The Photovoltaic Panel

Student Objectives

The student:

- given basic photovoltaic panel installation design scenarios, will predict how the panel will function as variables (i.e. panel angle, shadows) are changed
- will explain how shadows, the angle of the panel, reflectors and temperature affect the electrical output of the photovoltaic panel
- will determine the angle of incidence of the Sun.

Key Words:

amp
angle of incidence
current output
electricity
efficiency
multimeter
orientation
photovoltaic
volt
watt

Materials:

- 3V photovoltaic panel (i.e. Junior Solar Sprint competition panel)
- multimeter
- protractor
- ice
- aluminum foil or disposable baking pans, or other reflective material
- Science Journal

Time:

1 hour

Background Information

The output rating for any size photovoltaic device is the amount of electricity in watts expected when sunlight and temperature are at Standard Test Conditions (STC). The STC for photovoltaics are: irradiance (sunlight) at 1000 W/m^2, temperature of 25^o C, and solar spectrum (air mass) at AM 1.5 (sea level with the sun directly overhead would be AM 1.0). When any of these three factors are different than the standard amounts, the electrical output of the photovoltaics will vary from the amount given as the rating for the panel. Real world variables that affect the electrical output of photovoltaics are:

- **time of day** – As the Sun moves across the sky during the day, the amount of air mass that sunlight has to travel through varies. A graph of the intensity of sunlight throughout the hours of a clear day would be bell-shaped.
- **season of the year** – In the northern hemisphere, the Sun is higher in the sky (less air mass) in the summer than in the winter. The difference in the angle of the Sun between summer and winter is 47^o, a difference in air mass of approximately .75.

- **latitude** – because of the tilt of the Earth, the higher the latitude above 23½ º, the more atmosphere that sunlight must go through to reach the surface. Latitudes between 23½º N and 23½º S will have two days each year when the Sun is directly overhead at noon–an airmass of 1.0 at sea level.
- **angle** – photovoltaic output is the highest when the cell/panel is perpendicular to the sunlight. To maximize the electric output of a photovoltaic cell/module/array throughout the year, it would need to track the Sun on two axis to remain perpendicular to the Sun throughout the day and seasons. In real world situations, most panels are mounted in one fixed direction (south facing) and to one fixed angle. As the sunlight moves away from the perpendicular during the day (east-west axis) or during the seasons (north-south) axis, the output of the array decreases.
- **temperature** – Heat can reduce a photovoltaic cell's electrical output. Specifically, higher temperature increases the conductivity of the semiconductor, and charges become balanced within the material, which reduces the magnitude of the electric field, inhibiting the charge separation, which lowers the voltage across the cell. Higher temperatures can decrease the electrical output by 10% or more; conversely, cooling photovoltaics in warm climates can increase their output.
- **irradiance** – (measure of the power density of the sunlight that strikes the earth) - This is affected by weather phenomena such as clouds, but also particulate matter in the air. Latitude figures into the range that this value can take (air mass again) so that in some areas a clear sunny day at solar noon would have an irradiance level of 900 W/m^2, while others would have 1200 W/m^2.
- **shadows** – as expected, any shadow on a photovoltaic cell decreases its output. In a single cell, the amount of shading is proportional to the decrease in output. However, in a panel or module where cells are connected in series, shading can produce a significant voltage drop that can result in a decrease in electric output far greater than the percentage of the panel that is shaded.
- **reflection** – extra light reflected onto photovoltaics will increase their electric output. Snow banks, bodies of water, or mirrors can increase the output of a panel or module. However, care must be taken not to increase the temperature of the cells, or these benefits will be negated.

Procedure

1. Students should work in teams (2 – 4 students).
2. Lead a classroom review of photovoltaics and basic electricity.
3. Discuss with students their previous findings in the *Solar Powered Systems* activity. Have the students hypothesize what their results will be using the 3V panel which is larger than what they used in previous experiments.
4. Pass out materials. Remind the students that their panels are fragile and can be broken if bent. If your students have not used a multimeter, you may wish to take a few minutes to demonstrate its use and explain the settings.
5. Assist students as needed with the lab activity.
6. Students should complete the exercises in their Science Journal.

Answer Key

Note: Answers will vary between seasons and time of day, but students should discover:

1. Shading drastically affects the output of the panel; shading 1/3 of a panel will decrease the amount of power output by more than 1/3.
2. The best angle is with the face of the panel perpendicular to the Sun at, on, or near, the angle of incidence subtracted from 90º. (The 90º is so the front face of the panel is perpendicular to the sunlight.) Additional fun note: The best angle for your panel on solar noon in the summer will be your latitude.
3. The students should notice an increase in the amperage output of the photovoltaic panel. *(However, reflectors can also increase the temperature, which in the long run would negate the increase.)*
4. The amperage output of the cells will increase as the cell cools (one of the easiest ways for the students to understand this, is to explain that the cells are made of the same type of materials as semiconductors and computer chips).

Key Words & Definitions

- **amp** – unit of measure of the number of electrons flowing through a wire per unit of time (current)
- **angle of incidence** – the angle of the Sun in relation to level ground. Varies according to location (latitude) and time of day.
- **current output** – the number of amps flowing through the circuit at a particular time
- **electricity** – general term for the type of energy concerned with the flow of electrons
- **efficiency** – the degree to which a system produces the desired effect without waste. In energy, it is used to describe the amount of available energy source that is turned into energy that we can use; for example the percentage of sunlight that is turned into electricity.
- **multimeter** – an instrument to measure electrical output in amps and volts and resistance in ohms
- **orientation** – position in relation to the points of the compass and elevation angle
- **photovoltaic** – the effect of producing electric current using light
- **volt** – the unit of measure of the force of electricity in a circuit. The volt is not a unit of flow, it is analogous to pressure of water in a hose.
- **watt** – the standard unit used to measure electricity, specifically the rate at which electrical energy is dissipated. The watt is the equivalent of one joule per second.

Related Research

1. Photovoltaic mounting systems that track the Sun during the day are not common. Research why this is currently the case. What would have to be different for tracking systems to become more common?
2. What is the current efficiency that is being reported in laboratory experiments with photovoltaics? Why would the efficiencies reported in these experiments be higher than the efficiencies that are common on photovoltaic systems installed on homes and businesses today?

3. The American Solar Energy Society (ASES) hosts a yearly solar “tour” throughout the United States. Find out when the next tour is to be held in your state.

Related Reading

- ***Solar Energy Projects for the Evil Genius*** by Gavin Harper (McGraw-Hill, 2007)
  This book includes more than 50 solar energy projects with plans, diagrams and schematics.
- ***Photovoltaics: Design and Installation Manual*** by Solar Energy International (New Society Publishers, 2004
  The book contains a detailed description of PV system components, including PV modules, batteries, controllers and inverters. It also includes chapters on sizing photovoltaic systems, analyzing sites and installing PV systems. This book is suitable for advanced students and those designing and building their own systems.

Internet Sites

http://www.chuck-wright.com/SolarSprintPV/SolarSprintPV.html

Explains the basic physics of photovoltaics and specifically the 3V (Junior Solar Sprint) panel used in this activity. Inclueds graphs of the panel current and output power in varying conditions.

http://www.eia.gov/kids/energy.cfm?page=solar_home-basics

Department of Energy, Energy Kids photovoltaics page.

http://energy.gov/eere/energybasics/articles/photovoltaic-technology-basics

Department of Energy photovoltaics page explains how photovoltaics work and includes a brief animation.

https://www.fsec.ucf.edu/go/solar_basics/

Florida Solar Energy Center's photovoltaic fundamentals page explains the basics of photovoltaic cells including their manufacture, the components of systems, as well as the pros and cons of photovoltaic power. Site is suitable for teachers, mentors and advanced students.

https://ed.ted.com/lessons/the-sun-s-surprising-movement-across-the-sky-gordon-williamson#watch

Ted Ed lesson, *The Sun’s Surprising Movement Across the Sky*, explains the Sun’s analemma, solar noon, and the difference between sun time and clock time.

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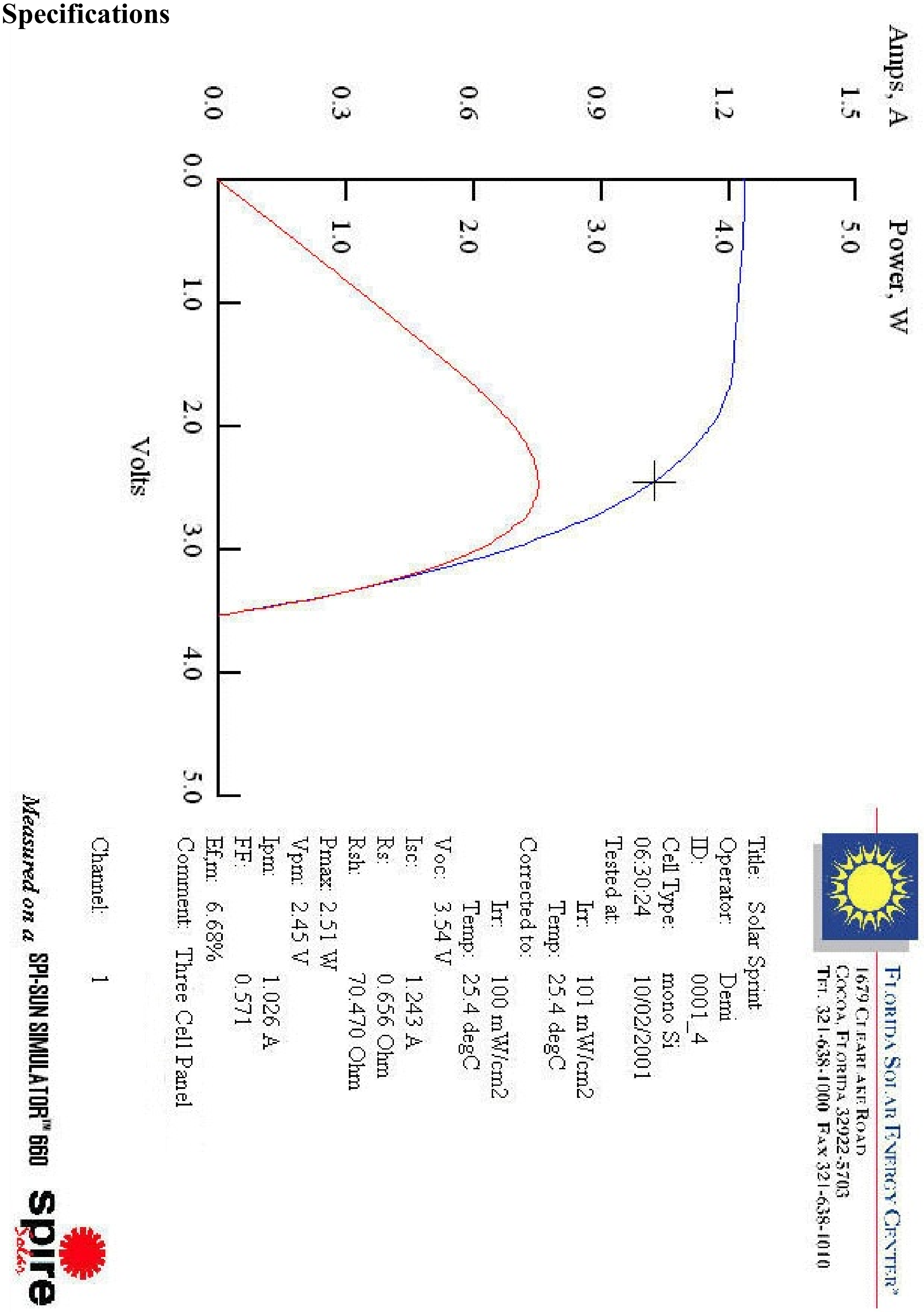
Panel Specifications



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Florida NGSS Standards & Related Subject Common Core

			.1	.2	.3	.4	.5	.6	.7	.8	.9	.10	.11	.12
Grade 6														
Practice of Science	**# 1**	**SC.6.N.1**	X			X	X							
Grade 7														
Practice of Science	**# 1**	**SC.7.N.1**	X											
Forms of Energy	**# 10**	**SC.7.P.10**	X											
Energy Transfer & Transformations	**# 11**	**SC.7.P.11**		X										
Grade 8														
Practice of Science	**# 1**	**SC.8.N.1**	X	X				X						

Sixth Grade Benchmarks
Science--Big Idea 1: The Practice of Science

- SC.6.N.1.1 - Define a problem from the sixth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.
- SC.6.N.1.4 - Discuss, compare, and negotiate methods used, results obtained, and explanations among groups of students conduction the same investigation.
- SC.6.N.1.5 - Recognize that science involves creativity, not just in designing experiments, but also in creating explanations that fit evidence.

Seventh Grade Benchmarks
Science--Big Idea 1: The Practice of Science

- SC.7.N.1.1 - Define a problem from the seventh grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

Science–Big Idea 10: Forms of Energy

- SC.7.P.10.1 - Illustrate that the Sun's energy arrives as radiation with a wide range of wavelengths, including infrared, visible, and ultraviolet, and that white light is made up of a spectrum of many different colors.

Science–Big Idea 11: Energy Transfer and Transformations

- SC.7.P.11.2 - Investigate and describe the transformation of energy from one form to another.

Eighth Grade Benchmarks

Science--Big Idea 1: The Practice of Science

- SC.8.N.1.1 - Define a problem from the eighth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.
- SC.8.N.1.2 - Design and conduct a study using repeated trails and replication.
- SC.8.N.1.6 - Understand that scientific investigations involve the collection of relevant empirical evidence, the use of logical reasoning, and the application of imagination in devising hypotheses, predictions, explanations and models to make sense of the collected evidence.

National Next Generation Science Standards - Sixth to Eighth Grade Standards

Science–Motion and Stability: Forces and Interactions

- MS-PS2-3 - Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

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Use the investigation below to learn more about photovoltaics and what things influence the electrical output of photovoltaic panels–for good and bad.

Test 1 - Effect of Shadows

1. Attach the leads of the solar panel to an amp meter (or a multimeter set to read direct current amps). You can use alligator clips, or put the probes from the multimeter snugly in a bend of the wire leads coming from your panel. Investigate the effect of shadows on part of the panel. What happens to the **amperage** of the panel if you cover one of the three cells?

2. What happens if you shade ½ of one of these cells?

Test 2 - Angle of the Panel

3. Determine the angle of incidence of the sun. To do this, take a long slender object (such as a pencil) and with one end touching the ground, point the other end towards the sun. When you are pointing directly at the sun, the pointer will not cast any shadow. Then with your protractor, measure this angle and record it below and in the chart in #4.

   Time of day: __________________ Daylight savings time? ____ Yes ____ No

   Angle of incidence: ___________________

4. Determine if the angle of the panel has an effect on its power output. Using your protractor to measure the angle between the ground and the panel, set your panel at the angles listed in the chart on the next page. Then record the **amperage** measurement. Note: To get an accurate amperage reading, make sure that the tilted side of your panel is in an orientation that is facing toward the Sun! An angle of 0º would be flat on the ground. A 90º degree angle would be perpendicular to the ground.

   For the last angle to test, subtract your angle of incidence you recorded above from 90º. Put that angle measurement on the left side of the table and take an amperage measurement with your panel at that angle.

Angle of Panel	Amperage measurement
0º	
20º	
40º	
60º	
90º - Angle of incidence = ___________	

5. What angle produced the highest amperage reading?

6. For the last measurement, why did you subtract your angle of incidence from 90º?

7. How did your highest amperage reading compare to your angle of incidence? What conclusion can you make about which direction to point your panel to get the highest amperage output? (Hint: Think about what angle the Sun's rays need to hit the panel to get the highest output)

Test 3 – Reflectors

7. Will reflecting more light into the panel significantly increase the **amperage** output of the panel? To find out, use aluminum foil or other shiny surface to reflect more light onto the panel. Take an amperage reading without the reflector first, then add your reflective material. Try varying the angle of the reflector to get the highest reading possible. Record your findings below.

   Amperage without reflector _________________

   Highest amperage obtained using a reflector ___________________

8. What did you have to do to get your highest amperage reading?

Test 4 – Temperature

9. Take a **voltage** reading from your panel. (Your panel is probably fairly warm from being in the Sun during the previous exercises; however, if you have just brought your panel out into the Sun, give it a few minutes to warm up a bit before you take your reading.) Record the amperage below. Then take a piece of ice or a cloth dampened with ice water and gently chill the surface of the panel. Take a second reading and record below.

   "Warm" voltage ___________________ "Chilled" voltage ___________________

10. Did cooling off the panel seem to make a difference?