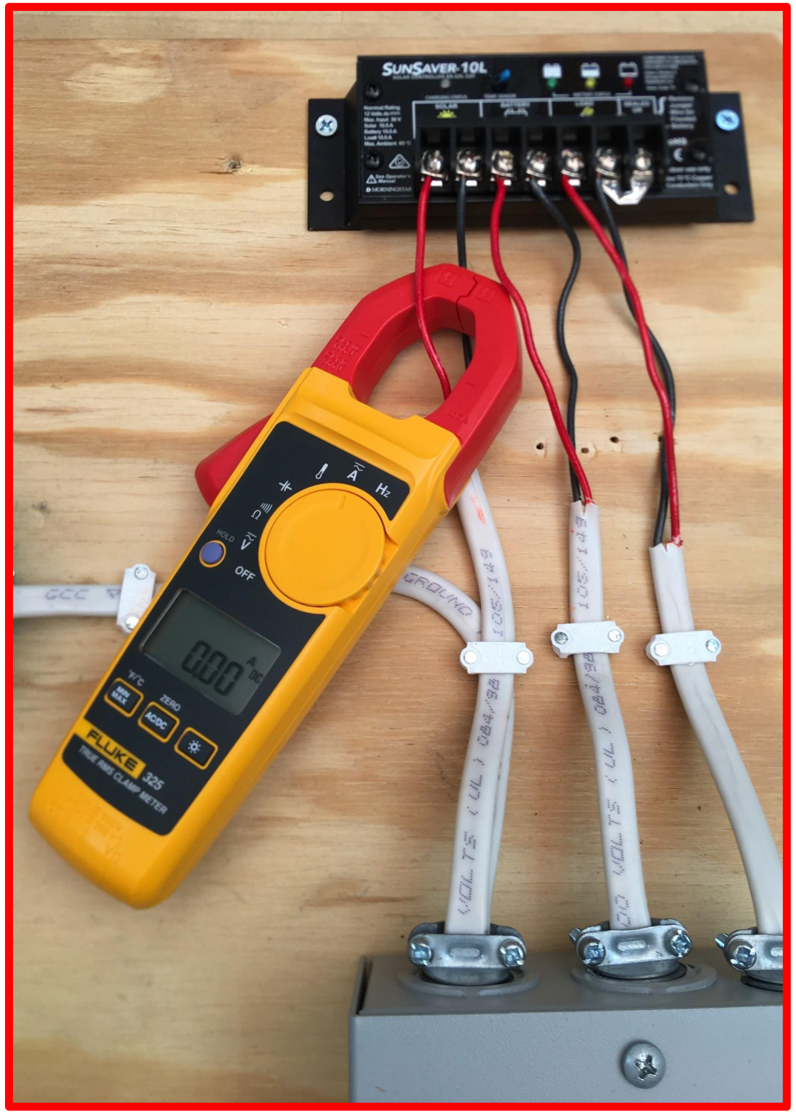
- → Battery switch is on
- → Solar PV switch is on representing sunlight
- → Light bulb switch is off representing all loads being off



- Students quickly measure the electrical potential of the battery at the charge controller
- This provides an electrical potential with which to compare after the battery has charged for a few minutes

Condition 3: Daytime with No Load

- Students predict, measure, then explain:
  - **current** from the PV module
  - **current** to the Battery
  - **electrical potential** of the Battery
- Steps 16-22
- Questions 8-11



Condition 4: Daytime with Load

- Battery switch is on
- Solar PV switch is on representing sunlight
- Light bulb switch is on

Condition 4: Daytime with Load

- Students measure and explain:
  - **electrical potential** of the Load, Battery and PV Module
  - **current** of the Load, Battery and PV module
- Steps 23-24
- Questions 12-14

Condition 5: Nighttime with Load

- Battery switch is on
- Solar PV switch is off representing no sunlight
- Light bulb switch is on

Condition 5: Nighttime with Load

- ➔ Students measure and explain:
  - **electrical potential** of the Load and Battery
  - **current** of the Load and Battery
- ➔ Steps 25-27
- ➔ Questions 15

Show What You Know

➔ Questions 16-19 ask students to elaborate on what they have learned in this lab and to connect this information to other knowledge the students have learned.

SHOW WHAT YOU KNOW:

Q16. A solar PV system with batteries is considerably more expensive than a grid-tied system. The owner of grid-tied only system sells the electricity they produce to their utility and buys what they can't produce from the utility. No battery storage is needed.

Despite the added expense, provide three good reasons why many people still choose to install a solar PV system with battery storage.

Read what's written next to all three blanks before writing about any one of them.

16-1. Provide a reason that is primarily place or location dependent.

*Answer

16-2. Provide a reason that is situation dependent, and different than your answer above.

*Answer

16-3. Provide a third reason that is different from either of your previous answers.

* Answer

Q17. Naturally a system without batteries will not need a charge controller. A PV system of this kind is almost always connected to the local electricity grid. A PV system without batteries that is connected to the local energy utility grid is said to be "grid-tied."

Provide two good and different reasons why many people choose a grid-tied PV system over one with battery storage.

17-1. * Answer

17-2. * Answer

Challenges in Teaching Lab

1. **Student Lack of Evaluation of Measured Quantities**

Challenges in Teaching Lab

2. Lack of Understanding of Electrical Quantities: Electrical Potential and Current

In this lab exercise, you'll work with two of the most basic units in electricity, Volts and Amps. Though you won't work with Power in this lab, Volts and Amps enable us to calculate electric Power in Watts, according to Ohm's Law. This Ohm's Law explanation page is placed here to provide you with an explanation for Amps and Volts.

Ohm's Law is named after a German Physicist Georg Ohm. It's used everywhere and all of the time in the electrical industry. Ohm's Law states that:

The POWER, P, flowing through an electrical circuit is the product of the CURRENT, I, multiplied by the ELECTRIC POTENTIAL, E

$$P = I \times E$$

This can be remembered as Power is "easy as PIE"

P	I	E
is POWER	is CURRENT	is ELECTRIC POTENTIAL
It's measured in units of	It's measured in units of	It's measured in units of
Watts (W)	**Amps (A)**	**Volts (V)**
and power is sometimes referred to as wattage	and current is sometimes referred to as amperage	and electric potential is sometimes referred to as voltage
It is the rate at which work is done (and energy is used) in an electrical circuit	It is the rate at which electrons flow through an electrical circuit	It is the amount of potential energy available to push electrons through an electrical circuit
$1\ \text{Watt} = \frac{\text{Joule}}{\text{second}}$	$1\ \text{Amp} = \frac{\text{Coulomb}}{\text{second}}$	$1\ \text{Volt} = \frac{\text{Joule}}{\text{Coulomb}}$
Students may also recall from physics class that Power = Work / time	*The symbol I comes from the French phrase "intensité de courant" (intensity of current).*	*Electric potential in some older texts was referred to as Electromotive Force (EMF). This is technically not correct, since electric potential is not a force.*

A historical note: Ohm's Law states that for a given resistance (R), the current in a circuit is given by I = E/R. It was James Prescott Joule, not Georg Simon Ohm, who first discovered the mathematical relationship between power dissipation and current in a circuit. Joule's discovery, published in 1841, is properly known as Joule's Law. However, the power equation is so commonly associated with the Ohm's Law equation relating voltage, current, and resistance (I=E/R) that it is frequently credited to Ohm.

Challenges in Teaching Lab

3. Evaluating the State of Charge of Batteries through Electrical Potential is an Art

Materials and Equipment List for Lab

- **List at the end of document**
- **Spreadsheet with possible sources for materials and equipment also on website**

Lab Can be Incorporated into Various Classes

- Chemistry
  - chemical reactions as battery charges and discharges
  - What are the types of batteries being installed?
  - What are the advantages and disadvantages of various battery chemistries?
  - Atomic charges produced by solar PV module
- Electrical Construction
  - Connection of components to create working system
  - Concept of open and closed circuits
  - Use of proper components to build safe system
  - Use of meters to troubleshoot system
- Electronics/Electrical Engineering
  - Construction of charge controller to properly charge battery
  - Use of diodes to maintain direction of current flow at night
  - P layer and N layer of photovoltaic cell

Lab Can be Incorporated into Various Classes

- Engineering
  - Sizing of battery, solar PV module and loads to achieve goals
  - Selection of proper equipment for durability and safety
- Physics
  - Photovoltaic effect
  - Operation of PN Junction of solar PV cell
- Renewable Energy
  - When are battery systems desirable?
  - What makes solar + storage a good match?
  - What policies encourage users to install battery systems?
  - What are the components of a battery system?
  - How can battery systems be used?
- Solar
  - All of the above!

Thank you for your attention!

Questions?

For more info, please see our Germany Study Abroad Blog at:

www.CreateEnergy.org