Solar Energy

Examining How Angle and Temperature Affect Solar Panels

Description

Students play the role of solar engineers as they test two factors that can affect solar panel efficiency: air temperature and angle of sunlight. They report their findings as if they were writing a user's manual.

Grade Level

5 – 12

Objectives

Students will:

- Investigate how changing angle and temperature affects solar panel efficiency
- Explain how solar electricity is produced
- Recognize solar energy as alternative to fossil fuels

Time

1 Hour

Common Core State Standards

English Language Arts Standards >> Speaking & Listening >> Grade 5
CCSS.ELA-LITERACY.SL.5.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 5 topics and texts, building on others' ideas and expressing their own clearly.

English Language Arts Standards >> Science & Technical Subjects >> Grade 6-8
CCSS.ELA-LITERACY.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.
CCSS.ELA-LITERACY.RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

English Language Arts Standards >> Science & Technical Subjects >> Grade 9-10
CCSS.ELA-LITERACY.RST.9-10.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
CCSS.ELA-LITERACY.RST.9-10.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

English Language Arts Standards >> Science & Technical Subjects >> Grade 11-12
CCSS.ELA-LITERACY.RST.11-12.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
CCSS.ELA-LITERACY.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

Mathematics Standards >> Statistics & Probability >> Grade 6
CCSS.MATH.CONTENT.6.SP.B.4: Display numerical data in plots on a number line, including dot plots, histograms, and box plots.

Mathematics Standards >> Statistics & Probability >> Interpreting Categorical & Quantitative Data >> High School
CCSS.MATH.CONTENT.HSS.ID.A.1: Represent data with plots on the real number line (dot plots, histograms, and box plots).

New Mexico State Science Standards

(Strand – Standard – Benchmark – Performance Standard)
5th Grade
1-1-1-1: Plan and conduct investigations, including formulating testable questions, making systematic observations, developing logical conclusions, and communicating findings.
1-1-1-2: Use appropriate technologies (e.g., calculators, computers, balances, spring scales, microscopes) to perform scientific tests and to collect and display data.
1-1-1-3: Use graphic representations (e.g., charts, graphs, tables, labeled diagrams) to present data and produce explanations for investigations.
1-1-1-5: Communicate the steps and results of a scientific investigation.
1-1-3-1: Use appropriate units to make precise and varied measurements.
3-1-1-1: Describe the contributions of science to understanding local or current issues (e.g., watershed and community decisions regarding water use).

6th Grade
1-1-1-1: Construct appropriate graphs from data and develop qualitative and quantitative statements about the relationships between variables being investigated.
1-1-3-2: Use probabilities, patterns, and relationships to explain data and observations.

3-1-1-1: Examine the role of scientific knowledge in decisions (e.g., space exploration, what to eat, preventive medicine and medical treatment).

7th Grade
1-1-1-2: Use models to explain the relationships between variables being investigated.

8th Grade
1-1-1-2: Use a variety of technologies to gather, analyze and interpret scientific data.
1-1-3-1: Use mathematical expressions and techniques to explain data and observations and to communicate findings (e.g., formulas and equations, significant figures, graphing, sampling, estimation, mean).
2-1-2-3: Distinguish between renewable and nonrenewable sources of energy.
2-1-2-4: Know that electrical energy is the flow of electrons through electrical conductors that connect sources of electrical energy to points of use, including: electrical current paths through parallel and series circuits, production of electricity by fossil-fueled and nuclear power plants, wind generators, geothermal plants, and solar cells, use of electricity by appliances and equipment (e.g., calculators, hair dryers, light bulbs, motors).
3-1-1-4: Critically analyze risks and benefits associated with technologies related to energy production.

9th – 12th Grade
1-1-1-3: Use appropriate technologies to collect, analyze, and communicate scientific data (e.g., computers, calculators, balances, microscopes).
1-1-1-4: Convey results of investigations using scientific concepts, methodologies, and expressions, including: scientific language and symbols, diagrams, charts, and other data displays, mathematical expressions and processes (e.g., mean, median, slope, proportionality, clear, logical, and concise communication, reasoned arguments).
3-1-1-3: Evaluate the influences of technology on society (e.g., communications, petroleum, transportation, nuclear energy, computers, medicine, genetic engineering) including both desired and undesired effects, and including some historical examples (e.g., the wheel, the plow, the printing press, the lightning rod).
3-1-1-9: Describe how scientific knowledge helps decision makers with local, national, and global challenges (e.g., Waste Isolation Pilot Project [WIPP], mining, drought, population growth, alternative energy, climate change).
3-1-1-19: Know that science plays a role in many different kinds of careers and activities (e.g., public service, volunteers, public office holders, researchers, teachers, doctors, nurses, technicians, farmers, ranchers).

Next Generation Science Standards

5th Grade
5-ESS3-1: Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Middle School
MS-ESS3-3: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

High School
HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
HS-ESS3-4: Evaluate or refine a technological solution that reduces the impacts of human activities on natural systems.

Materials

- *Solar Energy* handout [1 per student]
- PowerPoint presentation
- Computer and projector*
- Station task cards [3 per station, 6 total]
- Angle and output station [materials for 3 stations]
    - Multimeter with cables [3]
    - Solar panel with leads [3]
    - Flashlight with Velcro [3]
    - Clear ruler with Velcro on top and bottom [3]
    - Protractor with Velcro [3]
- Temperature and output station [materials for 3 stations]
    - Multimeter with cables [3]
    - Solar panel with leads [3]
    - Flashlight with Velcro [3]
    - Color ruler with Velcro on top only [3]
    - 8 in. pie pans [2 stacked per station, 6 total]

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* Not included in kit

Materials (continued from previous page)

- Temperature and output station (continued from previous page)
  - Digital thermometer [3]
  - Clear plastic container with hole on top for leads and thermometer [3]
  - Bath towels [3]
  - 200 mg weights [3]
  - Stopwatches [3]
  - Beakers [3]
  - Approximately 2 L of water warmed up to 55°C (approximately 130°F)*

* Not included in kit

Background

In New Mexico, solar energy is a growing industry. With an average of more than 275 days of sunshine a year, solar energy has become one of the most feasible options for alternative energy in our state.

When photons (small particles of light) hit a solar panel, they dislodge electrons that then migrate to the surface of the solar panel. As these free, negatively charged electrons surface, an imbalance is created with bottom of the panel, which is positively charged. This imbalance creates voltage potential. When a load is attached, these dislodged electrons flow through the circuit and power the load.

The efficiency of this process, and ultimately the efficiency of the solar panel, depends on environmental factors. The angle at which the sunlight hits the solar panel and the air temperature surrounding the solar panel are two factors that affect voltage. Depending on angle, more or fewer photons hit a solar panel. The number of photons that are exciting electrons within the solar panel is directly related to the amount of electricity that can be produced. At illumination angles closer to 90°, more photons directly hit the solar panel. As the illumination angle moves away from 90°, the light becomes more spread out, and fewer photons directly hit the solar panel.

Additionally, temperature affects solar panel efficiency. As temperature increases, the electrons in the solar panel have more thermal energy. With more thermal energy in the electrons, there is less of an imbalance in the solar panel when the electrons are knocked loose. Less of an imbalance means less electricity is produced.

The growth of the solar industry in New Mexico means that potential jobs in solar are becoming available. In this activity, students will take on the role of a solar engineer as they investigate these two factors that affect solar energy.

Tips for Entire Class Participation

- There are supplies to set up three identical stations for both of the station activities (six stations total). Divide students into six groups when it is time to rotate through the stations.
- When possible, we recommend setting up stations on tables where students can stand all around the set-up, rather than on a table or lab bench against the wall. This allows more students to have a good view and easy access to the station.
- Students will need to work together to accurately collect data at each station.
  - At the angle and output station, students can each take a turn holding the flashlight to collect a data point. One person can be the multimeter reader, while another records the data on the handout.
  - At the temperature and output station, students can take on specific roles.
    - One student can hold the flashlight while the data is being collected.
    - One student can watch the stopwatch and call out every 30 seconds.

- One student can read the thermometer.
- One student can read the multimeter.

Preparation

1. Plan to divide students into six groups for the activity stations.
2. Heat approximately two liters of water to 55°C (approx. 130°F).
3. Set up three angle and output stations:
    a. Plug the cables into the multimeter (students will attach solar panel leads to multimeter).
    b. Remove solar panel with leads from envelope and place near multimeter.
    c. Place flashlight, clear plastic ruler and protractor near the solar panel and multimeter.
    d. Set out station task card.
4. Set up three temperature and output stations:
    a. Spread out a towel at each station. Do all of the following on top of the towel.
    b. Plug the cables into the multimeter (students will attach solar panel leads to multimeter).
    c. Remove solar panel with leads from envelope and place solar panel in the clear plastic container. Run the solar panel leads through the hole in the top of the container from the inside out.
    d. Place the weight in the bottom of the container and snap the lid closed.
    e. Place two stacked pie pans, a digital thermometer (sheath removed), stopwatch, flashlight, beaker, and color ruler on the towel at the station.
    f. Have the warm water accessible to students at these stations.
    g. Set out station task card.
5. Draw the Angle and Output: Whole Class and Temperature and Output: Whole Class data tables (page 2 of the handout) on the board.
6. Prep computer, projector and PowerPoint.

Teaching Guide

Introduction: Identifying the Need for Solar (~10 minutes)

1. Slide 2: Review the four previous lessons and how they point to a need for alternative forms of energy.
    a. *Insulating You, Insulating Earth*: We learned increasing greenhouse gases in our atmosphere from burning fossil fuels are causing global temperatures to increase and the global climate to change. Alternative forms of energy release fewer greenhouse gases to our atmosphere.
    b. *Energy Resources and* Use: We were able to see how transitioning to renewable resources can contribute to increased efficiency of energy resources and help a country meet its long-term energy needs.
    c. *Energy Audit*: We measured how much energy household appliances use while being operated and calculated how many kilograms of CO_2 could be saved from the atmosphere if we reduced our use. If we used more renewable energy, the amount of CO_2 released to the atmosphere would decrease.
    d. *Energy Data* Jam: We looked at energy in New Mexico, where it comes from and how it is used. We saw that in New Mexico, we rely heavily on non-renewable resources rather than renewable resources.
2. Slide 3: What can we conclude?
    a. It is clear that switching to renewable forms of energy will be necessary for long-term sustainability.
    b. Ask students what forms of renewable energy they think would be most successful in New Mexico? [answer: solar or wind].
3. Slide 4: Give an overview of the job of a solar engineer.
    a. Explain that students are playing the role of a solar engineer throughout today's lesson.

b. A solar engineer plans, designs, and implements solar energy projects. They may manage anything from large-scale municipal projects to home rooftop installations.
c. Solar engineering is one of many career options related to renewable energy sources.
d. New Mexico hires the second highest number of solar engineers, second only to California.
e. Qualifications to be a solar engineer include:
    i. Bachelor's degree in mechanical or electrical engineering
    ii. Professional license
f. A part of a solar engineer's job is to report on the efficiency of the solar panels that they are installing. To do this, solar engineers must conduct tests to determine the conditions that solar panels produce the most electricity.
g. This is what you will be doing today, conducting tests to determine when solar panels produce the most electricity.
h. Before we do that though, we must review how a solar panel works to create usable electricity.

4. Slide 5: Give a brief overview of how solar panels work.
    a. Sunlight is made up of photons, small particles of solar energy.
    b. Solar panels are comprised of photovoltaic cells, materials that have been designed specifically to convert sunlight into electricity.
    c. When enough sunlight is absorbed in the photovoltaic cell, electrons in the cell are dislodged by the photons.
    d. When the electrons are dislodged and leave their position, a hole is formed in that place.
    e. Due to special materials used in the solar panels, these freed electrons migrate towards the surface of the photovoltaic cell.
    f. When many freed electrons, each carrying a negative charge, migrate towards the front surface of the cell, an imbalance is created with the positively-charged back surface. This imbalance creates a voltage potential like the negative and positive terminals of a battery.
    g. Electrical conductors are placed in the panel to absorb the electrons. When these conductors are placed in an electrical circuit, the electrons can flow through the circuit, powering an external load.
    h. Explain that students are going to determine how the angle of sunlight hitting the solar panel and how the air temperature surrounding the panel affect the voltage produced by the solar panel.

Procedures: Activity Stations (~ 40 minutes)

1. Slide 6: Give an introduction to the angle and output station.
    a. Students will have 12 minutes at each station to complete the procedures on the task card.
    b. The first station asks the question: How does the angle of illumination affect the solar panel output in volts?
    c. Be sure that you move through the procedures exactly as the task card states.
    d. Here are the instructions from the task card:

1) Turn to page 1 on your handout.
2) Make a prediction at the top of page
3) Connect the positive (red) and negative (black) wire leads from the solar panel to the red and black multimeter cables. Be sure that red is attached to red and black is attached to black.
4) Turn the multimeter knob to the left to select voltage range 20 V.
5) Attach the flashlight to the ruler using the Velcro. The flashlight should shine towards the center of the ruler.
6) Turn on your flashlight.

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7) Place the protractor at the base of the solar panel, with the wires coming out of the top of the solar panel **(see image)**. The Velcro on the protractor should be facing away from the solar panel.
8) Attach the ruler and flashlight to the protractor with the Velcro so you can read 90° on the protractor through the ruler. At this angle, the flashlight will illuminate the solar panel.
9) Record the voltage to the nearest 0.01V in *Angle and Output Data* for 90°.
10) Detach the ruler and pivot it to the left until you read 60° through the center of the ruler. Attach the small piece of Velcro on the ruler to the small piece of Velcro on the protractor. Keep the ruler and protractor flat against the table surface.
11) Be sure the flashlight illuminates the solar panel. Record the voltage for 60°.
12) Repeat steps 10 and 11 for 40° and 20°.
13) Turn off flashlight and multimeter, disconnect wire leads and detach Velcro.
14) Graph your data on *Graph: Angle and Output.* Note: you will plot your data points from right to left.
15) Answer question 1 on the bottom of page 1.

2. Slide 7: Give an introduction to the temperature and output station.
    a. At this station, students will answer the question: How does temperature affect the solar panel output in volts?
    b. Remind students once again to follow the procedures exactly as the task card states.
    c. Safety note: Practice caution when working with the warm water. Follow directions carefully. Do not let wires come into contact with the water.
    d. Here are the instructions from the task card:

1) Turn to page 2 on your handout.
2) Make a prediction at the top of page 2.
3) Connect the positive (red) and negative (black) wire leads from the solar panel to the red and black multimeter cables. Be sure that red is attached to red and black is attached to black.
4) Turn the multimeter knob to the left to select voltage range 20 V.
5) Attach the flashlight to the ruler using the Velcro. The flashlight should shine towards the center of the ruler.
6) Insert the thermometer in the hole on top of the container. Turn on the thermometer and be sure it is reading in °C.
7) Turn on the flashlight. Place the ruler with flashlight against the base of the clear container **(see images).** The flashlight should be illuminating some parts of the solar panel.
8) Record the temperature and voltage in *Temperature and Output Data* in the row *Room Temperature*.
9) Use the beaker to measure 300 mL of warm water and pour it into the pie pan that is sitting on the towel.
10) Carefully, place the container with the solar panel into the pie pan, being sure that the wires do not go near the water.
11) Place the ruler with flashlight against the base of the container in the pie pan. The ruler can get wet.
12) Using the stopwatch, record the temperature and voltage every 30 seconds for 4 minutes.
13) After 4 minutes, turn off thermometer, flashlight and multimeter. Remove clear container from water and set on towel. Disconnect wire leads from multimeter and pour out water from pie pan. Remove thermometer from container. Open the lid of the container to air out for next group.

3. Slide 8: Have this slide up while students are completing the station activities.

4. Slide 9: Once students have completed both activity stations, have them share their group data with the whole class. As students share their data and you write them on the board, students should fill out their whole class data tables on their handout.
    a. For the angle and output whole class data, have each student group share the angle that produced the most voltage (20°, 40°, 60° or 90°).
5. Slide 10: Have students share their groups' temperature and output data.
    a. Begin by having each group identify the values they are going to share.
    b. Have each group find the highest voltage they recorded during their temperature and output trial. Have students circle and write an "H" next to the temperature associated with that voltage; this is their **temperature at maximum voltage.**
    c. Next, have each group find the lowest voltage they recorded during their trial. Have students circle and write an "L" next to the temperature associated with that voltage; this is their **temperature at minimum voltage**.
    d. Students will share their "H" temperature value in the first column, and their "L" temperature value in the second column.

Results and Conclusions (~10 minutes)

1. Slide 11: Results
    a. Have students respond to results questions 1 – 3 regarding best temperature and angle for maximum solar panel output.
2. Slide 12: Conclusion
    a. In conclusion, have students write a two-paragraph summary of their data. They should be writing this summary from the perspective of a solar engineer. Their task is to write a section of a user guide for solar panels. They need to write the sections on solar panel output as it relates to temperature and angle. They should use evidence from their experiments in these paragraphs.

Extensions

1. Run an additional trial of the temperature and output experiment with ice water rather than warm water to determine the effects of colder temperatures on solar panel output.
    a. Students can predict how the voltage will respond with cooler temperatures, or specifically, a temperature they think will produce the highest voltage.
2. Have students test angles that were not included in their task card for the angle and output experiment.

This lesson has been adapted for New Mexico Climate Champions from "Solar Cell Misconceptions" by Carolina. <http://www.carolina.com/teacher-resources/Interactive/solar-cell-misconceptions/tr29719.tr>