Solar Powered System

Student Objective
The student:
- understands that light energy from the Sun can be turned into electricity with a photovoltaic (solar) cell
- knows how variables such as clouds, shading and direction of panel tilt can affect the electrical output of the photovoltaic cell
- will explain how reflectors and temperature affect the electrical output of the photovoltaic panel
- will determine the angle of incidence of the Sun.

Key Words:
ampere (amp)
angle of incidence
coulomb
current
load
multimeter
orientation
photovoltaic (PV)
volt
watt

Materials
- 3V photovoltaic panel
- wires with alligator clips
- multimeter
- protractor
- ice
- aluminum foil (or other reflective material)
- Laboratory Manual

Time:
1 class period for lab work
1 class period (or assigned homework) for writing assignment
1 class period for presentations

Background Information

The stated 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 is irradiance (sunlight) at 1000 W/m^2, temperature of 25° 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°, a difference in air mass of approximately .75.

- **latitude –** because of the tilt of the Earth, the higher the latitude above 23½ °, the more atmosphere that sunlight must go through to reach the surface. Latitudes between 23½° N and 23½° 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. (Higher temperature increases the conductivity of the semiconductor, charges become balanced within the material, reducing the magnitude of the electric field, and 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 amperage 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. **Engage:** Show the video, *How Do Solar Panels Work*, listed in the Internet Sites section. Lead a discussion on what a photovoltaic (PV or "solar") cell is made of and how it works.
2. Distribute materials. If necessary, review how to set up and use a multimeter.
3. **Explore:** Have the students complete the activity as outlined in the Laboratory Manual stopping before the Writing Assignment.
4. **Explain and Elaborate:** After completing the activity, have the students share their results with the class, and discuss the variables that affect the output of the photovoltaic cell such as:
   - time of day

- weather conditions including temperature and available radiation
- time of year
- location (latitude) on Earth
- thickness of atmosphere that sunlight must penetrate
- angle of the panel's installation

Have the students reach a consensus of which variables/conditions increase the power output of a photovoltaic cell, and which variables/conditions decrease the power output. Which of these can be controlled?

5. Questions for further discussion:
   - What can we do to produce even more electricity? *(Use more panels, adjust the position of the panel to account for the movement of the Sun, or use reflectors if overheating of the panel can be controlled)*
   - How do you use photovoltaics to power things at night? *(You need a device to store the electricity–a battery)*
   - What could we do to produce more electricity on a cloudy day? *(Use more cells/panels in the system or use reflectors and control for heat)*
6. Explain to the students that they will be using the results of their investigation to write a magazine (or scientific journal) article titled "How to produce the most electric power from photovoltaics in _____ , Florida (insert your city)." These articles will then be shared. This article can be assigned for homework, or done during class time at the instructor's discretion.

Procedure (presentation day)

1. Each group selects the best written article from their group to present to the class.
2. After the presentations, the class decides which article from the presentations to share within the school and/or community.

Evaluation and Student Assessment

You may wish to review the students' lab results, but the main focus should be the students' ability to generate an explanation, report evidence and reasoning, communicate the results of a scientific investigation, and to evaluate the merits of explanations produced by others.

Use a holistic FSA ELA Writing Scoring Guide to rate these criteria points:

Criteria	Mastered the skill	Some mastery is evident	Needs improvement
Procedure – explained logically and flows smoothly			
Terms and units – used appropriately			
Scientific principle – at least one is included			

Data – is provided and justified by referencing multiple trials			
Summary – reported data supports the claims and guidelines			
Reasoning – logical and complete			
Overall scientific writing ability			

Key Words and Definitions

- **ampere (amp)** – the electrical unit for current, measuring flow of electron energy through a conducting material, per second
- **angle of incidence –** the angle formed from the incoming ray (incident ray) and the perpendicular angle formed from the reflecting. The angle of incidence varies according to location (latitude) and time of day.
- **coulomb** – the unit of measure of electric charge that is defined as the charge transported by a steady current of one ampere in one second
- **current** – the rate of flow of the charged particles; amps flowing through the circuit at a particular time
- **load** – a device to which power is delivered, such as a motor, a light, or a household appliance
- **multimeter** – an instrument used to measure electrical output in amps, volts and resistance in ohms
- **orientation** – position in relation to the reference points of the compass and elevation angle
- **photovoltaic** – the effect of producing electric current from photons of light energy
- **volt** – the unit measuring the electric force or potential difference in a circuit
- **watt** – the standard unit of power; equivalent to one joule per second

Related Research

1. How are photovoltaics used in the space program? In telecommunications? Use the internet to collect data and pictures of these applications. Are the photovoltaic cells different or the same as those used in terrestrial applications?
2. How are photovoltaic cells made? Research the difference between single crystal, poly crystalline and thin film cells. Which type is the cheapest to produce? Which has the highest efficiency?
3. How can silicon be obtained from sand? Demonstrate the chemical reaction in this activity: **http://www.popsci.com/diy/article/2005-10/making-silicon-sand** Use all chemical safety practices or team this activity with your chemistry teacher.
4. What are the leading countries (and/or states in the U.S.) using photovoltaic cells and

solar energy to produce electricity?

5. Where in your school and/or community are places, devices, or systems that would be easy to convert to phovoltaics? Think outside the box!
6. Develop a marketing survey to determine the public's view of using solar energy to produce electricity. Survey fellow students, family, and friends to obtain survey results and use this information to produce a 60 second infomercial about photovoltaics.

Related Reading

- ***From Space to Earth: The Story of Solar Electricity*** by John Perlin (Aatec Publications, 1999)

  John Perlin surveys the fascinating evolution of photovoltaics from its problematic and controversial nineteenth century beginnings to its indispensable and versatile role as a power source for contemporary daily life. More than the story of a technology, *From Space To Earth* is also a chronicle of the individuals who persevered, took chances, bucked authority, innovated, invented, and crusaded to provide humanity with renewable energy.

Internet Sites

https://ed.ted.com/lessons/how-do-solar-panels-work-richard-komp

Ted Ed lesson, *How Do Solar Panels Work*, tells how photovoltaic cells work. The lesson also includes questions and discussion topics.

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.

https://www.youtube.com/watch?v=2iRfbWOJtog

BOSCH Solar, How It's Made, video follows the manufacturing process from silicon sand to a rooftop.

http://www.engineeringtoolbox.com/electrical-formulas-d_455.html

Common electrical formulas and conversions.

https://www.youtube.com/watch?v=TCq0K3DlFdc

Monocrystalline vs. Polycrystalline Solar Panels - What's the Difference?, video explains the difference in the manufacturing process and differences in efficiency between the two types of crystalline panels.

http://qrg.northwestern.edu/projects/vss/docs/Power/zoom-solar-panels.html

Northwestern University, Qualitative Reasoning Group's website containing modules explaining the use of radiant energy in space systems including the use of photovoltaics.

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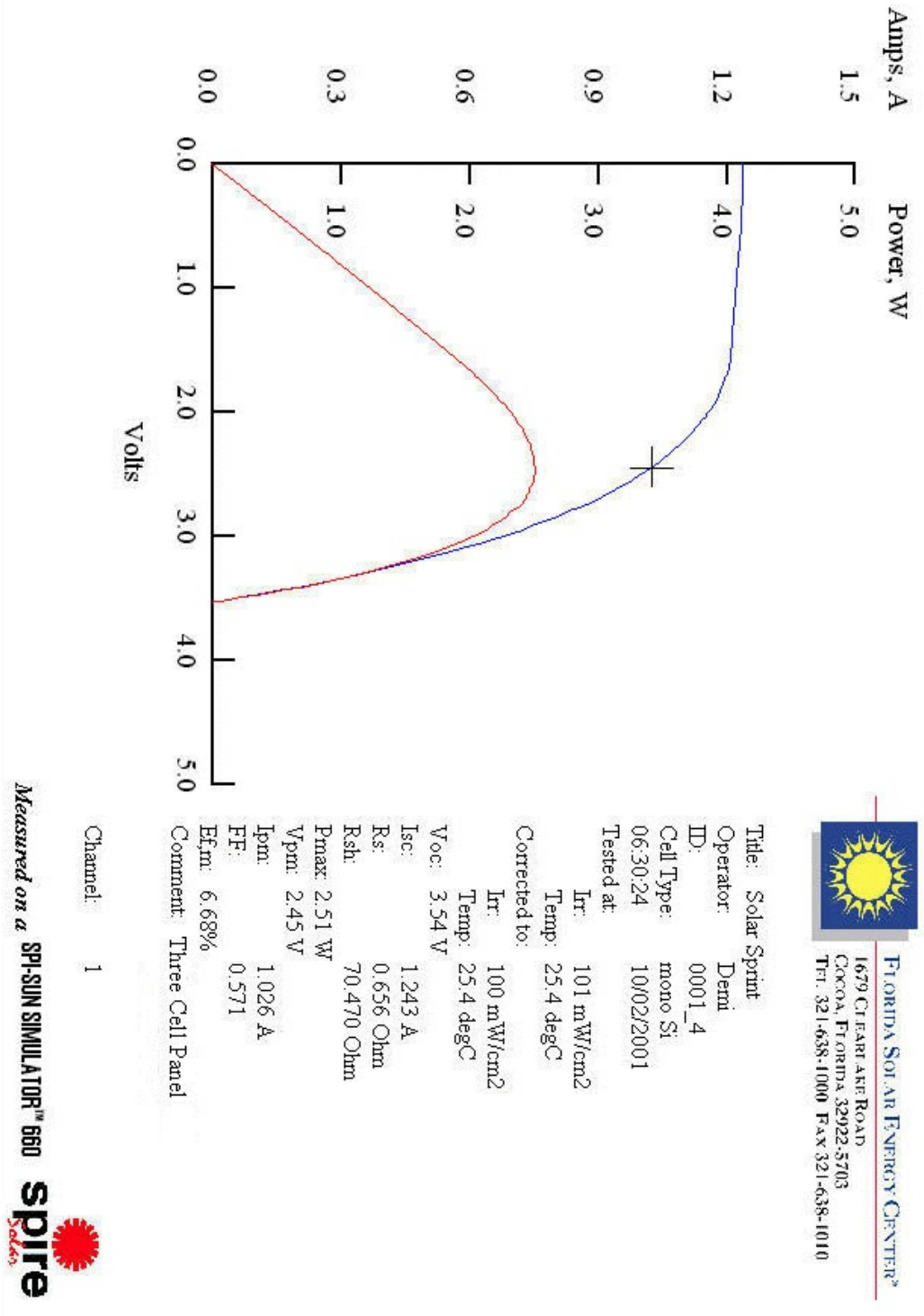

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Florida NGSS Standards & Related Subject Common Core

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Nature of Science																					
Standard 1	**SC.912.N.1.**	**X**																			
Physical Science																					
Standard 10	**SC.912.P.10.**	**X**														**X**					
Life Science																					
Standard 17	**SC.912.L.17.**																	**X**			
Language Arts Standards		**Grades 9 & 10:** LAFS.910.W.1.2, LAFS.910.W.2.4, LAFS.910.WHST.1.1, **Grades 11 & 12:** LAFS.1112.W.1.2, LAFS.1112.W.2.4, LAFS.1112.WHST.1.2																			

Science–Standard 1: The Practice of Science

- SC.912.N.1.1- Define a problem based on a specific body of knowledge, for example: biology, chemistry, physics, and earth/space science, and do the following: 1) pose questions about the natural world, 2) conduct systematic observations, 6) use tools to gather, analyze, and interpret data, 7) pose answers, explanations, or descriptions of events, 8) generate explanations that explicate or describe natural phenomena, 9) use appropriate evidence and reasoning to justify these explanations to others, 10) communicate results of scientific investigations.

Science–Standard 10: Energy

- SC.912.P.10.1 - Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.
- SC912.P.10.15 - Investigate and explain the relationships among current, voltage, resistance and power.

Science–Standard 17: Interdependence

- SC.912.L.17.17 - Assess the effectiveness of innovative methods of protecting the environment.

Language Arts–Writing Standards

- LAFS.910.W.1.2 & LAFS.1112.W.1.2 - Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.
- LAFS.910.W.2.4 & LAFS.1112.W.2.4 - Produce clear and coherent writing in which the

development, organization, and style are appropriate to task, purpose, and audience.

Language Arts–Writing Standards for Literacy in Science and Technical Subjects

- LAFS.910.WHST.1.1 & LAFS.1112.WHST.1.1 - Write arguments focused on discipline-specific content.

National Next Generation Science Standards

Motion and Stability: Forces and Interactions

- HS-PS2-6 - Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Earth and Human Activity

- HS-ESS3-4 - Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

Note: Related Common Core Language Arts Standards are listed in the Florida section above

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Effect of Shadows

1. Attach the leads of the solar panel to a multimeter and set the multimeter to read direct current **amperage**. 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?

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. Complete the data below.

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

   Angle of incidence: _____
   Complimentary angle to the angle of incidence (hint: sum of both equal 90º) _____
   This angle in geometry is also called the "**normal**", a surface that is perpendicular to a vector–in this case the rays of the Sun.

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 below. Then record the **amperage** measurement.
   Note: To get an accurate 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

Angle of Panel	Amperage measurement
0º	
20º	
40º	
60º	
Normal (angle) to the Sun _____	

5. What angle produced the highest amperage reading?

6. How did this compare to your angle of incidence? What conclusion can you make about which direction to point your panel to get the highest output?

Reflectors

7. Will reflecting more light into the panel significantly increase the 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. Describe what you did to get your highest amperage reading:

9. How does changing the angle of reflection (independent variable) effect the amperage output (the dependable variable)?

Temperature

Solar car race teams that race full size solar cars (such as the Dell-Winston Solar Car Challenge) will often spray water on the car's solar panel to keep them cool. Investigate how temperature affects your panel.

10. 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. Take your "warm" amperage reading and record it below. Then take a plastic baggie of ice or a cloth dampened with ice water and chill the top and bottom surfaces of the panel. Leave the baggie or cloth on the bottom of the panel and take a second reading. Record it below.

    "Warm" amperage _____ "Chilled" amperage _____

11. Did cooling off the panel seem to make a difference? If so, how?

12. How would this affect panels in cooler climates?

13. Identify the independent and dependent variable during this investigation.

Writing Assignment

14. Based on the results from this lab activity and the class discussion, write a newspaper or magazine article reporting "How to produce the most electric power from photovoltaics in _____ , Florida (insert your city)" Your article is to include:
    - Title
    - Procedure used during your investigative study
    - Results of your data
    - Guidelines and precautions for others to consider when installing photovoltaics.
    - Validating results. Note: Scientists often perform multiple trials to validate the evidence and claims of their investigative results. Use your classmates' results in your article to support the evidence and claims you make in your summary. Remember, you must give credit to others' (your classmates) results.