

Solar Car Series: Angle/Energy Amount

SPN LESSON #13



TEACHER INFORMATION

LEARNING OUTCOME: Following experiences with a solar panel, students are able to make an informed decision as to whether to incorporate a photovoltaic device into their car design in order to adjust to the position of the Sun in the sky.

LESSON OVERVIEW:

In this lesson, students observe how changing the angle of the solar panel in relationship to the Sun changes the intensity of sunlight and affects the amount of electrical output from the solar panel. [Those students and schools planning on participating in the Junior Solar Sprint competition will need to develop some means of incorporating a mechanism into their car design which will allow them to adjust to the Sun's position in the sky at the time of day the competition is run.] This activity will foster students' understanding of this critical consideration for the race and in a broader sense, underscore the effect of changing sunlight intensities on everyday activities.

GRADE-LEVEL APPROPRIATENESS:

This Level II general energy, technology education lesson is designed for students in grades 5–8.

MATERIALS: Large-diameter straws, solar cells, motors with propeller or spinner, one-minute timers, outdoor work area in sunlight, magnetic compasses, protractors mounted on rectangular blocks of wood

SAFETY: There are no safety concerns involved with the main lesson. However, if the instructor chooses to take the class out on the roof to measure the angle of the solar collectors, there exists the obvious concern of student/teacher falls.

TEACHING THE LESSON: Set aside one period plus parts of two others for this lesson.

A. Teacher demonstration: Use of the protractor and alignment of the straw with a light source.

1. Using an overhead projector and an empty pen barrel, manipulate the pen barrel to demonstrate how it can be positioned so that it casts a minimal shadow (a circle) when it is aligned with the rays of light coming from the projector. Explain that when the pen, or any other straight tube (such as a straw), is pointed directly at the Sun, this same type of minimal shadow will be produced. Whenever the tube is out of alignment with the Sun, the sides of the tube will cast a more obvious shadow.

2. Using a protractor, solar cell panel, and straw, demonstrate how to use the protractor to measure angles in general and specifically how to measure the angle between sunlight rays and the surface of the solar panel.
- B. Pass out student handouts. Give students time to read and review the directions for this exercise.
- C. Review procedures with students. Relate to them that with some care they can rest the edge of the wood under the solar panel on a flat surface and support it with their hands so that the angle between it and the Sun's rays will remain somewhat constant. Remind them that they will be working in groups (three per group is optimum) and to make sure they collect all the data asked of them.
- D. Warn students to be gentle with the fragile solar panels. Have students gather in groups and pick up equipment.
- E. Designate the outside work area.

Lesson Extensions

At some locations, teachers might have a situation that allows them to take the class out on the roof to observe the solar panels mounted on the rooftop of the school. Those students might measure the angle of pitch and the directional orientation of the panels. Relate this information to the conclusions drawn from the SPN lesson #15, *During what part of the day can the most Sun power be collected?* Lesson #15 is also part of the Solar Car series.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION ***[Numbers in brackets are NYSED Intermediate Science Core Major Understandings.]***

RESPONSES TO DIRECTED QUESTIONS:

Hypothesis: [variable responses] A typical response might be "As the angle increases, the amount of sunlight collected will increase." [Standard 1: S1.1a, 1.2a]

2. If the straw is not perpendicular as seen from all sides, then the sunlight angle will not be hitting the collector at 90°. [Standard 1: 3.2d]

3. [variable] The data should show a gradual increase in value as the angle increases. [Standard 1: S2.3c]

5. a) Title: How Sunlight Angle Affects Electric Energy Output from a Solar Cell [Standard 1: S1.3]

b) Label: Number of Turns [Standard1: S3.1b]

c) [variable according to data] Scale should have even gradations and encompass all student values. [Standard1: S3.1b]

RESPONSES TO DEVELOP YOUR UNDERSTANDING QUESTIONS:

1. Sunlight angle [Standard 1: M1.1a, S2.2d]

2. Direct relationship [Standard 1: M1.1b]
3. 90° [Standard 1: S1.2]
4. Sunlight energy is more concentrated in a smaller area when the Sun's rays are more perpendicular. They are spread over a wider area when the rays are received at a lower angle. [Standard 1: S1.3, S2.1, S3.2e]
5. The car must have a mechanism to allow the direction of the solar panels to be changed according to the time of day and the orientation of the racecourse. [Standard 1: T1.1a]
6. The greatest amount of energy is received by that region of Earth receiving the most vertical sunlight rays. The least energy is received at the top and bottom of the Earth diagram. [Standard 6: 2.3]
7. The vertical rays hitting the solar panel transferred the most energy to the solar panel; vertical rays from the Sun hitting Earth's surface must do the same. [Standard 6: 1.2]
8. a) near the equator; b) near the poles [Standard 4: 1.1f]
9. The Sun is higher in the sky in those areas receiving more vertical rays. Or, people leaving at lower latitudes receive the most sunlight at noon. [Standard 4: 1.1f]
10. No, it produces differences in weather and climate (warmer near the equator), and it leads to the development of air masses over these source areas. [Standard 4: 2.2j,k,l]
11. Air in the hot region rises and flows along the top of the atmosphere toward the poles. Air in the cold regions flows along Earth's surface toward the equator. These air movements are called winds. (They are the underlying cause of the planetary wind system.) More sophisticated students might respond that the equator's air flows towards the tropics and sinks there. Polar air tends to flow along the Earth's surface and rises in temperate regions. Temperate region air flows on top of the atmosphere, sinking both at the poles and in the tropics. In effect, there are three circulation cells formed by these phenomena. [Standard 4: 4.2a,b]
12. The school has a fixed position for its solar panel because it would be more expensive to provide a movable system. [You may want your students to compare solar collector energy absorption values versus angle of solar collector on the NREL Web site.http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/sum2/state.html]
13. Collectors face South. The optimum angle to install photovoltaic modules is between 30 degrees and latitude minus 15 degrees. For SPN ballast pan roof mounts on schools, the modules are installed at 30 degrees. For SPN awning mounts on schools walls, the modules are installed at 45 degrees so they do not stick out too much.
14. Facing the collector bank South at this angle maximizes sunlight absorption.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

Junior Solar Sprint, "So ... You Want to Build a Model Solar Car" [NREL/BK-820-30826: revised 8/23/01]

BACKGROUND INFORMATION

This activity is the second of several preliminary classroom investigations leading to an understanding of the scientific phenomena underlying the operation of, and the eventual building of, a competitive model solar car. This competition is sponsored by the Junior Solar Sprint (JSS)

Program, developed originally under the auspices of the U.S. Department of Energy and currently sponsored by the Northeast Sustainable Energy Association (NESEA) and the U.S. Army. Visit NESEA at www.nesea.org for complete information and more learning activities.

The purpose of this activity is for students to develop these understandings:

- 1) ideally, the angle of the collecting panels should be adjusted in relation to the Sun's position
- 2) this angle directly affects the electrical output of the solar panels
- 3) this output in turn directly affects the rate of spin of the motor.

Solar energy absorption by the solar panel is optimized when the angle of insolation approaches perpendicular. Student-collected data should reveal this pattern as collection closest to perpendicular should produce the greatest number of spins on their motors.

The meteorology and astronomy components of the activity give students the opportunity to review differences in the angle of insolation experienced on Earth and its effect on climate and weather. The questions are meant to stimulate thought and to lead to meaningful classroom discussion and clarification during post-data collection review.

The more perpendicular the Sun's rays are to the collecting surface, whether it is the Earth's surface or the surface of the solar panel, the more concentrated the energy will be and the greater the solar gain. This perpendicularity leads to greater solar energy collection and more electrical output by the solar panel, and also to warmer temperatures in those areas of Earth receiving more direct sunlight. On Earth, the differences in heating create the basic variations in climate temperatures experienced from the equator to the poles. This temperature imbalance induces heat energy flow from the equator toward the poles primarily in the form of winds (both surface and large-scale planetary winds).

REFERENCES FOR BACKGROUND INFORMATION

Strahler, Arthur. *The Earth Sciences*, Harper & Row, 1963.

This book in any of its many editions is an invaluable reference.

Any of several Earth science texts and review books will be helpful.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA: 1: M1.1a, 1.1b, S1.1a, 1.2a, 1.3, 2.1, 2.2d, 2.3c, 3.1b, 3.2d,e, T1.1a; 4:1.1f, 2.2j,k,l, 4.2a,b; 6: 1.2, 2.3

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematical Analysis Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically.

M1.1: Extend mathematical notation and symbolism to include variables and algebraic expressions in order to describe and compare quantities and express mathematical relationships.

M1.1a: Identify independent and dependent variables.

M1.1b: Identify relationships among variables including: direct, indirect, cyclic, constant; identify non-related material.

Science Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

S1.1: Formulate questions independently with the aid of references appropriate for guiding the search for explanations of everyday observations.

S1.1a: Formulate questions about natural phenomena.

S1.2: Construct explanations independently for natural phenomena, especially by proposing preliminary visual models of phenomena.

S1.2a: Independently formulate a hypothesis.

S1.3: Represent, present, and defend their proposed explanations of everyday observations so that they can be understood and assessed by others.

Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

S2.1: Use conventional techniques and those of their own design to make further observations and refine their explanations, guided by a need for more information.

S2.2: Develop, present, and defend formal research proposals for testing their own explanations of common phenomena, including ways of obtaining needed observations and ways of conducting simple controlled experiments.

S2.2d: Identify independent variables (manipulated), dependent variables (responding), and constants in a simple controlled experiment.

S2.3: Carry out their research proposals, recording observations and measurements (e.g., lab notes, audiotape, computer disk, videotape) to help assess the explanation.

S2.3c: Collect quantitative and qualitative data.

Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

S3.1: Design charts, tables, graphs, and other representations of observations in conventional and creative ways to help them address their research question or hypothesis.

S3.1b: Generate and use scales, create legends, and appropriately label axes.

S3.2: Interpret the organized data to answer the research question or hypothesis and to gain insight into the problem.

S3.2d: Formulate and defend explanations and conclusions as they relate to scientific phenomena.

S3.2e: Form and defend a logical argument about cause-and-effect relationships in an investigation.

Engineering Design Key Idea 1: Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints); this process is used to develop technological solutions to problems within given constraints.

T1.1: Identify needs and opportunities for technical solutions from an investigation of situations of general or social interest.

T1.1a: Identify a scientific or human need that is subject to a technological solution which applies scientific principles.

Standard 4

Physical Setting

Key Idea 1: The Earth and celestial phenomena can be described by principles of relative motion and perspective.

1.1: Explain daily, monthly, and seasonal changes on Earth.

1.1f: The latitude/longitude coordinate system and our system of time are based on celestial observations.

Key Idea 2: Many of the phenomena that we observe on Earth involve interactions among components of air, water, and land.

2.2: Describe volcano and earthquake patterns, the rock cycle, and weather and climate changes.

2.2j: Climate is the characteristic weather that prevails from season to season and year to year.

2.2k: The uneven heating of Earth's surface is the cause of weather.

2.2l: Air masses form when air remains nearly stationary over a large section of Earth's surface and takes on the conditions of temperature and humidity from that location. Weather conditions at a location are determined primarily by temperature, humidity, and pressure of air masses over that location.

Key Idea 4: Energy exists in many forms, and when these forms change energy is conserved.

4.2: Observe and describe heating and cooling events.

4.2a: Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.

4.2b: Heat can be transferred through matter by the collisions of atoms and/or molecules (conduction) or through space (radiation). In a liquid or gas, currents will facilitate the transfer of heat (convection).

Standard 6—Interconnectedness: Common Themes: Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Key Idea 1: Through systems thinking, people can recognize the commonalities that exist among all systems and how parts of a system interrelate and combine to perform specific functions.

1.2: Describe the differences and similarities among engineering systems, natural systems, and social systems.

Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

2.3: Demonstrate the effectiveness of different models to represent the same thing and the same model to represent different things.

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www.nysesda.org

Should you have questions about this activity or suggestions for improvement, please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name _____

Date _____

Angle/Energy Amount

Topic: Does the angle at which sunlight strikes a photovoltaic solar cell affect the amount of energy collected by the solar cell?

[Before you continue, write a brief hypothesis that addresses this question.]

Materials needed:

- Large-diameter straw
- Solar cell
- Electric motor with propeller or spinner
- One-minute timer
- Outdoor work area with sunlight
- Protractor mounted on a rectangular block of wood

Procedure: (Working in small groups is advised.)

1. Collect the materials you will need for this experiment.
2. When instructed to do so, carefully carry your equipment outside to the work area designated by your teacher. Stand so that you are not blocking the sunlight to the solar cell. Resting the solar cell support board on a flat surface, tilt the solar cell so that the sunlight hits the solar panel at an angle of 90° in all directions (the straw must be perpendicular to the solar panel when observed from all sides). QUESTION: Why does the straw have to appear to make a 90° angle when viewed from all sides?

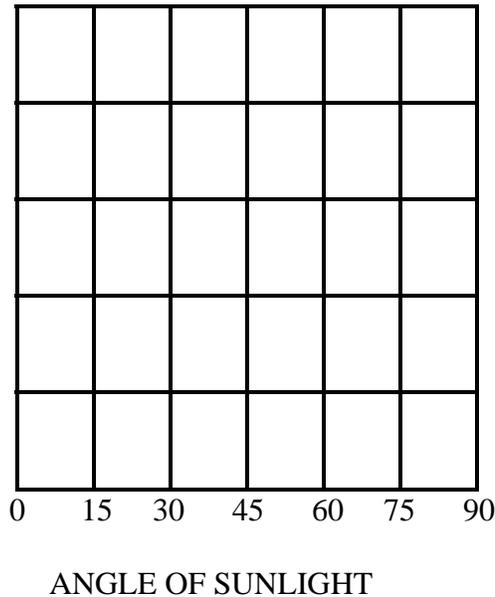
3. Being careful to hold the solar panel gently and to not block any of the sunlight from hitting the panel, count how many times the electric motor turns during one minute. Enter your data in the correct location in the chart below.

Sunlight Angle	15	30	45	60	75	90
Motor Turns						

4. For each of the sunlight angles indicated on the chart above, repeat the data collection described in steps 2 and 3. Be sure to carefully measure each sunlight angle and to hold the solar panel as steady as possible without blocking the light.

5. In the space below, construct a line graph of the cumulative data showing the relationship between the angle of sunlight and the average number of turns. Before you begin:
- Write an appropriate title for the graph.
 - Write an appropriate label on the vertical scale.
 - Determine and write an appropriate numerical scale (for the data you recorded) on the vertical axis.

Title:



DEVELOP YOUR UNDERSTANDING

Respond to the following questions using information gathered during this activity whenever possible.

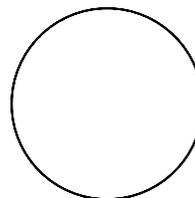
1. Which variable on the graph is the independent variable? _____
2. What term most accurately describes the relationship between the two variables on the graph?

3. Which angle of sunlight produced the greatest number of turns of your motor? _____
4. Explain why that angle of sunlight produced the greatest output of electrical energy from the solar panel.

5. How can this information and the procedures used in this activity be useful in the design of your solar-powered car?

6. The diagram below represents radiation from the Sun (sunlight) approaching Earth. Add to this diagram by indicating the part of Earth that is receiving the greatest amount of sunlight and the part of Earth receiving the least amount of sunlight

SUN'S RAYS



7. How did the information gathered during this activity relate to the answer you gave to question 4? _____

8. a) What general area of latitude on Earth normally receives the most direct and intense sunlight at noontime? _____
b) The least? _____

9. For people living in these areas of different latitude, how does the position of the Sun differ at noontime? _____

10. Does the model of Earth shown above indicate that Earth is evenly heated? ____ What effect does this uneven heating of Earth's surface produce?

11. On Earth, how does the extra heat move from the hotter region to the cooler region? _____ What is this movement called? _____

12. What explanation can you provide for why the solar panel on your roof is fixed in position rather than movable to follow the Sun?

13. In what direction are your school's solar collectors facing and what is the angle of the panels in relationship to horizontal?

Direction: _____; Angle: _____

14. Explain why you think this direction and angular values were chosen.
