Evaluation of Different Solar Cells using a Multimeter

By Madonna Brinkman – MEMC RET 2018

Overview:

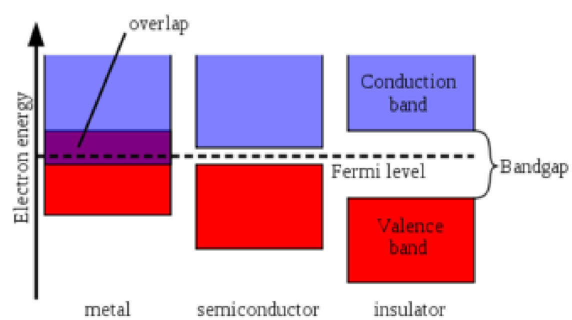
A solar cell is a light-sensitive material that collects solar energy and converts it to electrical energy. To understand the basic science, student will spend a day learning about how to set up and measure a circuit using a breadboard and multimeter. Students will then engage in cooperative learning groups to learn and draw visual models of solar cells science after view assigned video clips. After developing an understanding of solar cells, students will compare different types of solar cells by measuring their voltage and current under different resistance.

- The thrilling potential for off-grid solar energy https://www.ted.com/talks/amar_inamdar_the_thrilling_potential_for_off_grid_solar_energy
- Printable solar cells - https://www.ted.com/talks/hannah_burckstummer_a_printable_flexible_organic_solar_cell
- Why thin film solar cells? https://www.cei.washington.edu/education/science-of-solar/solar-cell-basics/

Background:

Electrons in atoms exist in different energy levels. Electrons in inner energy levels or core electrons are strongly attracted to the nucleus. Those electrons in the highest energy level form the valence band. Above the valance band exists area called the conduction band. The conduction band represents a distance from the nucleus where electrons have enough energy to overcome the intramolecular force of the nucleus and flow freely. The difference in energy between the valance band and conduction band is known as the band gap. The band gap is the energy that must be overcome to get electrons to flow freely within the material.

Elements are classified as conductors, semiconductors, and insulators based on energy relationship between the valence and conduction bands. Metals are conductors because their band gap is very small and can be easily overcome the energy difference to get electrons to flow. In semiconductors elements the band gap is slightly larger but be overcome by absorbing thermal energy to allow electrons to flow. Non-metal elements are insulators. These elements have a large band gap. These elements generally do not conduct electricity.



https://energyeducation.ca/encyclopedia/Band

Research Connection:

We are trying to create new materials which are more efficient solar collectors and which use the full solar spectrum.

NGSS Standards:

Standard Number	Standard text
HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects).
HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*
HS-PS4-5	Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*
HS-ETS1-1	Defining and Delimiting Engineering Problems and Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS3-3)

Materials:

- Various types of solar cells (monocrystalline silicon, polycrystalline silicon, amorphous silicon, and organic photovoltaic cell)
- Multimeter
- Various Resistors (220 Ω, 110 Ω, 74 Ω, 68 Ω, 10
- Breadboard

Procedure: ***Evaluation of Solar Cells using a Multimeter and Resistors***

1. Connect the leads to the solar panel to the outside powerlines on the breadboard.
2. Connect the first resistor to the outside powerlines on the breadboard.
3. Connect the multimeter across the resistor to measure voltage. Record voltage.
4. Calculate the current (I = V/R) and power (P = V x I). Record in the table given.
5. Repeat this process substituting each resistor. Record the data in the table given.
6. Plot a graph of voltage versus current to identify the point at which the panel gives optimal current and voltage.
7. Determine the maximum of the rectangle under the curve.
8. Calculate the difference between the maximum voltage and current your measured in lab and the manufacturer's data.

Calculations

Current = $\frac{\text{Voltage}}{\text{Resistance}}$

Power = Voltage x Current

Cell Area = Length x Width

Power/mm^2 = Power/Cell Area

Experimental Data Table

Solar Cell Type	Resistance (Ω	Voltage (V)	Current (Ampere)	Power (W)	Cell Area	Maximum Power/mm^2
Monocrystalline Silicon	1000					
	450					
	220					
	100					
	47					
	20					
	10					
	0					
Polycrystalline Silicon	1000					
	450					
	220					
	100					
	47					
	20					
	10					
	0					
Amorphous Silicon	1000					
	470					
	220					
	100					
	47					
	20					
	10					
	0					
Organic Photovolatic Cells	1000					
	470					
	220					
	100					
	47					
	20					
	10					
	1					

Extensions:

Future investigations

- Evaluate energy production with multiple solar cells connected in series
- Evaluate the effect of different lighting on energy production (different light sources or different wavelengths of light using filters)
- Evaluate the effect of temperature on energy production
- Evaluate the effect of the distance between the light and the solar cell affects energy production
- Compare dye sensitized solar cells to commercial silicon solar cells

Resources:

Understanding Breadboards and Circuits

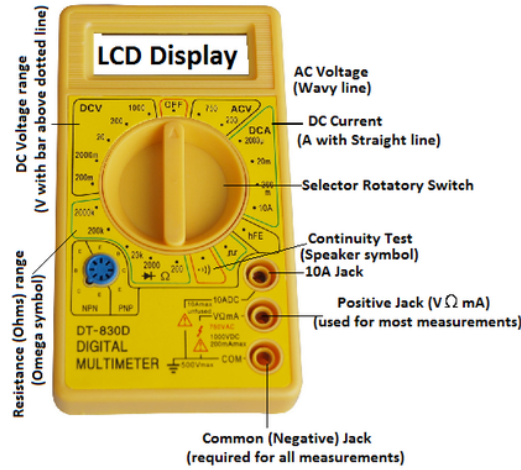
https://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-breadboard

Fundamentals
https://www.teachengineering.org/content/cub_/lessons/cub_pveff/Attachments/cub_pveff_lesson03_fundamentalsarticle_v11_tedl_dwc.pdf

Sources:

- Monocrystalline solar cells
- Polycrystalline solar cells
- Amorphous solar cells
- Breadboard (Amazon, FICBOX 400 tie points Solderless Breadboard (6 Pack), $12.29)
- Alligator clips (Amazon, AUSTOR 6 Groups Test Leads Set with Alligator Clips 39 Inches Double-end Jumper Wire Alligator Clamps Test Wires, $8.99)
- Breadboard Jumper Wires (Amazon, EAONE 420 Pieces Preformed Breadboard Jumper Wire Kit, 14 Lengths Assorted Jumper Wire with Free Box, $10.99)
- 8 - 9 V Batteries with Charger (Amazon, EBL 9V 8 Bay Smart Charger with EBL 8 Pack 9V 6F22 600mAh High Volume Rechargeable Batteries, $44.99)
- Resistor (Amazon, Elegoo 17 Values 1% Resistor Kit Assortment, 0 Ohm-1M Ohm (Pack of 525), $11.86)
- Light emitting diodes (Amazon, CO RODE RGB LED, 3mm 5mm LED Diode Light Kit with Color White Red Blue Green Yellow UV, Fast, Slow Flashing, RGB, $13.99)

How to Use a Multimeter **(Science Buddies)**



A multimeter is a tool used to measure different characteristics of electrical circuits (voltage, current, and resistance).

Measuring Continuity

1. Plug your black probe into the COM port and the red probe into the continuity or resistance port. Touch the probes together and listen for the beep.
2. Touch the probes between different points on your circuit to ensure all points are connected.

Measuring Voltage

3. Plug your black probe into the COM port and the red probe into the low voltage port.
4. **Touch the probe tips to your circuit in parallel** with the element you want to measure voltage across. Be sure to use the red probe on the side connected to the positive battery terminal and the black probe on the side connected to the negative terminal. If these orientations are not correct, the voltage reading will be negative.
    a. If the multimeter screen reads “0”, then the range is probably too high.
    b. If the multimeter screen reads “OVER”, “OL, or “1”, then the range is probably too low.

Measuring Current

1. Plug your black probe into the COM port and the red probe into the low voltage port. There may be multiple sockets for measuring current. It is always safer to start out with the socket that can measure larger current. Plug the red socket into the high current port.
2. Battery and solar cell circuits are direct current circuits. Choose the correct setting based on the battery type or solar cell voltage.
5. **Touch the probes tips to your circuit in series** to the current you want to measure. Be sure to use the red probe on the side connected to the positive battery terminal and the black probe on the side connected to the negative terminal. If these orientations are not correct, the current reading will be negative.
    a. If the multimeter screen reads “0”, then the range is probably too high.
    b. If the multimeter screen reads “OVER”, “OL, or “1”, then the range is probably too low.

Measuring Resistance

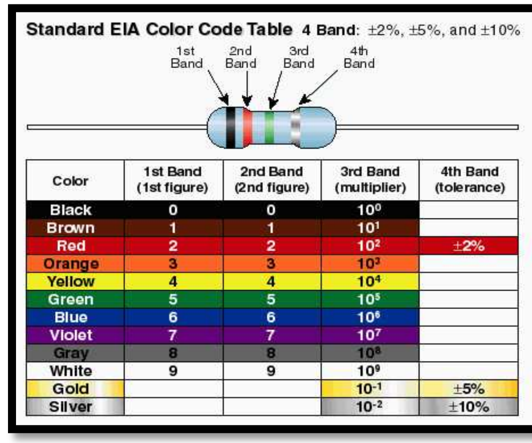
1. Plug your black probe into the COM port and the red probe into the port labeled Ω symbol. There may be multiple sockets for measuring current. It is always safer to start out with the socket that can measure larger current. Plug the red socket into the high current port.
2. Choose the correct resistance measurement setting on the multimeter’s dial.
3. **Caution: The power supply to your circuit must be turned off before measuring resistance. If the circuit is not off, the reading may be incorrect.**
4. Connect the multimeter probes to each side of the object. For most resistors, the resistance is always positive, so it does not matter how the probes are attached. One exception to this is a diode. Diodes conduct electricity in one direction (high resistance in only one direction).

How to Use a Breadboard (**Science Buddies**)

A solderless breadboard is electrical component that allows scientists and engineers to create electrical circuits without using alligator clips or solder joints. These breadboards are designed so that you can push metal leads into holes which connect with metal to complete the circuit.

A breadboard is divided into   parts. Power buses or rails line both sides of the breadboard and are typically used to supply electrical circuit. On most breadboards, holes lining the red line represent the positive bus, also known as the power bus or voltage bus. Holes lining the black or blue line are referred to as the negative or ground bus. In the middle of the breadboard are two sets of 5 holes labeled A-E and F-J. Holes within each of these sets are connected. There is not a connection between the two groups.

Practice with Resistors



Standard EIA Color Code Table 4 Band: ±2%, ±5%, and ±10%

Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

Resistors are coded with 4 bands of color painted on the outside. Starting opposite the end with the Gold or Silver band:

- The first band is the first number
- The second band gives us the second number
- The third band gives us the number of zeros behind the first two numbers.
- The fourth band gives us the tolerance of the device.

Examples Problems

Resistor	Color On Bands				Resistor Value ± Tolerance
	Band 1	Band 2	Band 3 Multiplier	Band 4 Tolerance	
	Orange	Blue	Red	Gold	3600 Ω ± 180 Ω
	3	6	10^2	± 5 %	
	Brown	Black	Yellow	Silver	
	1	0	10^4	± 10 %	
	Red	Red	Brown	Gold	
	2	2	10^1	± 10 %	
Problem 1	Brown	Brown	Brown	Gold	
Problem 2	Yellow	Violet	Black	Gold	
Problem 3	Brown	Black	Black	Gold	
Problem 4	Blac	Green	Orange	Gold	
Problem 5	Blue	Purple	Yellow	Silver	
Problem 6					220 ± 11 Ω
Problem7					860 ± 86 Ω

Cooperative Group Learning of Solar Cell Science

In this activity, you will work in cooperative learning groups to learn and draw visual models of solar cells science after view assigned video clips. Once the visual model is completed, other groups will review your work leaving questions and thoughts at your station. Upon completing the gallery walk return to your station to discuss questions and revise your final model.

Step 1: Background Information

You will be assigned a video or written article on solar cells science. Quietly watch or read your resource two times taking notes if necessary.

- Resources
  - https://www.youtube.com/watch?v=u0hckM8TKY0
  - https://www.youtube.com/watch?v=qIJx2PRGKqw
  - https://www.youtube.com/watch?v=f01UyQj0feM
  - https://www.youtube.com/watch?v=UJ8XW9AgUrw
  - https://energyeducation.ca/encyclopedia/Band_gap
  - http://solardat.uoregon.edu/download/Lessons/Appendix_E_HowSolarCellsWork.pdf

Step 2: Cooperative Learning Group Discussion

Your group will be given a group of pictures relating to different scientific concepts in understanding solar cells. Use the white board, markers, your notes and these pictures to discuss the solar cell science. Create a visual model of the solar cell science using pictures and words. Take and upload a picture of your product. Answer these questions

Concept 1 How is energy from the sun transferred to electrons?
Concept 2: Why do some elements conduct electricity?
Concept 3: How can changes in the silicon crystalline structure promote electron transfer?
Concept 4: How does placing n-type silicon and p-type silicon together facilitate the capture of solar energy?
Concept 5: How does the form a silicon used affect energy production?

Step 3: Gallery Walk

As a group, rotate to each of the other group stations. Carefully review their visual model of the solar cell science. How do they represent each process? How do they represent the movement of energy and electrons? Before moving on, write your questions and thoughts about their work on the Post-it,

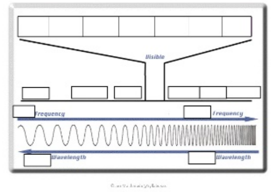
Step 4: Revising your Visual Model

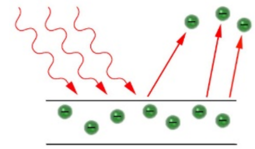
As you return to your visual model take time to review all questions and comments left by other groups. Are there ways to improve your visual model? What did other groups include in their model that was not represented in your model? On a new whiteboard, revise your model adding new information and clarifying concepts/symbols. Take and upload a picture of your product.

Step 5: Debrief

Cooperative Group Learning of Solar Cell Science – Schematics and Terms

Concept 1 How is energy from the sun transferred to electrons?

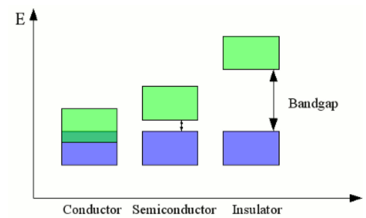




Terms: absorption, electrons, electromagnetic spectrum, photons, photoelectric effect

How are the wavelength, frequency, and energy of related in the electromagnetic spectrum? How does the energy of the photon relate to the displacement of the electron? What types of elements undergo the photoelectric effect?
How does the energy of the light relate to electron movement from different materials?

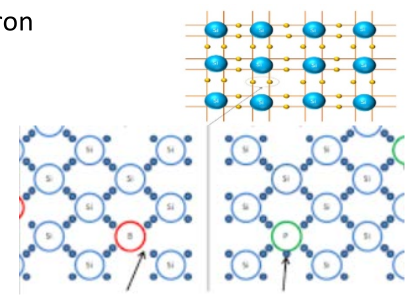
Concept 2: Why do some elements conduct electricity?



Terms: conduction band, insulators, metals, electrons, electricity, valence electrons, metals, semiconductors, valence band, conduction band

How are electrons arranged around an atom? How do the electrostatic forces differ for core and valence electrons? What is the conduction band? What is a band gap?
Why can't electrons occupy the space between the valence band and conduction band?
How does the energy of the light relate to electron movement from different materials?

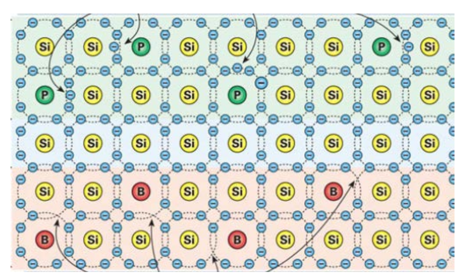
Concept 3: How can changes in the silicon crystalline structure promote electron transfer?



Terms: boron, covalent bonds, doping, electrons, free energy, n-type silicon, phosphorus, p-type silicon, p-n junction, semiconductor, silicon, sunlight

How do the electrons in silicon create a crystalline structure? What types of bonds are formed?
How does the addition of boron to crystalline silicon affect its structure? What is this type of doping called? How does it affect electron movement?
How does the addition of phosphorus to crystalline silicon affect its structure? What is this type of doping called? How does it affect electron movement?
How might the additions of each of these materials affect the band gap?

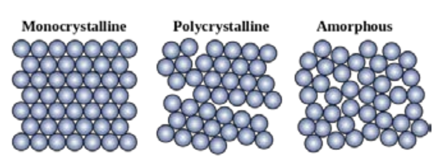
Concept 4: How does placing n-type silicon and p-type silicon together facilitate the capture of solar energy?



Terms: boron, covalent bonds, doping, electrons, electric field, free electrons, n-type silicon, phosphorus, p-type silicon, p-n junction, semiconductor, silicon, sunlight

What creates the p-n junction? Where is light absorbed in the solar cell? What happens when the energy is absorbed? Which material is the electron acceptor? Donor?
How does the band gap of each material promote the movement of electrons?

Concept 5: How does the form a silicon used affect energy production?



Terms: monocrystalline, polycrystalline, amorphous
How might the difference in silicon structure affect the transfer of electrons?