Solar Kit Lessons

Middle School Curriculum

Created by Northeast Sustainable Energy Association (NESEA)

Click on the links below to take you to the Chapter heading:

Solar Education for NY
SchoolPower ...Naturally

Solar Kit Lesson #1
Solar Cell Inquiry

TEACHER INFORMATION

LEARNING OUTCOME
After students carry on an open-ended inquiry of how solar panels and an AA battery can be used to power lamps and motors, they infer what forms of energy are used in each instance and predict how long each power source might be able to operate a device.

LESSON OVERVIEW
In this lesson, students use a selection of solar panels, lamps, motors, and an AA battery to get as many motors or lights to operate as they can in an allotted time period. For each successful arrangement, they draw a diagram of their setup, label the energy source and the forms of energy used, and make inferences and predictions.

GRADE-LEVEL APPROPRIATENESS
This Level I/II Physical Setting lesson is intended for use in grades 3–7.

MATERIALS
Per work group
- One or two (different if possible) small DC motors having an operating range of roughly 1–4 volts
- One or two (different if possible) light-emitting diodes (LEDs)
- One or two (different if possible) small incandescent flashlight bulbs
- Two 1V, 400 mA mini–solar panels with alligator clip leads*
- Sunlight, a gooseneck lamp with 100-watt incandescent bulb, or both
- One AA battery in holder with alligator clip leads

* Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY
Warn students
- not to touch lighted incandescent bulbs, since they become hot enough to cause a burn;
- not to let the alligator clips on the two wires connected to the battery touch, since the battery will quickly become "dead" (also, the battery might become hot enough to cause a burn).

TEACHING THE LESSON
Introduce the concept that there are different forms of energy, such as light, mechanical, electrical, chemical, and heat energy.

State that solar cells are objects that convert light energy into electrical energy. Hold up a mini–solar electric panel and show students that it is made up of solar cells.

Form student teams of two or three.

Provide each team with two solar cells, 1 AA battery in a holder, motor(s), a selection of light-emitting diodes (LEDs), a selection of small flashlight bulbs, and if direct sunlight is unavailable, a gooseneck lamp with a 100-watt incandescent bulb.

Challenge students with the task of connecting together items they have been given in ways that will cause a lamp to shine or a motor to spin. Each time they are successful, have them fill in a Record of Inquiry for that test.

Have students determine how long a circuit will remain "on" and compare the results with the proposal they recorded in the Record of Inquiry.

Tell students the cost of a 1V, 400 mA solar cell ($5.00), and the cost of one AA battery. Help them, as needed, as they calculate the cost of running a motor with a battery versus a solar cell for one hour, one week, and one month.

Discussion:
Review with students the different forms of energy that they encountered. Stress the particular form of energy at the source of power (light for photovoltaic-powered circuits and chemical for battery-powered circuits).

Compare the concept of power with the concept of energy. Ask students to identify which test setups produced more power as evidenced by a faster turning motor or a brighter glowing bulb, and which setups had the longer lasting source of energy.

Check to see if any teams noticed that LEDs work only when the red and black wires are connected according to the proper polarity (red to the positive terminal, black to the negative terminal), but that the motors and incandescent lamps work when the red and black wires are connected to either terminal. If so, have those students research the literature to come up with explanations for the phenomena.

Discuss the pros and cons of powering simple circuits using solar cells versus batteries (see the Background Information section).

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION
Answers will vary. Complete answers will include the following.

1) Clearly drawn and labeled diagrams.
2) Correct labeling of each form of energy that exists in the circuit depicted.
3) Correct identification of the source of energy (light from the Sun or a light bulb for photovoltaic-powered circuits and stored chemical energy for battery-powered circuits).

4) An appropriate identification of the power output provided by the circuit.

5) A cogent and feasible explanation of the energy available to power the circuit depicted.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This is not an adapted lesson.

BACKGROUND INFORMATION

Photovoltaic Cells: When a solar cell is exposed to typical light sources, negatively charged electrons almost instantly move to the top of the cell, leaving behind a crystal lattice of atoms having more positively charged protons than negatively charged electrons on the bottom of the cell. This movement rapidly reaches an internal state of equilibrium where the solar cell exhibits a voltage difference of about 0.5 volts between the top and the bottom of the cell.

When metal contacts are placed on the top and the bottom of a photovoltaic cell (solar cell) and each cell is connected to an electric circuit, electrons are drawn off the top of the cell, producing a current that can be used externally. Electrons from the top of the cell move through the electric circuit, replacing the missing electrons in the bottom of the cell. This movement continues as long as the cell is exposed to light having photons of sufficient energy to excite the photovoltaic crystal's electrons.

Power Versus Energy: Power is the rate at which work is done. Energy is the capacity of a physical system to do work. In this lesson, power is proportional to how fast a motor spins or how bright a bulb glows.

Energy available to do work depends on the circuit present. Circuits powered by batteries have energy to do work as long as the batteries are "charged" rather than "dead." The length of time that such a circuit will do work depends on the amount of energy stored in the battery. Circuits powered by solar cells have energy to do work as long as light is present.

Light-Emitting Diodes (LEDs): A light-emitting diode produces light when current passes through it. Unlike an incandescent bulb, current can pass through an LED in only one direction. LEDs are now readily available in flashlights and in strings of Christmas tree lights. LEDs typically can be purchased in electric supply stores.

REFERENCES FOR BACKGROUND INFORMATION

The Columbia Encyclopedia, Sixth Edition. 2001.
The American Heritage® Dictionary of the English Language: Fourth Edition. 2000.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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: Abstract and symbolic representations are used to communicate mathematically. (elementary)

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (elementary and intermediate)

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

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. (elementary and intermediate)

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

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

Key Idea 5: Energy and matter interact through forces that result in changes in motion. (elementary and intermediate)

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints. (elementary)

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Interdisciplinary Key Idea 1: The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena. (elementary and intermediate)

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)

www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Solar Cell Inquiry

Complete a **Record of Inquiry** each time a new arrangement succeeds—that is, each time a lamp goes on or a motor works.

Record of Inquiry

Test Number: _____________

1) Draw a diagram that shows how the items you used are connected. On your diagram, label each item and the color of the wires.

2) On your diagram, identify where each of the following forms of energy is present.

   Light   Mechanical   Electrical   Chemical   Heat

3) Where does the energy that powers the small lamp or motor come from?

4) How fast is the motor spinning, or how bright is the lamp operating? On a scale of one to five, circle the appropriate number.

LAMP					MOTOR				
1	2	3	4	5	1	2	3	4	5
Dim				Bright	Slow				Fast

5) How long do you predict the motor or lamp will remain on, if left as you have it connected? Back up your claim by explaining your prediction.

Solar Kit Lesson #2

Sunshine Timer

TEACHER INFORMATION

LEARNING OUTCOME
After collecting data on cloud cover using a simple instrument and displaying data through graphs, tables, and charts, students interpret data for patterns of cloud cover that affect solar-powered energy production and predict energy production under given cloud conditions.

LESSON OVERVIEW
Students use a simple and easy-to-understand homemade technological device, the sunshine timer, to monitor cloud cover over an extended study period. They become habituated to observing conditions in the sky such as location of the Sun and types of clouds present. This study provides daily and weekly opportunities for students to collect and display data; use graphs, tables, and charts to interpret data; make predictions; and relate patterns of cloud cover to their effect on solar energy production.

GRADE-LEVEL APPROPRIATENESS
This Level I/II Physical Setting lesson is intended for use in grades 3–6. It can easily be adapted for grades 7 and 8.

MATERIALS
- Student handouts
- 1 V, 400 mA mini–solar panel*
- Analog DC-powered clock (must run on one AA battery)
- Maximum temperature thermometer
- Highlighter (optional)

* Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY
Tell students not to look directly at the Sun. Permanent eye damage can result.

TEACHING THE LESSON
This lesson could easily be adapted to encompass fractions and percentages. It could readily be transferred to computer data-management software such as spreadsheets.

Preparation—Set up the sunshine timer: Remove the AA battery from the DC-powered clock. Use alligator clips to connect the mini–solar panel’s red lead to the clock’s positive (+)

battery terminal and black lead to the negative (-). The clock will run when the mini–solar panel is aimed at the Sun unless a cloud obscures the Sun. Set the clock to noon at the start of a data collection period. The clock will advance as long as clouds do not cover the Sun. In this way, the clock will record the number of hours of unobscured sunlight. Students can subtract the number of hours the clock advances from the number of hours of data collection to get the number of hours of cloud cover.

The clock can be powered by a mini–solar panel that is aimed within 45 degrees of facing the Sun directly. From August through April the Sun is within 45 degrees east of south to 45 degrees west of south for a three-hour period centered on noon. From May through July you will need to shorten the daily data collection period to two hours because the Sun will be at too great an angle from due south during the three-hour period centered on noon. Alternatively, you can extend the daily data collection period by adjusting the direction of the sunshine timer to track the Sun.

Opening Discussion: Begin by discussing how solar electric systems depend on radiation from the Sun to produce power. Demonstrate a mini–solar panel powering a small motor. Mention that the School Power Naturally project has installed solar electric systems in 50 New York State schools to partially address their energy needs. Explain that solar electricity is a growing energy source throughout New York State. Use information from the Background Information section to introduce the idea of peak electrical demand and the fact that the highest demand for electricity occurs during hot summer days when there are large amounts of sunshine.

Ask students what might hinder our using sunshine for electricity. What might New York State decision makers want scientists to study to determine if solar electric panels are a good way to supply electricity in the middle of the day?

Tell the students that they will conduct a long-term study of middle-of-the-day cloud cover. Demonstrate how the sunshine timer works and give students an opportunity to handle the timer and become familiar with it.

Help students determine where in the school or in the classroom they can place the cloud meter. It must receive sunlight for one to three hours around noontime unobscured by the shadows of trees, buildings, or other objects. It must face due south and tilt up at an angle to face the Sun at around noon. It must be protected from the weather.

Data Collection: Distribute the student handouts and explain the daily cloud logs. Have students record the length of the data collection period for each day and convert the time to minutes. At set intervals during the daily data collection period, have students check off the box that best fits the current cloud conditions. Have students use the "Weather Notes" section to record daily peak temperature. They could also use it for additional work involving cloud identification or to record experiences for other weather observation opportunities that you may want them to have.

Prediction: At or before the end of the data collection period, but before students check the sunshine timer, have them make a prediction on how many minutes of sunshine will have been recorded.

Data Collection: Have students record the length of sunshine for each day and convert it to minutes.

Data Calculation: Have students subtract the number of minutes of sunshine from the number of minutes for the data collection period to get the number of minutes of cloud cover. Students who would benefit from additional work with fractions or percentages might use these numbers for daily practice and to form additional weekly graphs.

Graphing: Distribute and explain graphs 1–3. Help students label the *x*- and *y*-axes. In the title of graph 2, students must fill in the number of minutes of the daily data collection. Have students fill in these graphs on a regular basis—for instance, daily or once a week.

Graph 1: This graph is actually five bar graphs on top of one another. Students should use a different color for each weather condition. For each day, have students record the number of times each weather condition is observed.

Graph 2: Have students graph their predictions with a pencil dot and the measured value as a bar colored with a highlighter.

Graph 3: Have students graph the peak daily temperature as a line graph.

Review Questions: Go over appropriate review questions daily, weekly, or at the end of the data collection period.

Have your predictions on the amount of sunshine improved over time? Have students discuss why.

What types of clouds or cloud cover seem to affect solar energy production the most?

What types affect it the least?

Visit schoolpowernaturally.org online to compare your data with the data available from the 50 New York schools having solar electric systems.

How do the solar intensity readings collected by the School Power Naturally schools compare to your daily sunshine readings? Have students discuss why these may be the same or different. Have them consider the length of time of daily data collection and the location of the schools.

How could solar electric power help provide electricity for the high midday demand of high-temperature days?

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

The results will vary depending on the kind and extent of cloud cover during the data collection period.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

The idea of using a solar-powered clock as a sunshine timer came from *Science Projects in Renewable Energy and Energy Efficiency*, written and designed by the National Renewable Energy Laboratory and published by the American Solar Energy Society, 1991.

The organization of classroom activities was adapted from *Renewable Energy Activities for Earth Science* prepared for the U.S. Department of Energy by the Solar Energy Project in cooperation with the New York State Education Department and the University at Albany Atmospheric Sciences Research Center (out of print).

BACKGROUND INFORMATION

Daily peak needs for electrical power in New York State's large metropolitan areas are closely coincident with available sunlight. New York's highest power demands occur during summer heat waves, when there are large amounts of sunshine.

Studies conducted by the University at Albany Atmospheric Sciences Research Center show that for the mid-Atlantic region (including downstate New York) sunlight is available when it is needed to offset peak power 60% to 70% of the time. This is comparable to much of Arizona, Florida, and California—the "traditional" solar areas.

The result is that, together with very small amounts of backup power (such as batteries) and/or programs to reduce peak demand for electricity, solar electric panels could provide a 100% guaranteed peak power source for New York's metropolitan areas.

REFERENCES FOR BACKGROUND INFORMATION

Why PV Makes Sense in New York State. University at Albany Atmospheric Sciences Research Center, 2001

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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.

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions.

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems.

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

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.

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

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 1: Students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence, and construct an argument.

Key Idea 2: Students use number sense and numeration to develop an understanding of the multiple uses of numbers in the real world, the use of numbers to communicate mathematically, and the use of numbers in the development of mathematical ideas.

Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships.

Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data.

Key Idea 6: Students use ideas of uncertainty to illustrate that mathematics involves more than exactness when dealing with everyday situations.

Key Idea 7: Students use patterns and functions to develop mathematical power, appreciate the true beauty of mathematics, and construct generalizations that describe patterns simply and efficiently.

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

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

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

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful information.

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

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions.

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www.nyserda.org

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(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Sunshine Timer
Daily Cloud Log

Data collection period: hours ____________ minutes ____________

converted to minutes _____________

Cloud Conditions

	Starting Observation	At the end of the 1st hour	At the end of the 2nd hour	At the end of the 3rd hour
Clear blue sky				
Heavy clouds passing by				
Thin clouds passing by				
Heavily overcast sky				
Light hazy sky				

Weather Notes
Daily peak temperature ___________

Prediction

Over the data collection period, I predict that we received ____________ minutes of sunshine.

Measured Data

length of time of sunshine: hours ____________ minutes ____________

converted to minutes _____________

Calculated Data

number of minutes of the data collection period min.

minus number of minutes of sunshine — ____________ min.

number of minutes of cloud cover min.

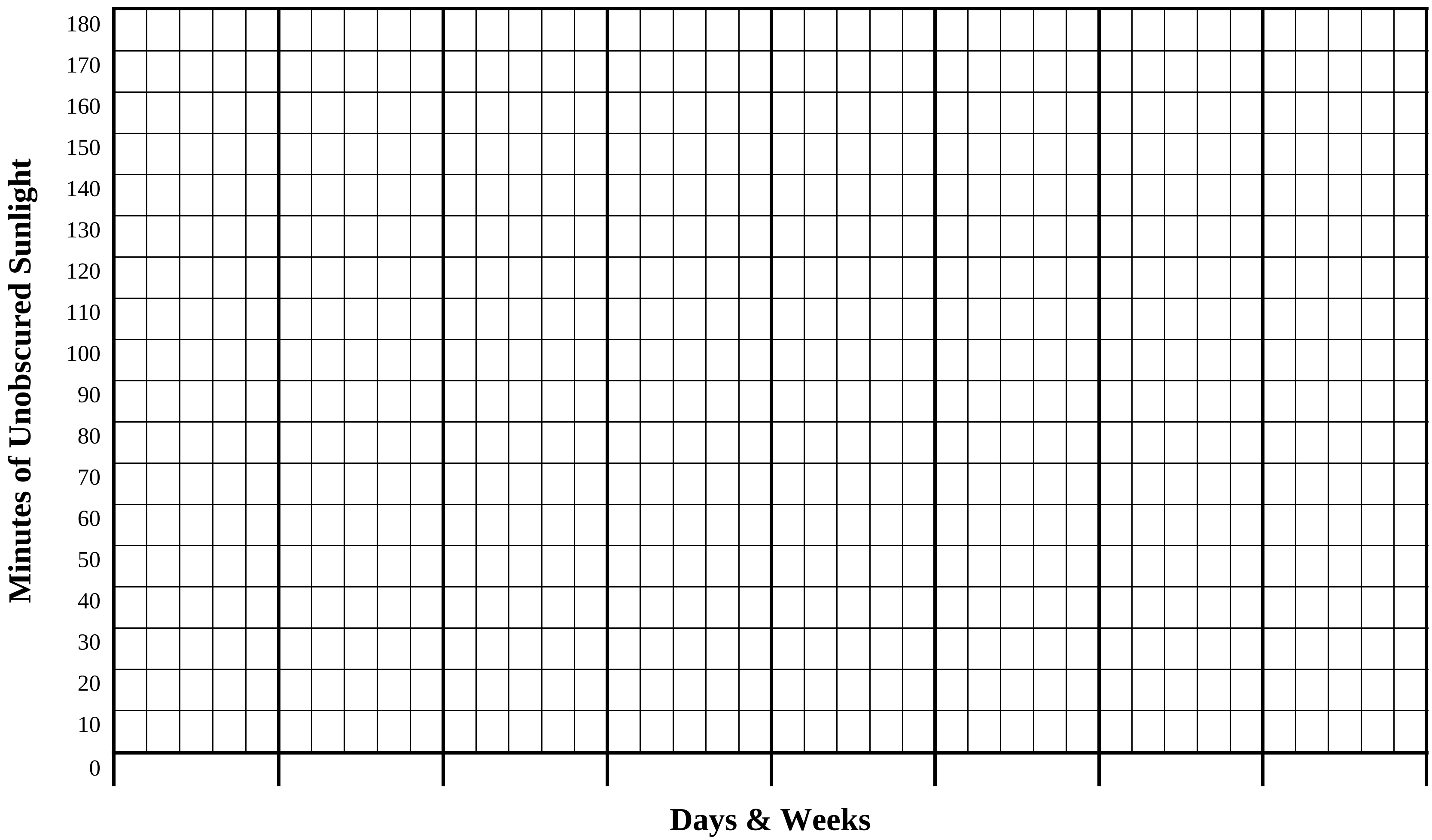
Name ________________________________

Graph 1
Cloud Cover Conditions Over the Sun

Days & Weeks								
Clear blue sky								
Heavy clouds passing by								
Thin clouds passing by								
Heavily overcast sky								
Light hazy sky								

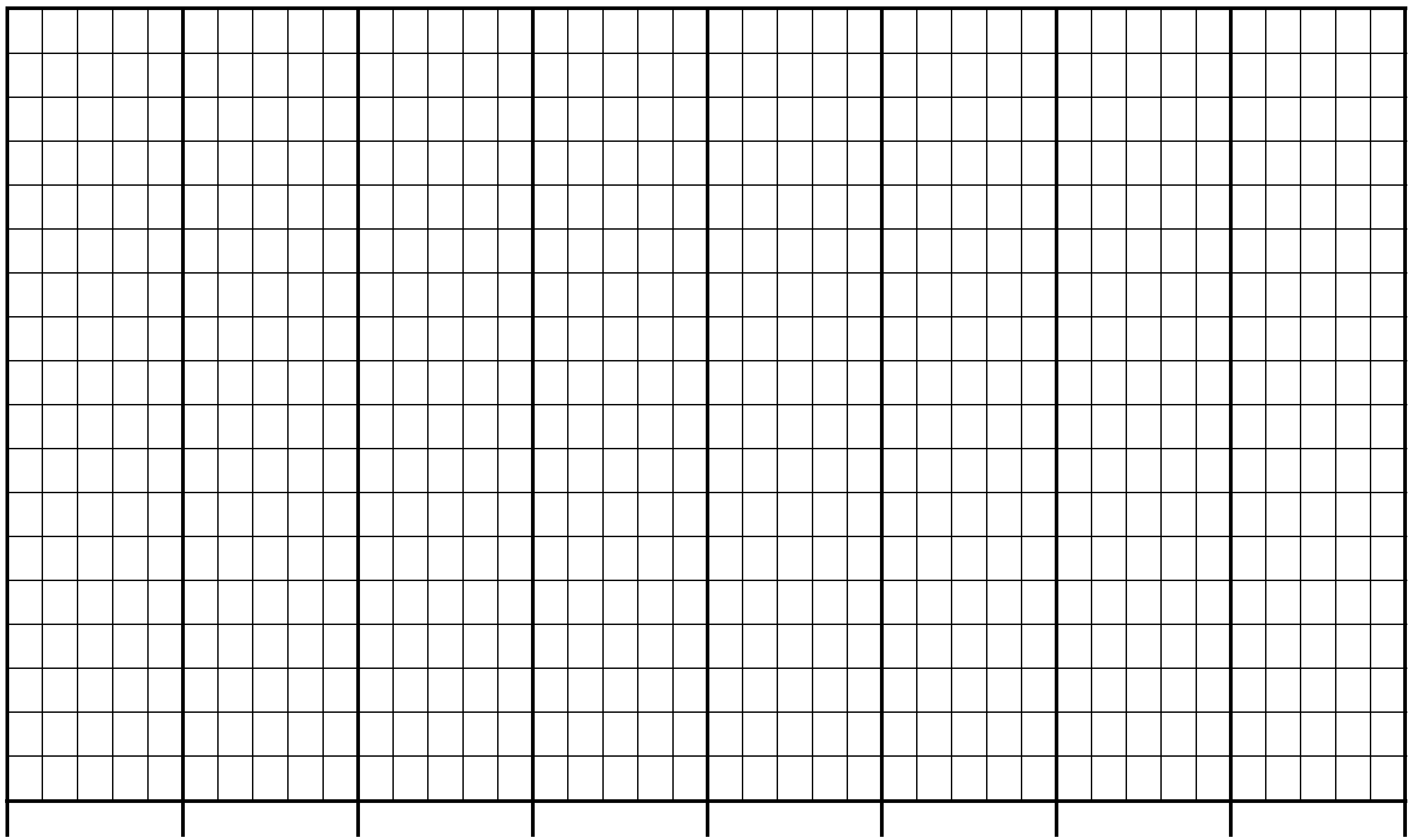
Name __________________________________

Graph 2
Minutes of Sunshine per ______-minute Period



Name ___________________________________

Graph 3
Daily Peak Temperature



Solar Kit Lesson #3
Parts of a Solar Panel – Part I

TEACHER INFORMATION

LEARNING OUTCOME
After examining electrical contacts and the use of solar cells and rechargeable batteries to power electric motors, students are able to describe how a solar cell is similar to and different from a rechargeable battery as a way to explain to others how a solar cell works.

LESSON OVERVIEW
Students use observation, critical thinking, and deductive and inductive reasoning to compare and contrast the characteristics of a solar cell to a rechargeable battery. By comparing and contrasting a solar cell to the more familiar rechargeable household battery, students discover a simple analogy to help them understand and explain to others how a solar cell works: similar to a rechargeable battery, a solar cell can be energized to provide a circuit with direct current. It is unlike a rechargeable battery in that it is energized by a different form of energy (light as opposed to electricity) and it can be energized instantly but it cannot store energy so it instantly becomes "dead" when that energy source is removed.

GRADE-LEVEL APPROPRIATENESS
This Level I and II Physical Setting, physical science and technology education lesson is intended for use in grades 4–6.

MATERIALS
Per work group
- student handout
- one rechargeable AA battery
- one AA battery holder
- one mini–solar panel*
- one piece of solar cell*
- gooseneck lamp with 150-watt incandescent bulb
- small project-motor (almost any small motor will work, but test your selection before using it in class to make sure it works with the low voltages of one AA battery and the mini–solar panel)

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY
Broken pieces of solar cell have sharp edges. Tell students to handle the small pieces as they would any sharp object, such as a piece of broken glass. Light bulbs get hot enough to burn. Instruct students not to touch the light bulb.

TEACHING THE LESSON

Students should already be familiar with recharging and using rechargeable batteries prior to this lesson. Have students work in teams of two.

Show students a piece of a solar cell and identify it. Tell students that a solar cell acts in some ways like a rechargeable battery; sometimes the cell is “dead” and sometimes it is energized and can provide electric power. Reveal that they are to investigate and report on how a solar cell is similar to and different from a rechargeable battery.

For each team, hand out an energized (charged) rechargeable AA battery. Show students that the battery’s two ends are covered with a metal contact. Discuss why this is necessary for the battery to be usable.

Distribute pieces of solar cells to student teams. Caution them that solar cells have sharp edges and are very fragile. Instruct students to hold the cells so that they are flat and not to bend them. They need to handle them as they would any sharp object, such as a piece of glass.

Point out that solar cells as well as batteries need metal contacts in order to be usable. Have students examine the cells and determine which parts of the cell they think are the metal contacts. Discuss with the class how one side of the cell is covered with a metal and the other side has a grid of metal lines.

Ask students to speculate why solar cells are made this way. Discuss how solar cells need to let as much light as possible into the cell and how they need to allow as much electricity as possible flow in or out of the top and bottom of the cell.

Distribute the student handout and have students complete the drawings called for in parts a and b of step 1.

Collect the solar cells. Now show students a mini–solar panel and identify it as a package of solar cells. Give each team one mini–solar panel and one AA battery holder. Tell students that, because solar cells are fragile, they are packaged in protective containers with wires that are brought to the outside and connected to the cell’s electrical contacts. Have them identify which metal contact on the batteries and which wire on a solar panel are marked with a positive (+) symbol. Do the same for the negative terminal. (Note: Many batteries only identify the positive terminal.)

Have students complete all parts of step 1 of the handout. As each team completes step 1, provide them with a small project-motor and, if no bright direct sunlight is available, a gooseneck lamp having a 150-watt incandescent bulb. Have them complete the rest of the handout.

Extension activity: Have students compose in writing a description of how a solar cell works, comparing and contrasting it to a battery. Have students orally describe to another person or to the group how a solar cell works as compared to a rechargeable battery.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

1a) Accurate drawing of a battery with the two ends labeled as having metal contacts.

1b) Accurate drawings of both sides of a solar cell with the metal contacts properly labeled.

1c) Accurate drawing of a mini–solar panel with the colors of the wire leads identified and the wire leads identified with a plus (+) or a minus (-) sign.

1d) Accurate drawing of a battery in a battery pack with the colors of the wire leads identified. Also, the wire leads should be identified with a plus (+) or a minus (-) sign.

1e) Answers may vary. A typical response might be that both have wires that are used as metal contacts.

2a) Electrical

2b) Students should describe recharging the battery with a battery charger on a regular basis.

2c) Light

2d) The solar panel is energized whenever it is exposed to a light source of sufficient energy. It acts like a "dead" battery when it is not exposed to the light source.

2e) Keep the solar panel exposed to a light source whenever it is needed to run the motor.

Venn Diagram:
List electrical characteristics of a rechargeable battery that are different from those of a solar cell.

Answers will vary. More complete answers might include such observations as:

(1) Rechargeable batteries are energized, or charged, using electricity as a source of power.

(2) It takes time to energize or charge a battery.

(3) Rechargeable batteries can store energy.

(4) Batteries discharge, or become dead, slowly.

List electrical characteristics that a solar cell and a battery have in common.

Answers will vary. More complete answers will include such observations as:

(1) Both have positive and negative metal contacts.

(2) Both can supply electric power (can be used to run a motor).

(3) Both can be energized by an external source of energy.

List electrical characteristics of a solar cell that are different from those of a rechargeable battery.

Answers will vary. More complete answers might include such observations as:

(1) Solar cells are energized using light as an energy source.

(2) Solar cells become instantly energized when exposed to light.

(3) Solar cells cannot store energy and they instantly become "dead" when the light source is removed.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ACTIVITY

This is not an adapted lesson..

BACKGROUND INFORMATION

By placing metal contacts on the top and bottom of a photovoltaic cell (solar cell) and connecting these to an electric circuit, we can draw electrons off the top of the cell to form a current that can be used externally. Electrons from the top of the cell move through the electric circuit to replace the missing electrons in the bottom of the cell. This movement will continue as long as the cell is exposed to light having photons that have sufficient energy to excite the photovoltaic crystal's electrons.

When a solar cell is exposed to such a light source, almost instantly it moves negatively charged electrons to the top of the cell, leaving behind a crystal lattice of silicon atoms that have more positively charged protons than electrons on the bottom of the cell. This movement quickly reaches an internal state of equilibrium at which time the solar cell exhibits a voltage difference of about 0.5 volts between the top and bottom of the cell.

In this lesson, we refer to this condition as an "energized" solar panel. The solar cell is now able to provide a direct electric current to a circuit. In this way, a solar cell works like a rechargeable battery: it can be energized by an external energy source. The solar cell is unlike a rechargeable battery in that the solar cell cannot store energy and so becomes "dead" as soon as the energy source is removed. It is also different from a rechargeable battery in that the solar cell uses a different form of energy, light as opposed to electrical energy, to become energized.

Parts of a PV Cell

The top of a PV cell contains a grid of metal contacts. The metal contacts must be

- thick enough and close enough together (low resistance) to allow for the required current to flow through them, yet
- thin enough and spaced far enough apart to let sufficient light into the cell.

The cell is covered with an antireflective coating that enables maximum penetration of light into the cell. This is necessary because silicon crystals are highly reflective.

The bottom of a PV cell is covered with a metal plate that allows electrons to move back into the cell with minimum resistance. The metal plate also acts to reflect light back through the cell.

PV cells are packaged in panels covered by protective glass or other transparent material and encased in a protective receptacle.

REFERENCES FOR BACKGROUND INFORMATION

Richard Komp, Ph.D., *Practical Photovoltaics: Electricity from Solar Cells*, aatec Publications, 2002.

Chris Mason of the Northeast Sustainable Energy Association provided the analogy of a solar cell as a rechargeable battery.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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 2: Deductive and inductive reasoning are used to reach mathematical conclusions. (elementary)

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (elementary and intermediate)

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

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. (elementary)

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 1: Students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence, and construct an argument. (elementary)

Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships. (elementary and intermediate)

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity. (elementary and intermediate)

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

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms. (elementary and intermediate)

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 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. (elementary and intermediate)

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)

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Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Names ____________________________________

____

Date ______________________________________

How Is a Solar Cell Like a Rechargeable Battery?

1) Electrical connections:
   a) Draw and label a battery. Describe each metal contact.

   b) Draw and label both sides of a solar cell. Describe the metal contacts.

   c) Draw and label a solar panel including both wires. Describe both wires.

   d) Insert the battery into the battery holder. Draw and label the system. Describe the relationship of the wires to the rest of the system.

   e) Describe one or more ways that a battery in a battery holder is like a solar cell in a solar panel.

2) **Electrical power:** Connect the battery to the motor in a variety of ways, and observe and record what happens. Connect the solar panel to the motor in different ways and observe and record what happens. Expose the solar panel to bright sunlight or a lamp provided by your teacher and observe and record what happens. ***Caution: Do not place the solar panel closer than six inches to a bright light bulb; the heat of the bulb might melt the panel's protective cover.***

   Use what you know about rechargeable batteries and what you observed to answer the following questions. Then fill out the Venn diagram on the next page.

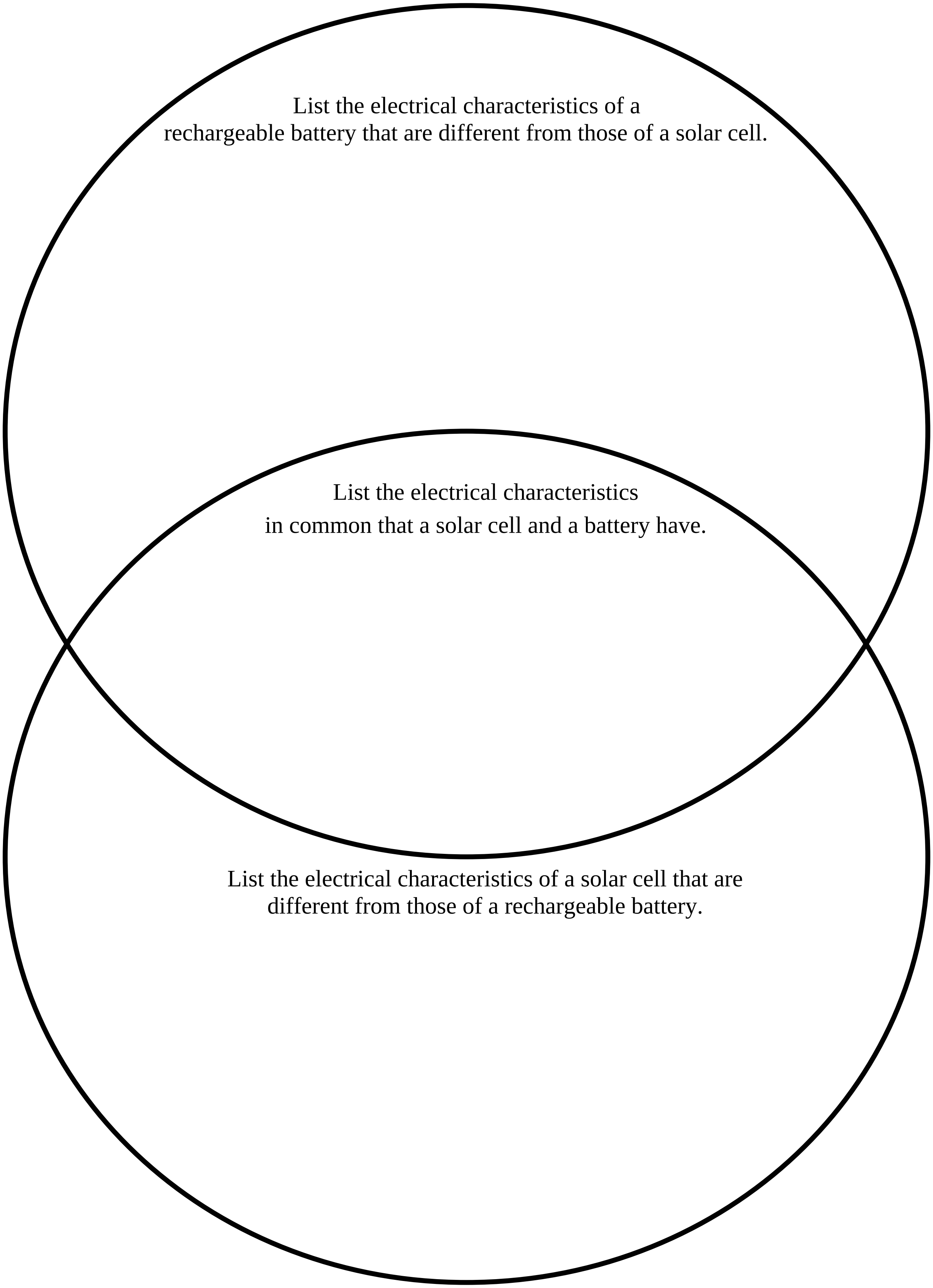
   a) From your knowledge of rechargeable batteries, what form of energy is used to charge a rechargeable battery? Circle one.
      i) light
      ii) electrical
      iii) heat
      iv) mechanical

   b) Using your knowledge of rechargeable batteries, what would you need to do if you wanted to run the motor every day for a long period of time?

   c) What form of energy is used to energize a solar panel? Circle one.
      i) light
      ii) electrical
      iii) heat
      iv) mechanical

   d) Describe the condition present when the solar panel is energized. Describe the condition present when the solar panel is "dead."

   e) From what you observed, what would you have to do to use this solar panel to run this motor every day for a long period of time?


List the electrical characteristics of a rechargeable battery that are different from those of a solar cell.
List the electrical characteristics in common that a solar cell and a battery have.
List the electrical characteristics of a solar cell that are different from those of a rechargeable battery.

Solar Kit Lesson #4
Parts of a Solar Panel – Lesson II

TEACHER INFORMATION

LEARNING OUTCOME
After reverse engineering a mini–solar panel to determine how it was constructed physically and electrically, students are able to describe how fragile solar cells are packaged to form a durable solar panel and how the series and parallel electrical connections that were used relate to the output voltage of the device.

LESSON OVERVIEW
Students use observation, critical thinking, and deductive and inductive reasoning to determine how a mini–solar panel is constructed.

GRADE-LEVEL APPROPRIATENESS
This Level I and II lesson is intended for use in grades 4–6.

MATERIALS
Per class
- Digital multimeter or analog voltmeter
- Lamp with 150-watt incandescent bulb
- AA battery
- Broken piece of solar cell*

Per work group
- Student handout
- One mini–solar panel*

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY
Broken pieces of solar cell have sharp edges. Instruct students to handle the small pieces as they would any sharp object such as a piece of broken glass. Light bulbs get hot enough to burn. Instruct students not to touch the light bulb.

TEACHING THE LESSON
This lesson is designed to follow the Solar Kit lesson *Parts of a Solar Panel – Lesson I.*

Show students a solar panel and identify it. Then show them a piece of solar cell and tell them that solar panels are made up of solar cell pieces such as this. Challenge them to figure out how a panel is put together. Explain that engineers do what you want them to do when they want to learn how someone else put together a product. They behave like detectives and look up facts about the product, examine the product, and draw diagrams that show how they think the product works.

Distribute the student handouts and have students look at the graphic for Fact 1. Define *voltage* and then demonstrate how to use a multimeter to measure the voltage across a battery and then a solar cell under a bright light. (If no bright direct sunlight is available, use a lamp with a 150-watt incandescent bulb.) Tell students that most small household batteries will measure about 1.5 volts and that most solar *cells* will measure about 0.5 volts.

Have students look at the graphic for Fact 2. Describe what it means to connect solar cells "in series" and then ask students how many solar cells would have to be connected in series to make the same voltage as a household battery. Discuss with them why this is so.

Have students look at the graphic for Fact 3. Describe what it means to connect solar cells "in parallel." Tell students that connecting two solar cells in parallel is the same as using a bigger solar cell and that a bigger solar cell can collect more light energy than a smaller one.

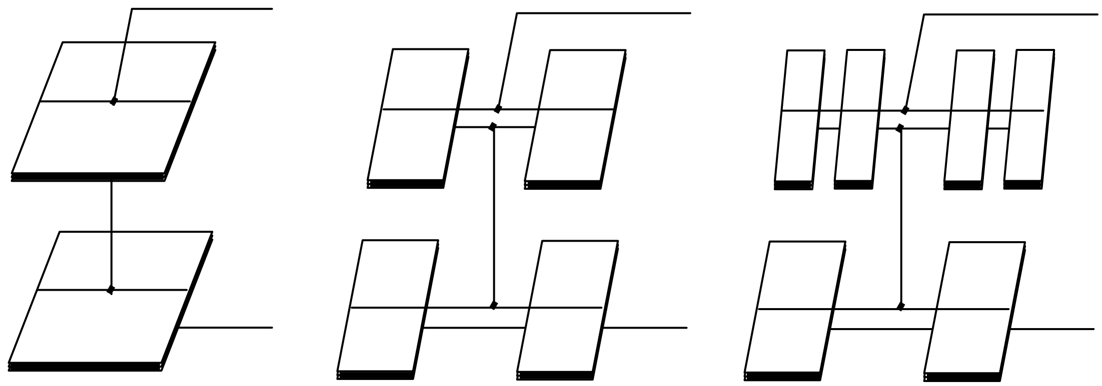
Form the class into teams of two and distribute the mini–solar panels. Have students complete question 1 of the handout as you go around to each team and help them measure the open-circuit voltage of their mini–solar panel and demonstrate once more how to measure the open circuit voltage of the solar cell. Students will need these measurement values to complete question 2 on the handout.

Extension activity: Provide a workstation with a selection of solar panels, a light source (the best light source is a sunny window), and a digital multimeter. Let student teams use the workstation in turns. Have students connect the solar panels in different combinations, predict the voltage output they expect, and then use the multimeter to check their prediction.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

1) Expect a drawing showing a clear plastic top to let light in and a rigid, shallow, plastic, open-topped box to hold the cells firmly in place. Two wires, one red and one black, extend from one end of the box. Some astute students may show the red wire marked with a plus (+) sign and the black wire marked with a minus (-) sign.

2) Expect a drawing showing two to eight cells. In this drawing, two groups of one to four cells should be shown connected in parallel and these two groups should be shown connected in series with each other. Typical drawings may look like this:



ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ACTIVITY
This is not an adapted activity.

BACKGROUND INFORMATION
By placing metal contacts on the top and bottom of a photovoltaic cell (solar cell) and connecting these to an electric circuit, we can draw electrons off the top of the cell to form a current that we can use externally. Electrons from the top of the cell move through the electric circuit to replace the missing electrons in the bottom of the cell. This movement will continue as long as the cell is exposed to light having photons that have high enough energy to excite the photovoltaic crystal’s electrons. In this way, a solar cell works like a battery in that it provides a circuit with direct current.

Each silicon PV cell produces about 0.5 volts when exposed to light. The amount of current PV cells produce is related to their surface area. Larger cells produce more current. Current multiplied by voltage equals power, so larger cells produce more power. The unit output of a PV cell is measured in watts per square meter.

To produce more current, you can connect two or more PV cells in parallel (negative terminals all connected together and positive terminals all connected together). The effect of this is to give you a larger solar cell.

To produce higher voltage, connect two or more PV cells in series (positive terminals are connected to the next cell’s negative terminal). The total voltage is the addition of each PV cell’s individual voltage.

Parts of a PV Cell
The top of a PV cell contains a grid of metal contacts. The metal contacts must be thick enough and close enough together (low resistance) to allow for the required current to flow through them, but thin enough and spaced far enough apart to let sufficient light into the cell. The cell is covered with an antireflective coating that enables maximum penetration of light into the cell. This is necessary because silicon crystals are highly reflective.

The bottom of a PV cell is covered with a metal plate that allows electrons to move back into the cell with minimum resistance. The metal plate also acts to reflect light back through the cell.

PV cells are packaged in panels of several cells connected in series or parallel to produce the desired voltage and current. A panel of cells is covered by protective glass or other transparent material and encased in a protective receptacle.

REFERENCES FOR BACKGROUND INFORMATION

Richard Komp, Ph.D., *Practical Photovoltaics: Electricity from Solar Cells*, aatec Publications, 2002.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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 2: Deductive and inductive reasoning are used to reach mathematical conclusions. (elementary and intermediate)

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems. (elementary and intermediate)

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (elementary)

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. (elementary)

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 1: Students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence, and construct an argument. (elementary)

Key Idea 2: Students use number sense and numeration to develop an understanding of the multiple uses of numbers in the real world, the use of numbers to communicate mathematically, and the use of numbers in the development of mathematical ideas. (elementary)

Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships. (elementary and intermediate)

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

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

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints. (elementary)

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms. (elementary)

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 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. (elementary and intermediate)

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(STUDENT HANDOUT SECTION FOLLOWS)

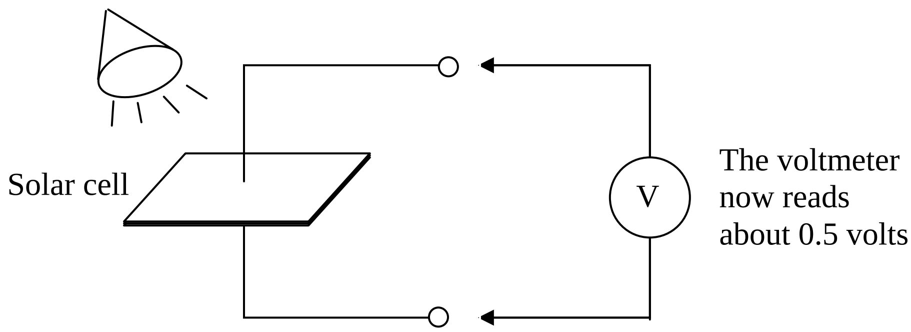
Name ___________________________________

Date ____________________________________

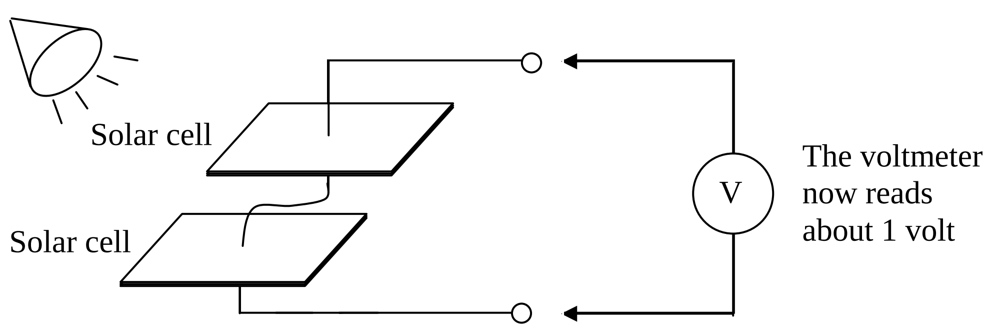
Parts of a Solar Panel – Lesson II

Sometimes engineers behave like detectives. This happens when they try to understand how someone else designed and constructed a product. That is what you will be doing today. By the time you finish, you will be able to explain in detail how a mini–solar panel was put together. You will start with a few given facts, find your own clues, and then record your ideas.

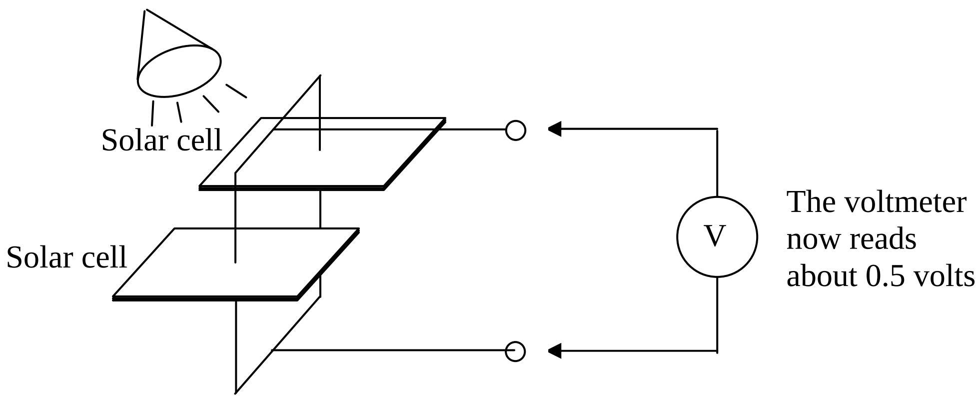
The facts:



Fact 1: A single solar cell produces about 0.5 volts when placed under a bright light.



Fact 2: Two solar cells connected front to back (also known as “in series”) add voltages together to produce about 1 volt while under a bright light.



Fact 3: Two solar cells connected side by side (also known as “in parallel”) do not add their voltages together. They produce about 0.5 volts while under a bright light.

In order to discover important clues, you are to carefully examine an actual solar panel. Use drawings to describe what you observe. With your teacher’s help, measure the solar panel’s voltage and use this information to help explain how you think the solar panel has been put together.

1) **Examine your solar panel:** How are the cells protected from being broken? How does the panel let light into the cells? How do we get electricity from the panel? Draw the panel showing how the panel was put together to accomplish each of these things. Label and describe each part.

2) How many cells are in your panel? How are they wired together? After your teacher helps you measure the voltage of your panel, draw a diagram that describes how you think the cells have been wired together. Explain why you think this.

Solar Kit Lesson #5
Build a Simple Ammeter

TEACHER INFORMATION

LEARNING OUTCOME
After building and working with a simple ammeter, students are able to describe the relationship between the direction of a current and the magnetic field it produces.

LESSON OVERVIEW
In this lesson, students:

- propose and test theories on why solar cells connected in parallel produce more current than in series; and
- apply conventional standards of (a) clockwise analog meter movement and (b) electrons flowing from a negative terminal.

Students build a simple ammeter to indicate the presence, direction, and strength of an electric current flowing through a wire. This device may be used later on to help students design and build a solar-powered battery charger in the Solar Kit lesson *Solar-Powered Battery Charger*.

GRADE-LEVEL APPROPRIATENESS
This Level II Physical Setting lesson is intended for use in physical science and technology education classes in grades 5–9.

MATERIALS
Per work group

- 150 cm enamel-coated magnet wire
- 2.5 cm length of drinking straw
- compass
- 2 large (“jumbo”) metal paper clips straightened and cut into six 5 cm long pieces of “wire”
- 15 x 40 cm piece of cardboard or card stock
- masking tape
- scissors
- two 1 V, 400 mA mini–solar panels* with alligator clip leads
- gooseneck lamp with 150-watt incandescent bulb

* Available in the provided Solar Education Kit, other materials are to be supplied by the teacher.

SAFETY
Warn students that the bulb will become hot enough to cause a burn if touched. If a battery is used to power the electromagnet, it should be connected for only short periods of time. Warn

students that if it is connected over a longer period, the battery or wire may get hot enough to cause a burn, and the battery will discharge quickly. Connecting an electromagnet to a mini–solar panel, however, poses no safety hazards.

TEACHING THE LESSON

Preparation: Prepare the workgroup materials. Use a pair of diagonal cutters to cut the jumbo paper clips into 5 cm long pieces and scissors to cut drinking straws into 2.5 cm long pieces.

Students should work in groups of two or more. Set out all materials but hold back one of the mini–solar panels at each of the workstations.

The basic concepts for an electromagnet are described in the student handout. If you need to familiarize yourself with these concepts, read the handout before holding the classroom discussion. Ask students to describe what they already know about electromagnets. Tell students that they will use such information in this activity to design and build a device to indicate the presence, direction, and strength of a current flowing from one or two solar panels. Pass out the handout and have students follow the directions.

Between steps 1 and 2, you may want to allow time for students to test their electromagnet by using a battery (for a current source) to pick up metal paper clips. Remember to warn students to connect the battery for only a short period of time.

Step 6 asks students to make a prediction expressed through a drawing. Tell them that after they complete their prediction, you will check their work and provide them with the second mini–solar panel.

Review Discussion:
Review with the students that the electromagnet exerts a force on the compass needle.

Discuss with students how a pointer swinging in a clockwise direction, by convention, describes a positive increase in value. Think of a speedometer on a car. Have students connect a solar panel so that the compass needle swings clockwise (toward the east). Then have them mark the terminal connected to the black wire with a minus (-) sign and the terminal connected to the red wire with a plus (+) sign.

Ask students to share their explanations of why parallel solar cells produce the most current. Help them understand that a solar cell limits the amount of current that flows through it.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

1) The finished electromagnet will have two 5 cm wire leads with the insulation removed.
2) Lamp and solar cell will be positioned as described in the handout.
3) Students can show that turning the light on and off will cause the compass needle to shift by 15 to 20 degrees.
4) The compass needle deflects in the opposite direction.

5) Arrows are drawn on the ammeter pointing along the two terminals. One terminal is marked with an *E*, the other with a *W*. Given a solar panel connected with either polarity, students can predict which way the compass needle will deflect.

6–7) Responses will vary in this part of the activity, but the diagram will typically show the two solar panels connected in parallel with the ammeter. Students will likely offer the following reason for connecting the panels in parallel: When solar panels are connected side by side (in parallel), the electrons from the second panel don't have to go through the higher resistance of a first solar panel, as they would if the panels were connected front to back (in series).

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

The idea of using an electromagnet and a compass to form a simple ammeter came from *"Thames & Kosmos Power House Experiments in Future Technics Experiment Manual,"* produced by Thames & Kosmos, LLC, Newport, RI, 2001.

BACKGROUND INFORMATION

Ammeters are designed with the use of a sensitive current detector. In this case, the current detector is a compass needle (a small magnet), held in the variable magnetic field of an electromagnet. As current in the electromagnet varies, so does the force on the compass needle.

Electricity flowing through a wire creates a magnetic field around that wire. Wrapping that wire in a coil creates an electromagnet. Wrapping the wire around a material that can be magnetized —iron objects, for example—turns such material into a magnet and effectively amplifies the magnetic field formed by the wire coil.

In this lesson, students use the magnetic field around a wire to create an electromagnet that is used to deflect a compass's magnetic needle, forming a simple ammeter. During the lesson they may notice that some of the paper clip wire has become semipermanently magnetized. Their design will need to compensate for this by adjusting the position of the ammeter on the table.

Commercial analog ammeters use a galvanometer as a sensitive current detector. A galvanometer contains a small coil attached to a spring placed in a fixed magnetic field. When current flows through the coil, magnetic attraction turns the coil against the pull of the spring. The coil is attached to the pointer of the analog meter.

REFERENCES FOR BACKGROUND INFORMATION

Georgia State University. C. R. Nave. HyperPhysics website:
http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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.

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (elementary and intermediate)

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. (elementary)

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

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. (elementary and intermediate)

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Measurement Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data. (elementary and intermediate)

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity. (elementary)

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

Key Idea 5: Energy and matter interact through forces that result in changes in motion. (elementary and intermediate)

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints. (elementary)

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms. (elementary and intermediate)

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 3: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems. (elementary and intermediate)

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions. (elementary and intermediate)

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Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Build a Simple Ammeter

In an upcoming lesson, you will design a solar-powered battery charger. But first, you need a way to test whether that battery charger is delivering electrons to the proper terminal of a dead battery. To do this, you now will build a simple ammeter that indicates the presence, direction, and strength of an electric current flowing through a wire.

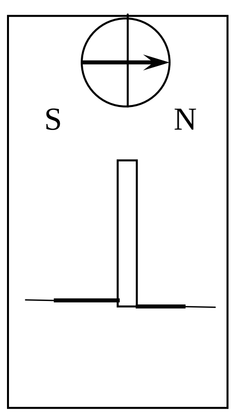
Here is information useful for completing this task:

1. Electricity flowing through a wire creates a magnetic field around that wire.
2. Wrapping that wire in a coil concentrates this field in a small space, making what is known as an electromagnet.
3. Wrapping the wire around a material that can be magnetized—iron objects, for example—turns such material into a magnet and effectively amplifies the magnetic field formed by the wire coil.
4. A magnetic field can move a magnet such as a compass needle.

1) **Build a small electromagnet.** Tape off one end of the straw. Tightly wrap the provided wire around 2.5 cm of drinking straw, leaving about 5 cm of each end of the wire unwrapped. If you run out of room on the straw, start another layer on top of the one just completed. When all the wire is wrapped, tape the wire in place. With scissors, scrape the insulation from the last 1 cm of both ends of the wire. The strength of this electromagnet can be adjusted by inserting various types and amounts of materials that can be magnetized (such as the wire used to make paper clips) into the coil.

2) **Current source:** Tape one mini–solar panel to the table and position the 150-watt lamp 120 cm above the panel. Do not place the lamp any closer as it may melt the panel's plastic cover. Turn the lamp on only while taking a measurement.

Figure 1



3) **Build the ammeter.** See figure 1. You are to construct a device that will deflect a compass needle 15 to 20 degrees when powered by the current source described above. Connect the solar cell leads to the two electromagnet leads.

Tape the compass to one end of the piece of cardboard so that the east-west axis is parallel to the long axis of the cardboard. Make sure that the north half of the compass face is visible. Position the electromagnet next to the compass. Adjust its position and the number of inserted paper clip wires to produce a device that will deflect the compass needle 15 to 20 degrees when the light is turned on.

When you have a working device, tape the electromagnet to the cardboard and the cardboard to the table.

4) **Test for the direction of a current.** Switch the solar panel's red and black wires. What do you see? Why?

5) **Calibrate your ammeter for direction of current.** On your ammeter, indicate the direction in which electrons flow to deflect the compass needle
   1) toward the west compass mark and
   2) toward the east compass mark.

Previously you learned that electrons flow from the top of a solar cell, making the top the negative terminal of a cell. By convention (artificial agreement), the black wire is connected to the negative terminal of the solar panel and the electrons flow out of the black wire.

Next to the terminal that is connected to the solar panel's black wire, draw an arrow indicating the direction in which the electrons are flowing. Next to the arrow, write a *W* if the compass needle is deflected toward the west compass mark and an *E* if it is deflected toward the east mark. Swap red and black wires and repeat.

6) **Make a prediction.** Draw a diagram that predicts how to connect two mini–solar panels to the ammeter so that the current is the greatest. Explain why you would connect the panels in this way. [Hint: Think of the electrons that are being energized by the light as workers traveling to their place of work, each in his or her own car.]

7) **Test for strength of current.** Tape the two solar panels to the table side by side. Position the lamp so it is the same distance from both panels. Again, do not place the lamp any closer to the panels than 120 cm or it may melt a panel's plastic cover.

   Connect the two solar panels to the electromagnet in many different ways. For each way, draw a diagram to predict how the panels are connected. Make sure to indicate red (positive) and black (negative) wires. For each, write down in which direction and how far the compass's needle is deflected. Circle the diagram that produces the most current (deflects the compass needle the most when the light is turned on). Does it match your prediction? If it does not, give a revised reason to explain why this configuration produces the most current.

Extension Activity. Modify the design of your ammeter so that it can be used to test the strength of an AA battery.

Caution: Connect a battery to your ammeter for only a short time. If you leave it connected for too long, the battery and the wire might overheat and cause a burn, plus the battery will discharge rapidly.

Solar panels self-limit the amount of current they produce. Household batteries can produce a much larger current when shorted. For this reason a battery would "peg" the ammeter you just built, making it useless as an indicator of strength. How might you modify the design of your ammeter so that it would work with a higher current device such as an AA battery?

Solar Kit Lesson #6
Solar-Powered Battery Charger

TEACHER INFORMATION

LEARNING OUTCOME
After designing and testing a solar-powered battery charger, students are able to describe the relationship between the direction of electrons flowing through a battery and a change in the battery's voltage.

LESSON OVERVIEW
In this lesson students design and construct their proposals intended to show the way solar cells must be connected to produce adequate voltage to recharge a battery.

In doing so, students use the simple ammeter they designed and built in the Solar Kit lesson *Build a Simple Ammeter*.

GRADE-LEVEL APPROPRIATENESS
This Level II Physical Setting lesson is intended for use in grades 5–9.

MATERIALS
Per work group
- Digital multimeter
- “Dead” rechargeable D-cell battery
- D-cell battery holder with alligator clip leads
- electromagnet-and-compass ammeter from the Solar Kit lesson *Build a Simple Ammeter*
- masking tape
- two 1 V, 400 mA mini–solar panels* with alligator clip leads
- gooseneck lamp with 150-watt incandescent bulb

* Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY
Warn students that the bulb will become hot enough to cause a burn if touched. If a charged battery powers the electromagnet, it should remain connected for only a short period of time. Warn students that if it is connected over a longer period, the battery or wire may get hot enough to cause a burn, and the battery will discharge quickly.

TEACHING THE LESSON
Preferably, this lesson directly follows the Solar Kit lesson *Build a Simple Ammeter*. Students should work in groups of two or more. Set out all materials at the workstations.

The basic concepts of recharging a battery are described in the student handout. If you are unfamiliar with these concepts, read the handout before the classroom discussion. Ask students to describe what they know about batteries and recharging batteries. Tell students that in this lesson they will use these concepts to design and test a solar-powered battery charger.

Show students how to use a digital multimeter to read voltages. If they do not have access to the electromagnet-and-compass ammeters from *Build a Simple Ammeter*, show them how to use the digital multimeter to read current in milliamps. Make sure they understand that if the ammeter reading is positive, the electrons are flowing into the negative terminal of the meter. You may want them to determine this by using the digital ammeter to complete a modified version of step 5 in *Build a Simple Ammeter*.

Pass out the handout and have students follow the directions.

Review Discussion:
Use a drawing or schematic to review with students why placing the solar panels in series was necessary to provide the electromotive force to drive electrons into the negative terminal of the battery.

Have students compare what they learned about placing solar panels in series in this lesson with what they learned about placing solar panels in parallel in *Build a Simple Ammeter*.

Review how to tell if a battery is recharged. (The battery will stop drawing current from the solar panels.)

You may want to set some of the charging circuits in direct sunlight for a day so students can see that the solar panels can fully recharge the batteries.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

1. Lamp and solar cell positioned as described in handout.

2. Measurements as follows:

	Voltage
Solar Panel 1	.9 V to 1.0 V
Solar Panel 2	.9 V to 1.0 V
Dead Battery	.3 V to .8 V
Charged Battery	1.5 V

3. Electromagnet-and-compass ammeter working as described.

4. Responses will vary. The final design, however, should show the two mini–solar panels, the dead battery, and the ammeter all wired in series with the negative terminal of the battery connected to the negative terminal of the series solar panels, perhaps through the ammeter. Students can demonstrate how the ammeter indicates that electrons are flowing into the negative terminal of the battery.

5. The solar panels are connected in series so their combined voltage can provide the force needed to push electrons into the negative terminal of the battery, even when it is almost recharged.

   The battery is recharged when the ammeter stops indicating that any electrons are moving. (The battery has stopped drawing current for the solar panels.)

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This activity is adapted from an activity designed and run by Richard Komp, Ph.D., president of the Maine Solar Energy Association and of the Sun Watt Corporation, and Byron Humphries, teacher. In their lesson, students build solar-powered battery chargers out of broken pieces of solar cells.

BACKGROUND INFORMATION

Building a solar-powered battery charger is an inherently safe activity for students because of the way solar cells self-limit the amount of current they produce. Recharging a battery at too fast a rate (too high a current) might cause a buildup of gas inside the battery, potentially causing it to explode. Charging batteries with mini–solar panels eliminates this potential safety hazard.

If a charging battery is left connected with no light source on the solar panels, it will leak current through the panels and slowly discharge. This leakage can be avoided by placing a diode in series in such a way as to block this reverse current. If this is done, another solar panel will be needed to overcome the voltage drop across the diode during charging.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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. (elementary)

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions. (elementary)

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems. (elementary and intermediate)

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (elementary and intermediate)

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. (elementary and intermediate)

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

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. (elementary)

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data. (elementary and intermediate)

Key Idea 6: Students use ideas of uncertainty to illustrate that mathematics involves more than exactness when dealing with everyday situations. (elementary)

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

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

Key Idea 5: Energy and motion interact through forces that result in changes in motion. (elementary and intermediate)

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints. (elementary and intermediate)

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 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions. (elementary and intermediate)

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Solar-Powered Battery Charger

In this activity you will design and test a solar-powered battery charger.

Introduction

The voltage of a power source indicates its ability to force electrons through an electrical circuit. When a battery is connected to a circuit (such as when you turn on the switch of a flashlight to connect its battery to its light bulb), it forces electrons out of its negative terminal (marked with a minus [-] sign), through the circuit, and into its positive terminal (marked with a plus [+] sign). This action slowly changes the chemical makeup of the battery. With use, this change reduces the voltage of the battery and at some point the battery can no longer force the electrons through the circuit. At this point we say the battery is "dead."

For some dead batteries, another power source can be used to force the electrons to flow in the opposite direction and cause the chemical makeup of the battery to return to its original state. The battery is then "recharged." In order to do this, the voltage of the other power source must be greater than the charged voltage of the battery.

In this lab you will use two mini–solar panels as a power source to recharge your battery.

1) **Power Source:** Tape two mini–solar panels to the table and position the 150-watt lamp 120 cm above the panels. Do not place the lamp any closer, as it may melt a panel's plastic cover. Position the lamp so it is the same distance from both panels. Turn the lamp on only when taking a measurement or testing your design.

2) **Measure voltages:** Follow your teacher's instructions on how to measure the open circuit output voltage of each solar panel and the dead battery. Record these measurements in table 1.

Table 1

	Voltage
Solar Panel 1	
Solar Panel 2	
Dead Battery	
Charged Battery	1.5 V

3) **Set up an ammeter:** Set up the electromagnet-and-compass ammeter your team built. Using one solar panel, test the ammeter to ensure it is still operational. The needle should deflect 15 to 20 degrees when the lamp is turned on.

4) **Design and test the battery charger:** On paper, draw a diagram showing how to connect the two solar panels, the dead battery, and the ammeter so that when the light is turned on, electrons will flow from the solar panels into the negative terminal (-) of the battery. Remember, your ammeter has been calibrated to tell you the direction in which electrons are flowing.

   Once you have drawn a circuit you believe will work, build and test it. If your ammeter does not show you that electrons are flowing into the negative terminal of the battery, check all of your connections. If this is not the problem, redesign your circuit. Then rebuild and retest it.

   When you have a working circuit, ask your teacher to confirm it.

5) **Complete the following:**
   Explain WHY you connected the two solar panels in the way you did in hopes of producing a working battery charger.

   Without touching the circuit, how would you know when your battery is recharged?

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Solar Kit Lesson #7

Positioning Solar Panels I: Explorations with Tracking

TEACHER INFORMATION

LEARNING OUTCOME: After using a mini–solar panel, and tracking and recording data on the Sun's position in the sky, students are able to identify relationships between position of the Sun and a solar panel's output power.

LESSON OVERVIEW: Through one day of activities, students track and record data on the Sun's position in the sky and on the output of a solar panel tracking the Sun. On a second day, students graph and analyze the data to identify relationships between
(1) the time of day,
(2) the altitude and azimuth of the Sun, and
(3) the positioning of a solar panel set to receive maximum solar energy.

From this analysis, they propose how to position a stationary solar panel to receive the most solar energy possible over the course of a day.

This is the first of two related Solar Kit lessons. In the second related lesson, *Positioning Solar Panels II: Explorations with Stationary Panels*, students evaluate their proposals for positioning a stationary solar panel and compare stationary and tracking systems.

GRADE-LEVEL APPROPRIATENESS: This Level II Physical Setting lesson is intended for use in physical science and technology education classrooms in grades 6–9.

MATERIALS
- Bubble level
- Compass

Per work group
- One 1V, 400 mA mini–solar panel* with conversion curve (see the Solar Kit lesson *Calibration Curve for a Radiation Meter*)
- Digital multimeter or ammeter
- Student handouts

* Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY: Tell students not to look directly at the Sun. Permanent eye damage might result. Instead, tell them to use a maximum current reading to indicate when a solar panel faces the Sun directly.

TEACHING THE LESSON: Allow for continuous data collection by performing the activity with all of your classes on the same day. If successive classes are working in small groups, numerically assign groups to particular setups. During lunch, preparatory, and supervisory periods, consider making arrangements for a few students to collect data. You might decide to collect early morning and late afternoon data yourself.

Preparation: Prepare the required number of Sun Trackers and printouts of the Panel Tracker.

Sun Tracker: Print out the Sun Tracker template. Straighten one bend in a large (jumbo) paper clip. Lay it on a table and bend the straightened section up 90 degrees. Punch this section through the middle of a 10 x 12 inch piece of corrugated cardboard and securely tape the still-bent portion of the paper clip to the cardboard. The straightened section of the paper clip should now form a three-inch-tall post sticking out of the cardboard.

Run the straightened section of paper clip through the center cross of the Sun Tracker template and glue the template to the cardboard. Adjust the post to stick up at 90 degrees from the surface of the paper. Use an object having a 90-degree angle to guide you.

Panel Tracker: Glue the Panel Tracker template to a piece of cardboard.

Position the trackers: Position the trackers where they will be as conveniently available to students as possible and where they will receive sunlight for as many daylight hours as possible. They should not be obscured by the shadows of trees, buildings, or other objects.

Use a compass to face the trackers true north and a bubble level to level them. (Note that the compass printed on the Sun Tracker is deliberately off by 180 degrees from the magnetic compass.) Make sure to adjust the compass to account for magnetic north.

Secure the trackers using weights or strong tape to prevent them from being blown away. If they need to be moved during the day, clearly mark their positions so they can be returned to the exact same location for continuing data collection.

Suggested Approach: To introduce the activity, discuss why the apparent path of the Sun across the sky is important in positioning solar panels to receive the most light. Explain what is really happening that makes the Sun appear to travel across the sky. Define the terms used in the lesson.

Ask for opinions on how to position a solar panel to absorb the most light in a given moment. Discuss the pros and cons of stationary-mounted versus tracking solar panels.

Divide the class into small groups. Go over the Sun Tracker, Panel Tracker, and Data Log with them. If the trackers will need to be moved during the day, you may want to show students how to use a bubble level and compass. Demonstrate how to use an ammeter and a panel's conversion curve to obtain milliamps and then convert to watts per square meter (W/m^2) (see the Solar Kit lesson *Calibration Curve for a Radiation Meter*). Distribute the handout *Tracking Solar Panel: Data Collection*, and have students take several readings and record their data in the Data Log.

Once a day's worth of data has been collected, copy completed sets of Data Logs and Sun Tracker sheets for redistribution to student teams.

Distribute a matched Data Log and Sun Tracker sheet to each team. Distribute the handout *Tracking Solar Panel: Data Analysis*, and graphs 1–4. Help students with the graphs and their questions as appropriate.

Use the responses to question 8 of the data analysis as experimental setups for *Positioning Solar Panels II: Explorations with Stationary Panels*.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Data Collection
The data collected will vary but specific patterns should emerge. For each row, the Sun's altitude and the tilt of the solar panel should add up to approximately 90 degrees. The length of shadow should decrease as the Sun's altitude increases. The Sun's azimuth and the angle east of north of the solar panel should be identical within an acceptable margin of error.

Data Analysis

1) You must position a solar panel perpendicular to the Sun's rays to receive the maximum intensity of light.

2) Some variation on the equation: altitude ($^\circ$) + tilt ($^\circ$) + $90^\circ = 180^\circ$

3) Accurate representation of the data collected

4) Accurate representation of the data collected

5) Accurate representation of the data collected

6) Accurate representation of the data collected

7) Students should notice that the Sun appears to move faster across the sky at midday.

8) Answers and reasoning will vary. Use the responses to generate class discussion and as experimental setups for *Positioning Solar Panels II: Explorations with Stationary Panels*.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY: Renewable Energy Activities for Earth Science. Solar Energy Project in cooperation with the New York State Education Department and SUNY Atmospheric Sciences Research Center (out of print).

BACKGROUND INFORMATION: The Sun only appears to move across the sky as a result of the Earth's daily rotation on its axis. The Sun's apparent position in the sky is commonly described by two coordinates, altitude and azimuth. Altitude is the angular distance above the horizon. Altitude is determined by the angle between a line drawn from the eye of the observer to the Sun and the plane of the horizon. Azimuth is the angular distance eastward from a defined direction, generally true north or true south. In this activity, azimuth is referenced from true north.

REFERENCES FOR BACKGROUND INFORMATION: Columbia On-line Encyclopedia. New York: Columbia University Press, 2002. New York: Bartleby.Com, 2002.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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.

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions.

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems.

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

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

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 1: Students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence, and construct an argument.

Key Idea 3: Students use mathematical operations and relationships among them to understand mathematics.

Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships.

Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data.

Key Idea 7: Students use patterns and functions to develop mathematical power, appreciate the true beauty of mathematics, and construct generalizations that describe patterns simply and efficiently.

Standard 4: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Physical Setting

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

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

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

Key Idea 3: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems.

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions.

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
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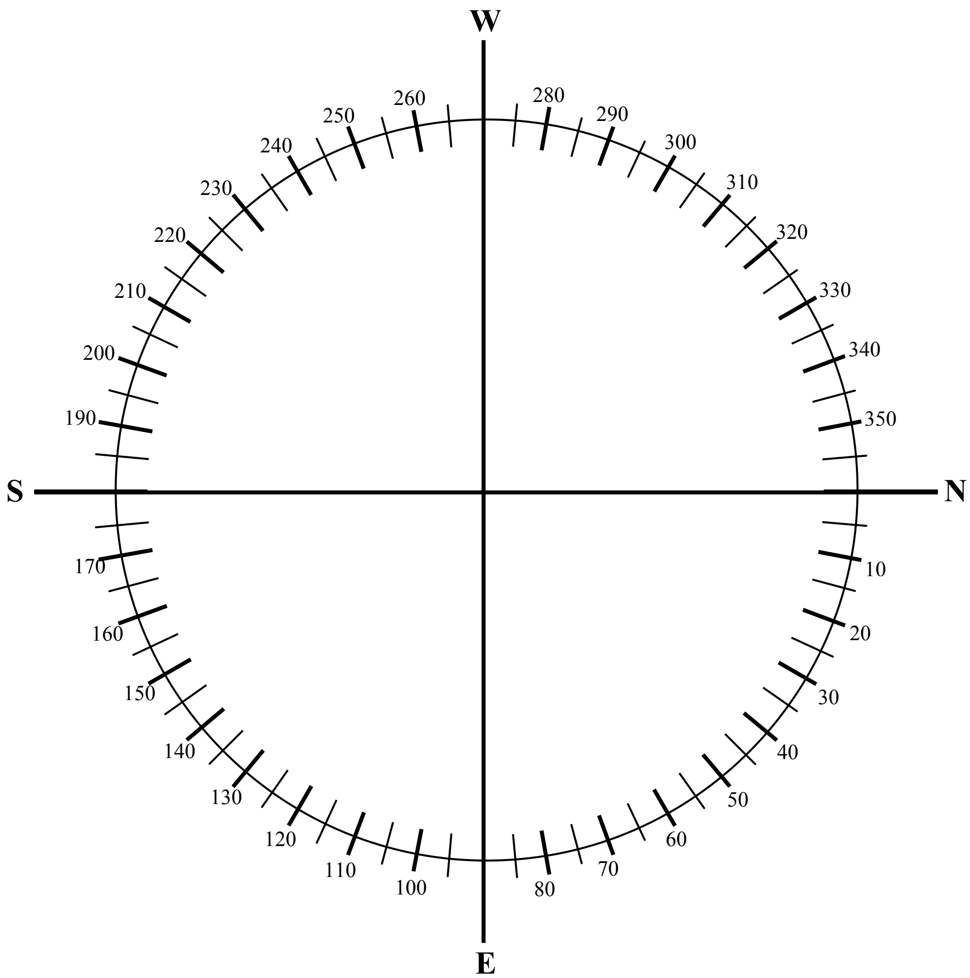
Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

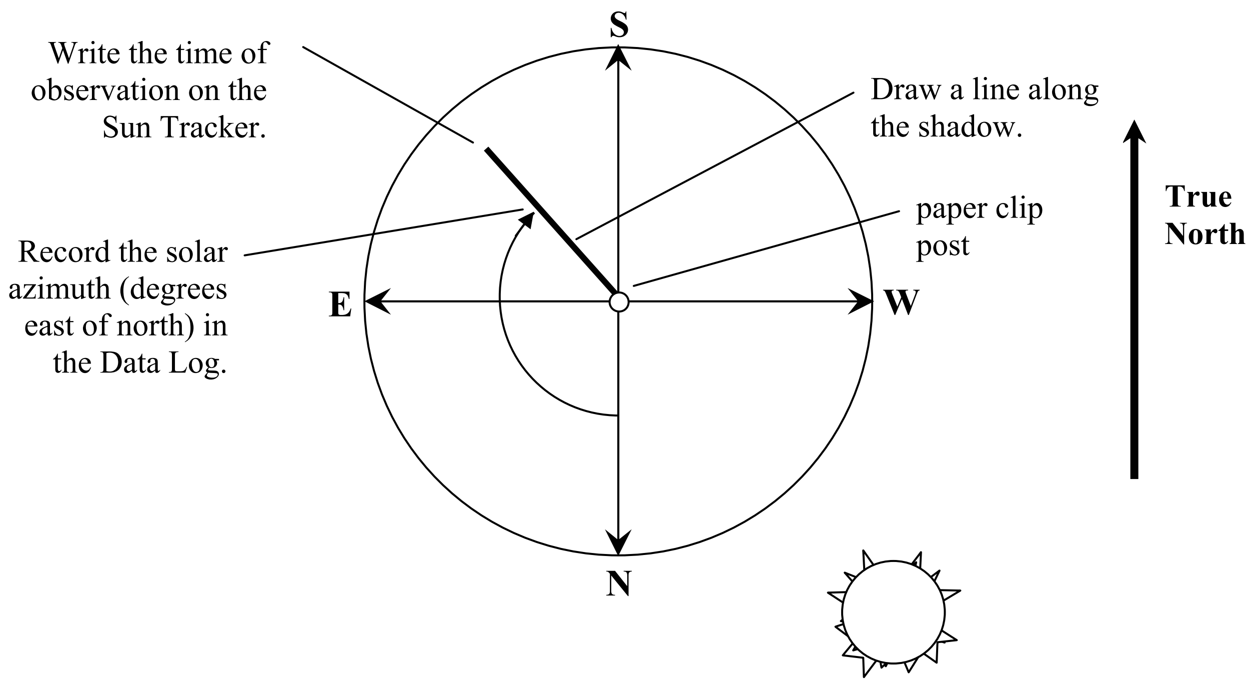
(STUDENT HANDOUT SECTION FOLLOWS)

Sun Tracker

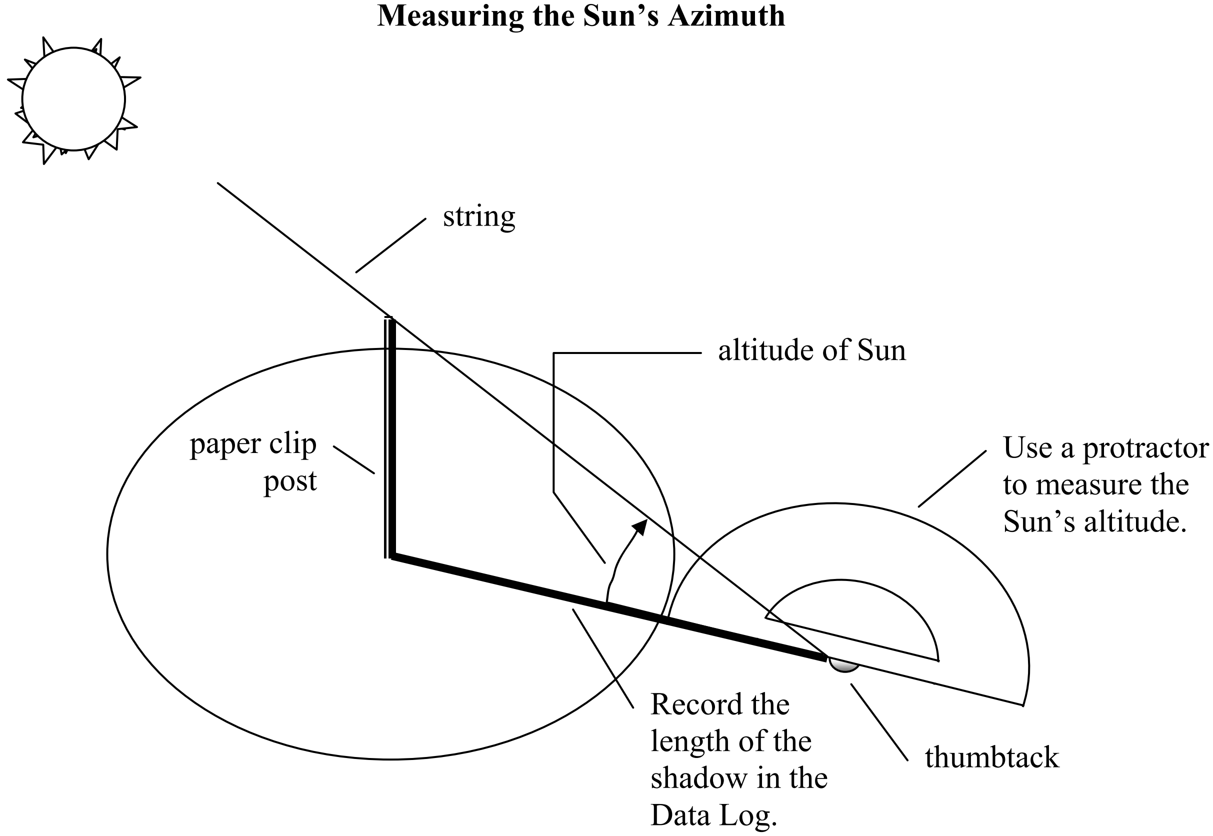
TRUE NORTH



How to Use the Sun Tracker

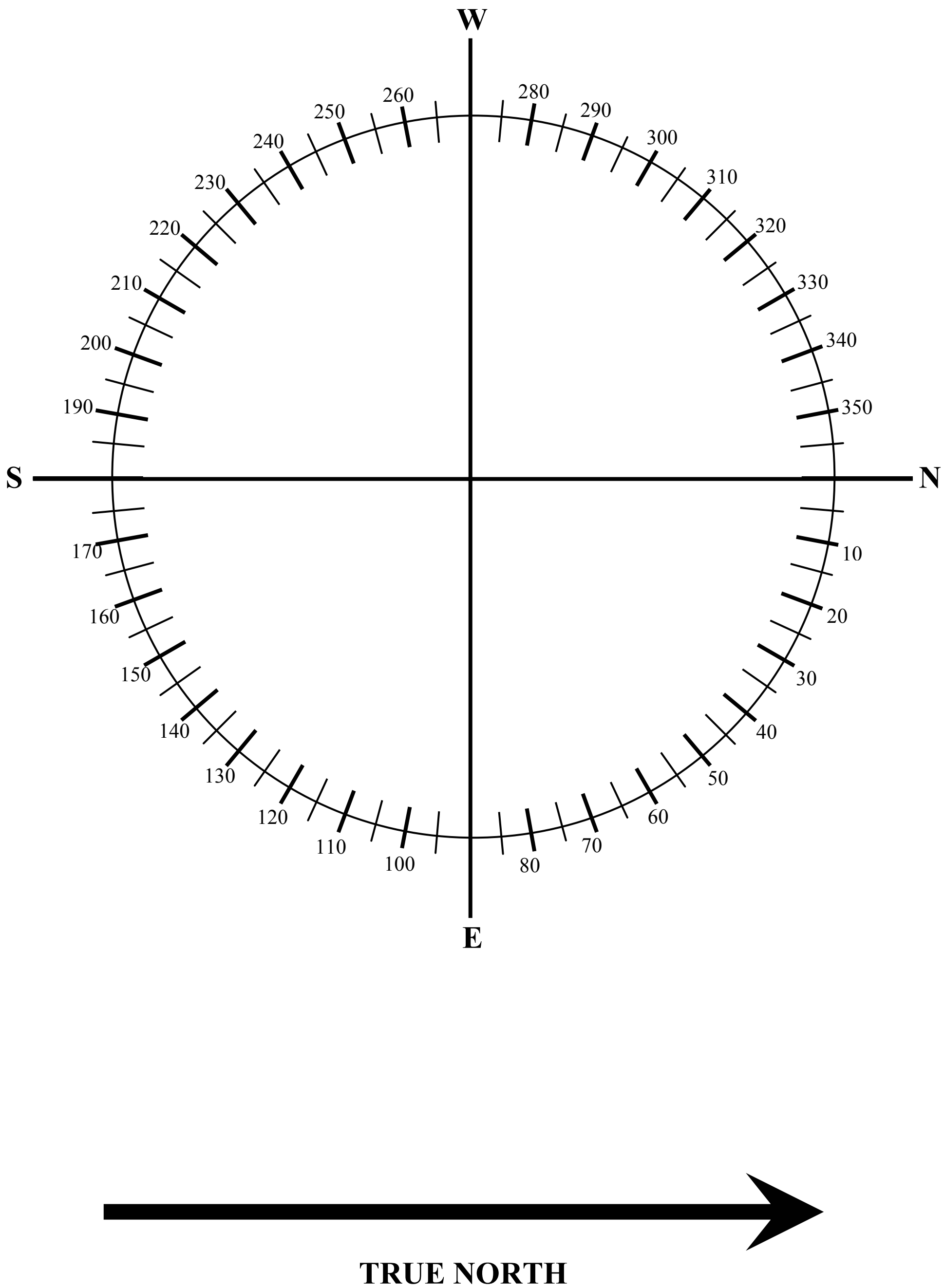


Measuring the Sun's Azimuth

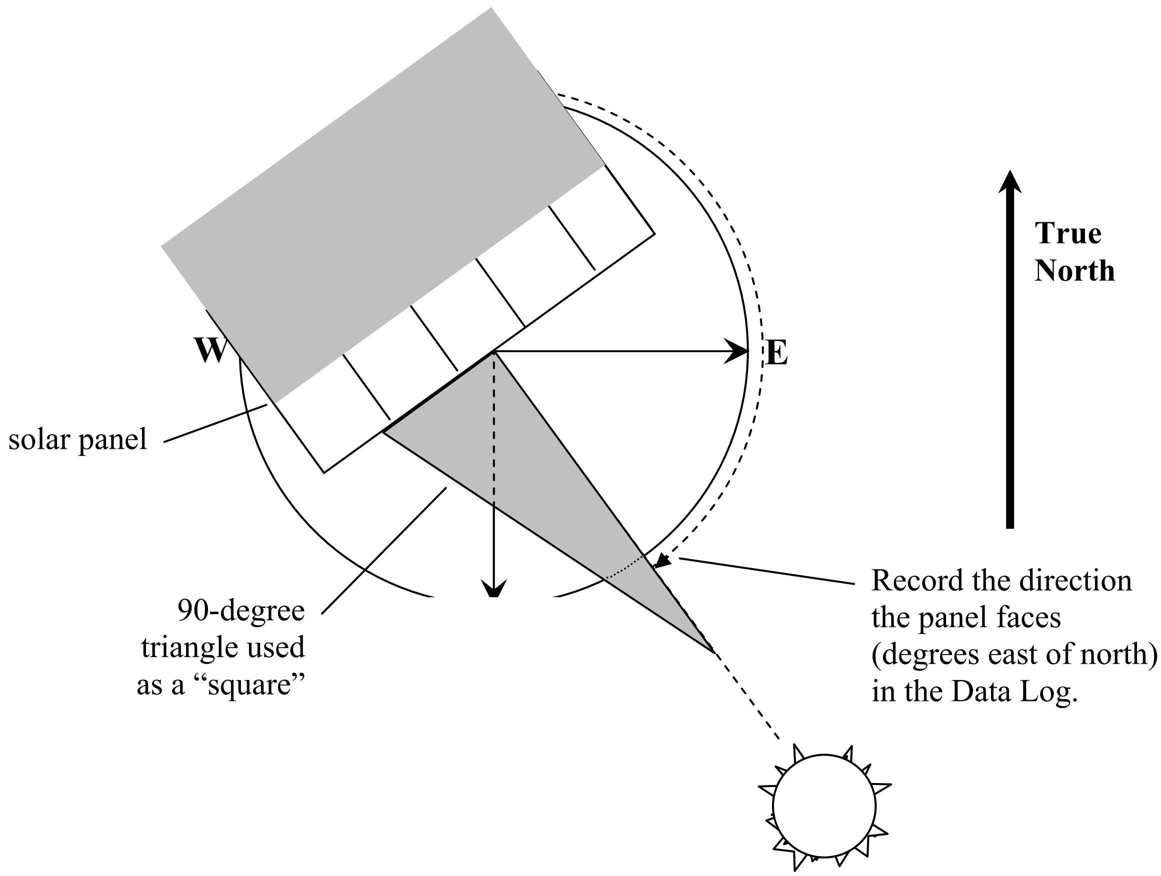


Measuring the Sun's Altitude

Panel Tracker



How to Use the Panel Tracker



Data Log

Date ____________________ Station Number ______________________

Time (hh:mm)	Tilt of solar panel ($^\circ$)	Angle of solar panel ($^\circ$ east of north)	Sun's Azimuth ($^\circ$ east of north)	Shadow Length (cm)	Sun's Altitude ($^\circ$)	Light intensity (W/m^2)

Name ___________________________________

Date ____________________________________

Tracking Solar Panel: Data Collection

1) Connect the ammeter to the solar panel. Point the solar panel toward the Sun and position it to obtain the maximum current reading from the ammeter. Maintaining the panel's direction, place the panel so its bottom edge runs through the center X of the Panel Tracker. Double check that it is still positioned for maximum current. Record the time of day in the Data Log and note the ammeter reading on a separate sheet of paper.

2) Use a protractor to measure the solar panel's angle from horizontal. Record this in the Data Log.

3) Measure the solar panel's angle east of north. Place the square along the edge of the solar panel so that the corner of the square is at the center of the Panel Tracker. The solar panel's angle east of north is where the edge of the square crosses the circle. Record this value in the Data Log.

4) Draw a line on the Sun Tracker along the post's shadow. Write the time at the end of the shadow. The Sun's angle east of north is known as the solar azimuth. Record the solar azimuth in the Data Log.

5) Measure the length of the shadow. Record this in the Data Log.

6) The angle of the Sun above the horizon is called the solar altitude. Use a string and protractor as shown in the diagram to measure the solar altitude. (Use the line you drew for the shadow instead of the actual shadow as this may have already moved.) Record this in the Data Log.

7) Convert the ammeter reading from step 1 to light intensity (W/m^2) and record this in the Data Log.

8) Repeat the above measurements in 10-minute intervals for as long as your teacher instructs you.

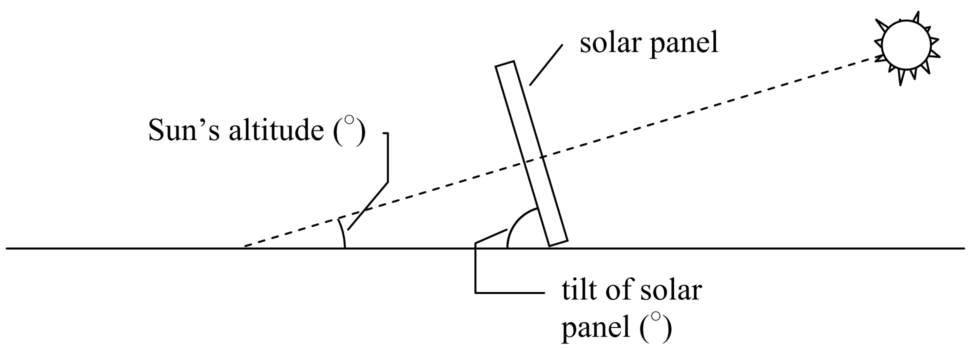
Name ___________________________________

Date ____________________________________

Tracking Solar Panel: Data Analysis

1) At what angle to the Sun's rays must you position a solar panel to expose the panel to the maximum intensity of light? Draw a diagram describing your answer.

2) Use the following diagram and data from the Data Log to propose a relationship between the Sun's altitude and the tilt of a solar panel positioned for maximum solar intensity.



Remember, the sum of the angles of a triangle equals 180°.

3) On graph 1, plot Shadow Length (cm) versus Time of Day.

4) On graph 2, plot Sun's Altitude (°) versus Time of Day.

5) On graph 3, plot the Solar Intensity (W/m^2) versus Time of Day.

6) For each row of data, draw an arrow on graph 4 in the appropriate azimuth direction of the Sun. Start each line at the Reference Point. Label the outer end of each arrow with the time of day.

7) Looking at graph 4, is there any time of day when the Sun appears to move faster across the sky? What is it?

8) During the lab, you always directed the solar panel to receive the maximum intensity of light. To do this, you used the feedback system of your eyes, your brain, and your hands. It is complicated and expensive to build a similar solar-tracking system with such items as light sensors, electronic control systems, and motors. Generally speaking, the added cost of design, materials, and maintenance outweighs the benefits of installing a solar-tracking system. Because of this, most solar-electric systems are stationary—the panels don't move.

   For stationary panels, you need to decide how to position them to receive the most solar energy over the course of a day. Review your data and graphs. At what angle east of north and what angle of tilt up from horizontal would you recommend positioning a solar panel to receive the most solar energy over the course of a day at this time of year?

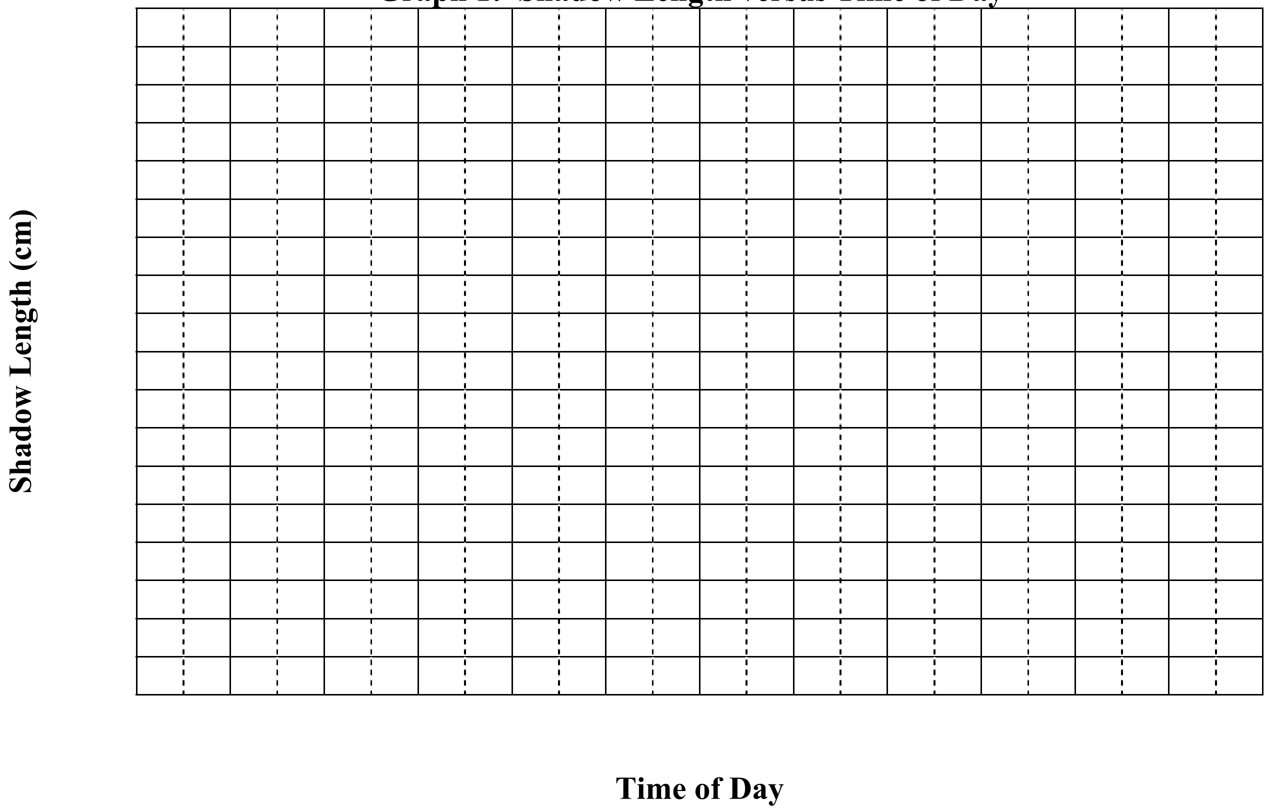
   Recommended position to receive the most solar energy over the course of a day at this time of year:

   Angle east of north _______________

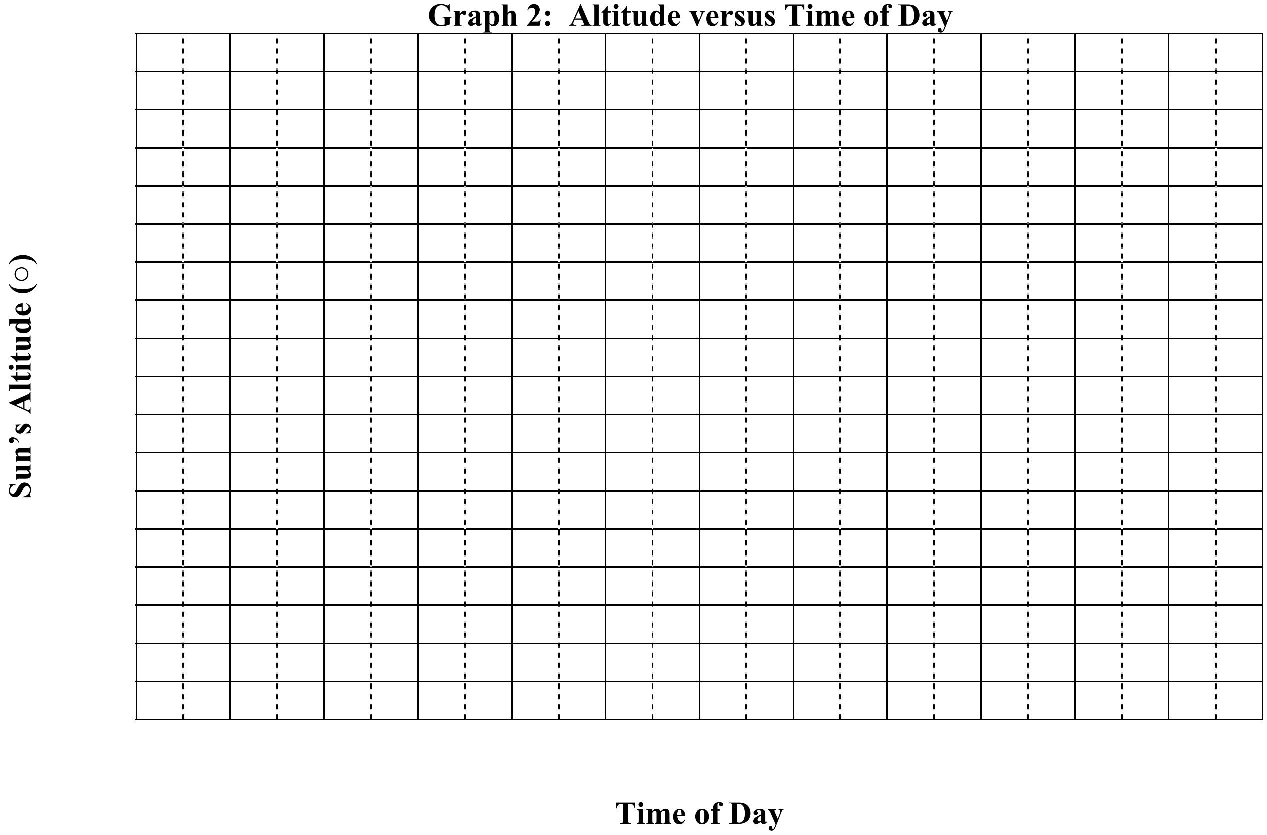
   Angle of tilt (if any) from horizontal ___________________

   Briefly, explain your reasoning.

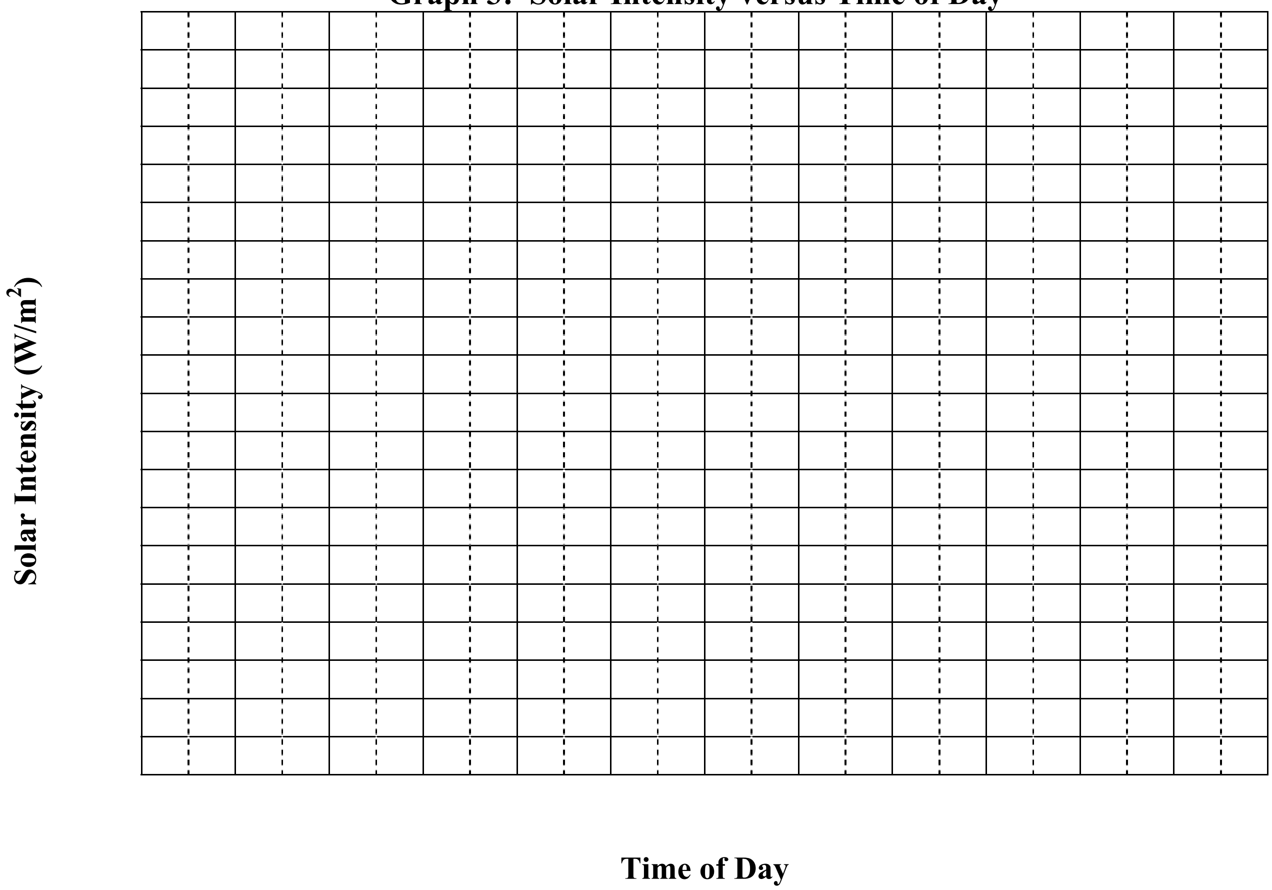
Graph 1: Shadow Length versus Time of Day



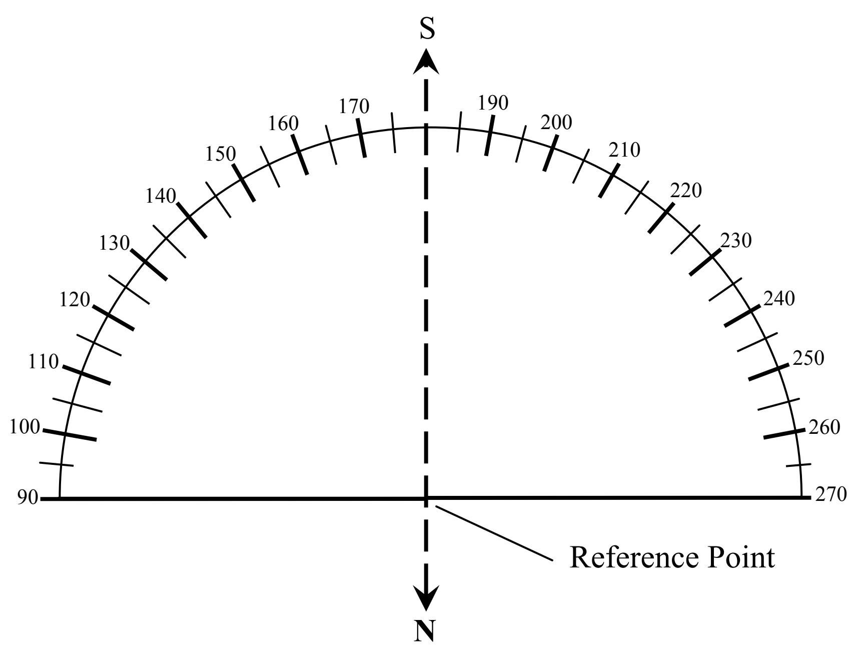
Graph 2: Altitude versus Time of Day



Graph 3: Solar Intensity versus Time of Day



Graph 4: Solar Azimuth versus Time of Day



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Solar Kit Lesson #8
Positioning Solar Panels II: Explorations with Stationary Panels

TEACHER INFORMATION

LEARNING OUTCOME
After collecting and analyzing data on the amount of sunlight that strikes solar panels in various stationary positions, students are able to identify an optimum mounting position for a given day of the year and explain why engineers typically mount PV modules in New York State facing due south and tilted at about 43 degrees from horizontal.

LESSON OVERVIEW
Students use a graphical integration technique to determine the amount of solar energy (W-hr/m^2) received by solar panels over a day in different stationary positions. From this data, they deduce which position a panel should be placed in to receive the most solar energy over a day at this time of year. Using what they have learned, they propose reasons why the 2 kW solar panels mounted on the 50 School Power … Naturally (sm) schools are positioned as they are.

This is the second of two related Solar Kit lessons. In the first lesson, *Positioning Solar Panels I: Explorations with Tracking*, students propose stationary positions for solar panels to receive the most energy at a given time of year. In this activity they experimentally check the accuracy of their proposals.

GRADE-LEVEL APPROPRIATENESS
This Level II lesson is intended for use in physical science and technology education classrooms in grades 6–9.

MATERIALS
Per work group
- Bubble level
- Compass
- One 1 V, 400 mA mini–solar panel* with conversion curve (see the Solar Kit lesson *Calibration Curve for a Radiation Meter*)
- Digital multimeter or ammeter
- Student handouts
- Experiment station consisting of three to four solar panel props mounted on a flat board of approximately 20 x 5 inches

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY

Tell students not to look directly at the Sun. Permanent eye damage might result. Instead, tell them to use a maximum current reading to indicate when a solar panel faces the Sun directly.

TEACHING THE LESSON

Allow for continuous data collection by performing the activity with all of your classes on the same day. If successive classes are working in small groups, numerically assign groups to particular setups. During lunch, preparatory, and supervisory periods, consider making arrangements for a few students to collect data. You might want to collect early morning and late afternoon data yourself. Data needs to be collected until the Sun is as low in the sky in the afternoon as it was when data collection started in the morning. (Daily data on solar altitude vs. time of day for specified geographic locations is available at: http://aa.usno.navy.mil/data/docs/AltAz.html)

Preparation for day one: Prepare five or six portable experiment stations, enough for one class working in small teams. Teams in different classes will use the same stations to collect data.

Table 1: Degree of tilt from horizontal

Board No.	1	2	3	4	5	6
For Five Teams	0^o	20^o	40^o	60^o	80^o	
	5^o	25^o	45^o	65^o	85^o	
	10^o	30^o	50^o	70^o	90^o	
	15^o	35^o	55^o	75^o		
For Six Teams	0^o	20^o	35^o	50^o	65^o	80^o
	5^o	25^o	40^o	55^o	70^o	85^o
	10^o	30^o	45^o	60^o	75^o	90^o
	15^o					

Build each experiment station on a portable flat board. Use the template in figure 1 to create cardboard props for students to mount their solar panels at the required tilt from horizontal. For each angle of tilt from horizontal:

1) Copy or glue the template to a piece of cardboard and cut it out along the outline.
2) Fold the two outside tabs back along the dashed lines. Fold each back 90 degrees.
3) Trim each of these tabs along the proper angled line for the desired angle of tilt.
4) Fold the bottom tab backward along the dashed line until it meets the bottom (trimmed) edges of the two side tabs.
5) Glue the bottom tab flat and the bottom edges of the two side tabs to the board.

Mount three to four props on each board so that they all face one long side of the board and tilt up from the horizontal at the angles described in table 1.

Prepare Data Logs for each experiment station by filling in the horizontal tilt angles on the blank Data Log supplied as a student handout. Supply each station with one Data Log for every direction east of north to be tested. To determine these directions, use student suggestions for question 8 from the handout *Tracking Solar Panel: Data Analysis* (see the Solar Kit lesson *Positioning Solar Panels I: Explorations with Tracking*).

Write on the chalkboard the stationary mounting positions that students suggested for question 8 from the handout *Tracking Solar Panel: Data Analysis* (see the Solar Kit lesson *Positioning Solar Panels I: Explorations with Tracking*).

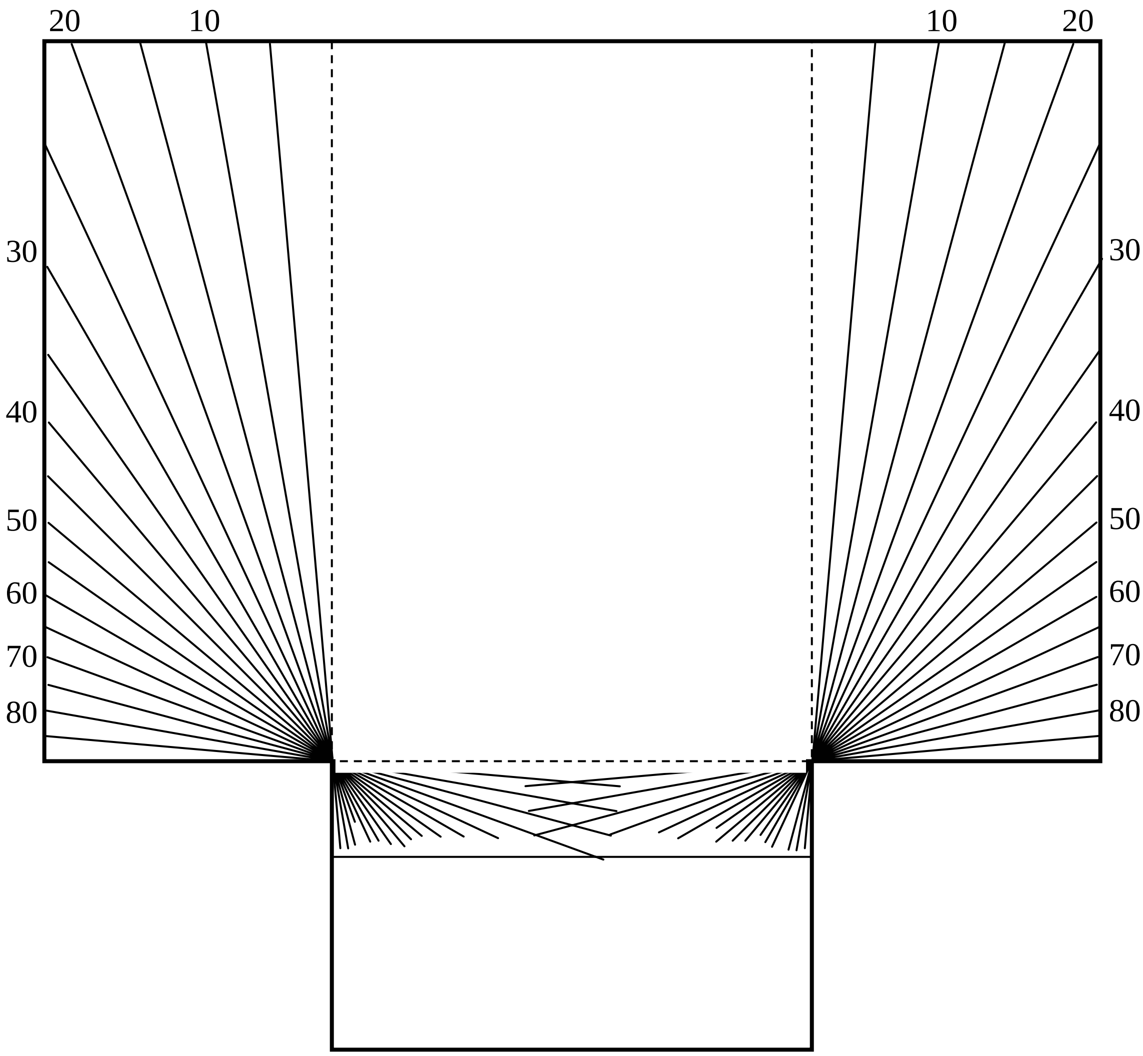


Figure 1: Template for building mounting props for solar panels

Suggested Approach – day one: Introduce the activity by posing the following situation. Describe a group of farmers who use solar panels to pump water to irrigate their crops. These farmers can't afford to buy or maintain tracking systems for their solar arrays but can adjust the arrays once each morning so as to get the most power during that day to pump water. Ask students to think about what angle east of north and what angle of tilt up from horizontal they

would recommend for positioning a solar panel to receive the most solar energy over the course of a day at this time of year.

Review with the class the selection of student responses to question 8 from the handout *Tracking Solar Panel: Data Analysis* (see the Solar Kit lesson *Positioning Solar Panels I: Explorations with Tracking*). Tell students that they will work in teams to test an array of positions and then extrapolate from the data how each of their suggested positions would perform.

Divide the class into small groups and hand out materials. Go over with students how to use the compass and the bubble level to position a board horizontally and to face the direction to be tested (e.g., one direction to test is due south, 180 degrees east of north). Assign as many student-suggested panel directions as time allows.

Demonstrate how to hold the mini–solar panels against the props for each experimental setup. Demonstrate how to use an ammeter and a panel's conversion curve to obtain milliamps and then convert to watts per square meter (W/m^2). (See the Solar Kit lesson *Calibration Curve for a Radiation Meter*.) Distribute the handout *Stationary Solar Panel: Data Collection*.

Direct students to collect data at a location where they will receive sunlight for as many daylight hours as possible, unobscured by the shadows of trees, buildings, or other objects. Have teams set their board to face one specified direction east of north, take one set of readings, and then adjust the direction of the experiment platform for the next set. Have them record data for each set of readings in a separate Data Log.

Preparation for day two: On day two, students will work in teams of two. Depending on the size of the class, each team will analyze data from two or more horizontal angles of tilt. Data for one horizontal angle of tilt is considered one data set. Copy the completed Data Logs as needed to distribute two or more data sets to each team.

Use the data collected to determine the vertical scale for students to use for graph 1. For the horizontal scale, let the distance between each solid vertical line represent one hour. Fill in the appropriate scales on the master copy. It is important that each student work with the same scale in order to visually compare data sets. Assign a pencil color for each direction that data was collected. Make 20 copies of graph 1, one for each horizontal angle of tilt and one for data on tracking.

Suggested Approach – day two: Distribute two or more data sets to each team along with a copy of graph 1 for each data set. Distribute the handout *Stationary Solar Panel: Data Analysis*. Help students with graphs and questions as appropriate.

When all teams have reached question 4, have them compare which direction (east of north) provided the solar panels with the greatest amount of solar energy throughout the day. Some students may have to count squares formed by the graph's grid to determine the curve with the largest area. Taken together, the data should point to one direction and it should be due south.

For question 5, have students use data for the panel direction east of north decided upon for question 4. Have each student estimate the area under the curve for his or her data set by estimating a count of the number of square grids and multiplying that number by the watt-hours per meter squared each grid represents.

Each grid represents a specific quantity in watt-hours per meter squared (W-h/m^2), depending on the scale used for the graphs. Students can calculate this value by multiplying the incremental difference between gridlines used for the *y*-axis by 0.5 hours, the incremental difference between gridlines for the *x*-axis. For instance, if the gridlines on the *y*-axis are marked for every 50 W/m^2, then each square grid represents 25 W-h/m^2.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Data Collection

The data collected will vary but specific patterns should emerge: panels facing true south should receive the most solar radiation as should panels tilted to face within a few degrees of the Sun's highest altitude.

Data Analysis

1) Students record the proper data on their Data Logs.

2) Accurate representation of the data collected.

3) Accurate assessment of plotted data.

4) Constructive and timely contribution to class discussion.

5) Accurate assessment of plotted data.

6) Constructive and timely contribution to class discussion.

7) Although results will vary, students should notice electrical output increase by up to 30 percent when compared to a non-tracking solar panel.

8) A solar panel tilted 43 degrees from the horizontal faces the mean apex altitude of the Sun over the course of a year. A panel directed at the Sun's highest altitude at the summer solstice would tilt $90^o – 70^o = 20^o$. A panel directed at the Sun's highest altitude at the winter solstice would tilt $90^o – 24^o = 66^o$. The mean between these two angles is 43^o.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

The basic idea for this activity is adapted from *Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*, Thames & Kosmos, LLC, Newport, RI, 2001. The organization of classroom activities was adapted from *Renewable Energy Activities for Junior High / Middle School Science*, prepared for the U.S. Department of Energy by the Solar Energy Project in cooperation with the New York State Education Department and the University at Albany Atmospheric Sciences Research Center (out of print).

BACKGROUND INFORMATION

Determining whether a tracking or stationary photovoltaic system is a wise investment depends on many factors including the intended application. Adding a tracking mechanism to a solar electric system introduces new electronic and mechanical components that will need to be purchased and maintained at a cost. Tracking systems are relatively expensive and this cost must be weighed against the alternate option of purchasing additional solar panels to increase power output.

Tracking systems give you the biggest boost of power output in situations where the Sun travels a wide arc in its daily traverse across the sky, such as during summer months in higher latitudes or year-round near the equator. In some situations, such as at a remote water pumping station, this increased output matches demand and the tracking system may be cost-effective. In other applications, such as an off-the-grid system designed to charge a homeowner's bank of batteries, the increased power is needed most in the winter and the extra power provided in the summer may be wasted. For a grid-tied system, the cost of adding a tracking system must be weighed against the cost of purchasing from the utility the amount of electricity the tracker would provide.

REFERENCES FOR BACKGROUND INFORMATION

The Solar Electric Independent Home Book, Fowler Solar Electric, Inc., 1993.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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. (intermediate level)

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions. (intermediate and commencement levels)

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems. (intermediate and commencement levels)

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (intermediate and commencement levels)

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. (intermediate level)

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

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 1: Students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence, and construct an argument. (intermediate level)

Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships. (intermediate and commencement levels)

Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data. (intermediate and commencement levels)

Key Idea 6: Students use ideas of uncertainty to illustrate that mathematics involves more than exactness when dealing with everyday situations. (intermediate level)

Key Idea 7: Students use patterns and functions to develop mathematical power, appreciate the true beauty of mathematics, and construct generalizations that describe patterns simply and efficiently. (intermediate level)

Standard 4—Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 1: The Earth and celestial phenomena can be described by principles of relative motion and perspective. (intermediate and commencement levels)

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

Standard 5—Technological Education: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints. (intermediate level)

Key Idea 4: Technological systems are designed to achieve specific results and produce outputs, such as products, structures, services, energy, or other systems. (intermediate and commencement levels)

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 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. (intermediate and commencement levels)

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions. (intermediate level)

Key Idea 6: In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs. (intermediate and commencement levels)

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Key Idea 1: The knowledge and skills of mathematics, science, and technology are used to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena. (intermediate and commencement levels)

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Data Log

Date ____________________ Station Number _________________

Direction East of North (degrees):

Weather Conditions:

Time (hh:mm)	Horz. Tilt: __________ (W/m^2)	Horz. Tilt: __________ (W/m^2)	Horz. Tilt: __________ (W/m^2)	Horz. Tilt: __________ (W/m^2)	Tracking (W/m^2)

Name ___________________________________

Date ____________________________________

Stationary Solar Panel: Data Collection

1) Record in the Data Log the weather conditions that best match what you see outside.

2) Position the experiment station so it lies level and faces the first direction to be tested. Record the time in the Data Log.

3) Connect the ammeter to the solar panel. For each position, hold the solar panel against the prop, read the ammeter, convert the reading to light intensity (W/m^2), and record this in the proper Data Log. Use the Data Log designated for this test direction.

4) Reposition the experiment station so it lies level and faces the next direction to be tested. Repeat step 3 for this new direction. Continue this for each direction to be tested.

5) Point the solar panel toward the Sun and position it to obtain the maximum current reading from the ammeter. Convert this reading to light intensity (W/m^2) and record this in the last Data Log you used under "Tracking."

6) Repeat the above measurements as often as your teacher instructs you to do so.

Name ___________________________________

Date ____________________________________

Stationary Solar Panel: Data Analysis

Your teacher will assign you data for two or more horizontal angles of tilt. Data for one horizontal angle of tilt is considered one data set. Complete the following for each data set. Use a separate graph for each data set.

1) On the graph supplied by your teacher, record the date and general weather conditions for the day in the title of the graph

2) For the assigned horizontal angle of tilt, plot one set of data for each direction east of north that data was collected. Use the pencil colors specified in the key to draw a smooth line through the data points for each set of data.

3) You can compare the total amount of energy that would be received over a day by a solar panel facing in each direction by comparing the area under the curves plotted for each direction. For which direction (east of north) that you plotted is the area under the curve the largest? (You can estimate the area under a curve by counting the number of square grids under the curve.)

4) With your teacher's direction, compare this with the results derived from data plotted by other students. As a class, decide which direction (east of north) the farmers should position their solar panels in to obtain the greatest amount of power.

5) For a panel facing in this direction and at your specified horizontal angle of tilt, estimate the total number of watt-hours of radiation a panel one square meter in size would have received on the day of your data collection. This is easier than it sounds. Your teacher will explain how to proceed.

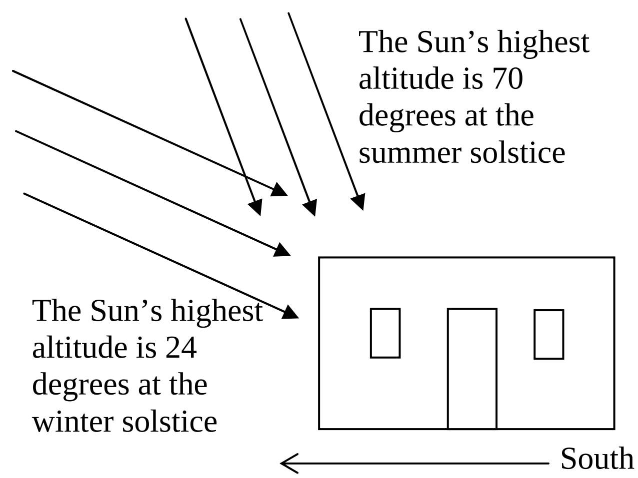
   A solar panel facing ________ degrees east of north, and tilted at an angle of ___________ degrees from the horizontal, would have received _____________watt-hours per square meter (W-h/m^2) of power on the day of your data collection.

6) With your teacher's direction, compare your estimate with the results derived from data plotted by other students. As a class, decide which horizontal angle of tilt the farmers should position their solar panels in to obtain the greatest amount of energy from the Sun at this time of year.

7) What percentage difference is there in solar radiation received between the best performing stationary panel and the tracking panel?

8) Fifty New York State schools have recently installed solar electric systems, in part to help supply energy to New York State's electrical power system. These panels were mounted facing due south with a tilt of 43 degrees from horizontal. In central New York State, the Sun's highest daily altitude changes from 24 degrees at the winter solstice (December 21) to 70 degrees at the summer solstice (June 21). Why do you think the engineers made the design choice of tilting the panels 43 degrees from horizontal?

Hint (see question 2 from the handout *Tracking Solar Panel: Data Analysis*): Use the relationship between the Sun's altitude and the optimum tilt of a solar panel to calculate the optimum tilt of a solar panel at the summer and winter solstices.

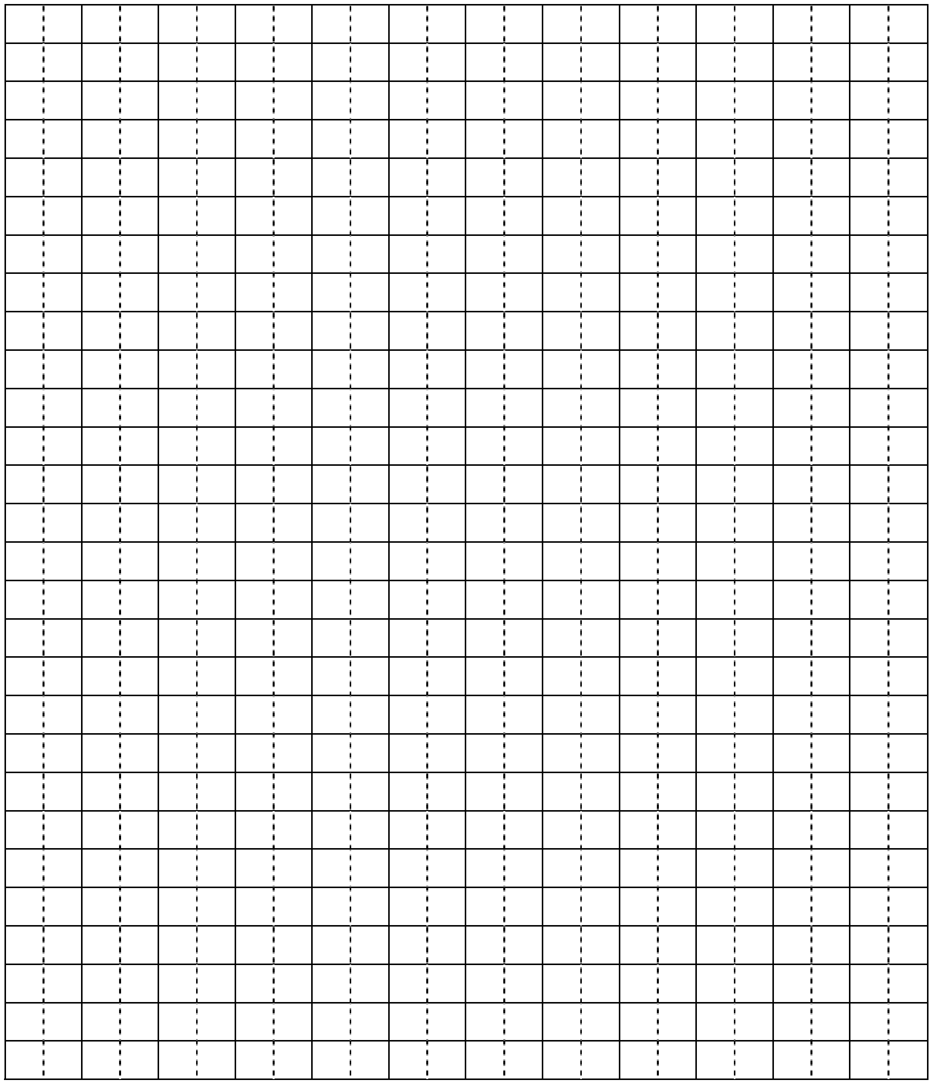


Graph 1: Solar Intensity versus Time of Day

Date: ________________ Weather conditions: ________________________________

Horizontal Angle of Tilt (degrees) ____

Solar Intensity (W/m^2)



Time of Day

Direction East of North (degrees)	**Pencil Color**

Solar Education for NY
SchoolPower ...Naturally

Solar Kit Lesson #9
Properties of Solar Radiation: Reflection, Transmission, and Absorption

TEACHER INFORMATION

LEARNING OUTCOME
After using a solar panel as a radiation meter to distinguish how well various materials reflect or transmit solar radiation, students are able to predict reflection and transmission properties for various materials, and test their predictions using their sense of touch.

LESSON OVERVIEW
Through experimentation, students observe and record levels of solar radiation reflected off and transmitted through various materials. They apply the results to potential consumer choices.

GRADE-LEVEL APPROPRIATENESS
This Level II Physical Setting lesson is intended for use in home and careers, physical science, and technology education classrooms in grades 6–9.

MATERIALS:
Per work group
- one 1 V, 400 mA mini–solar panels* with alligator clip leads
- one 45-degree mount for the solar panel
- digital multimeter
- a flat board such as a clipboard painted with flat black paint
- 30 cm of masking tape
- squares of materials, approximately 10 x 20 cm
    - Mirror
    - Window glass
    - Frosted glass
    - Aluminum foil
    - Unpainted copper sheeting
    - Wood
    - Waxed paper
    - Clear plastic wrap
    - Cellophane: clear, yellow, red, blue, green
    - Construction paper: black, yellow, red, blue, green

If working without the Sun,
- 150-watt incandescent bulb with lamp

* Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY

Tell students not to look directly at the Sun or at a direct reflection of the Sun. Permanent eye damage can result. Sand or tape any sharp-edged materials students will be handling such as glass or thin metal.

TEACHING THE LESSON

Preparation: Prepare one 45-degree solar panel mount for each team as described in figure 1. Cut out and assemble the test materials.

Suggested Approach: Crumple up several pieces of paper and throw them at a group of students. Ask students to describe how these pieces of paper and the group interacted. Some may have been caught; these were "absorbed" by the group. Others would have passed through or been "transmitted" through the students to the floor. And others may have bounced off or been "reflected" off students, desks, or chairs. Use the ensuing discussion to define *reflection, transmission*, and *absorption*.

If some students throw crumpled paper back at you or others, you can discuss how that piece of paper was absorbed and then "reradiated" by the group. This is a phenomenon that occurs in some materials (think of phosphorescent materials) but tell students that they will not be exploring such materials today.

Discuss the mathematical relationship between reflection, transmission, and absorption: incident solar radiation (I) must equal reflected (R) plus transmitted (T) plus absorbed (A) radiation.

$$I = R + T + A$$

Demonstrate how to use an ammeter and a panel's conversion curve to obtain milliamps and then convert to watts per square meter (W/m^2). (See the Solar Kit lesson *Calibration Curve for a Radiation Meter*). Distribute the handout *Transmission, Reflection, and Absorption* and have students follow the instructions.

If time for the activity is limited, groups can run either the transmission or reflection lab, then share their data prior to predicting the absorption capacities of the materials.

If weather conditions are unsuitable, or a proper sunlit space is not available for students to work with radiation directly obtained from the Sun, a 150-watt incandescent lamp can serve as an alternative. Keep any lamp at least 120 cm away from the solar panel or it might melt the protective cover.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

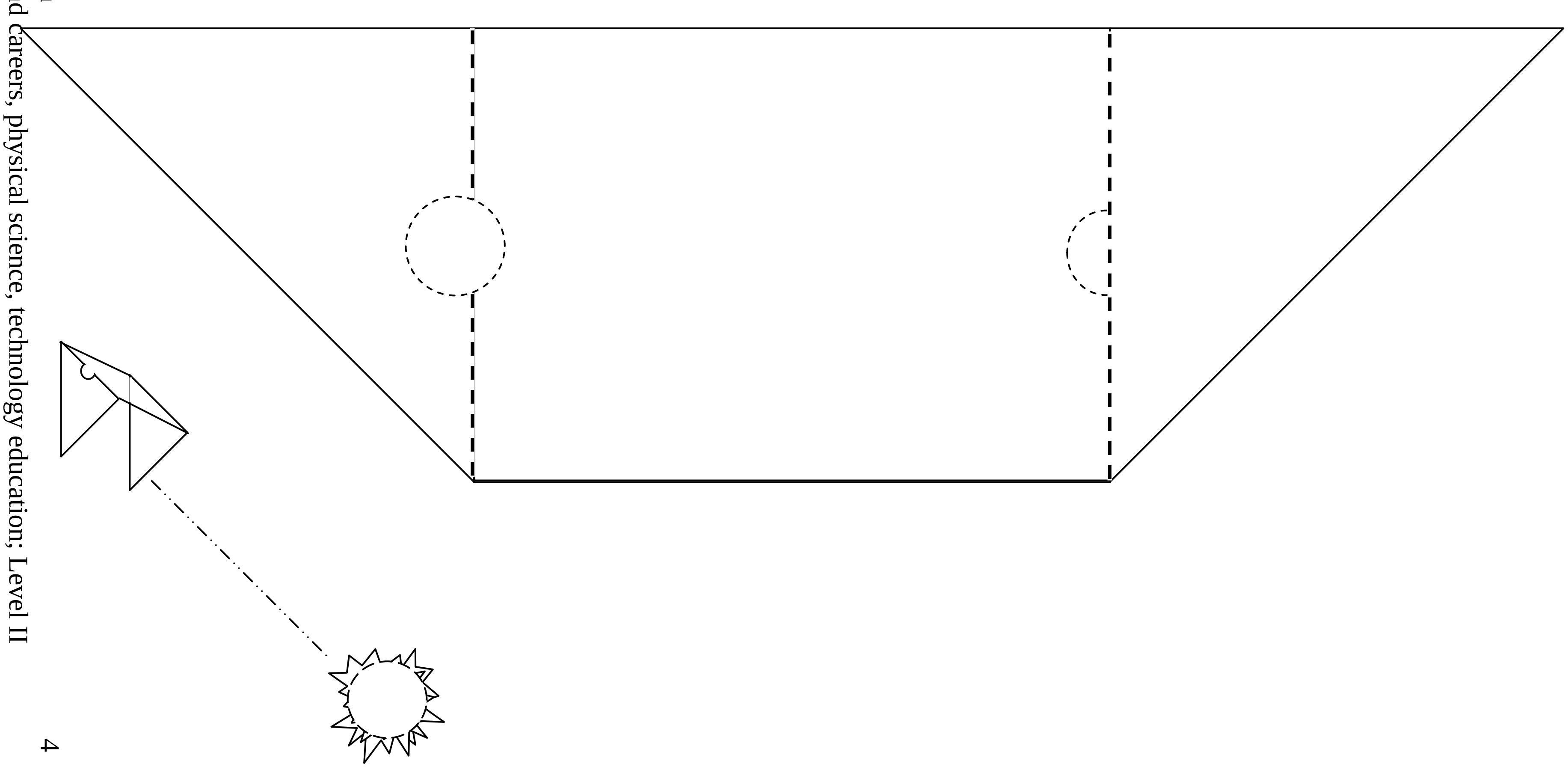
Data Collection: Results will vary due to several variables, especially variations in positioning and holding the solar cell and light conditions.

The mirror and aluminum foil should show the highest level of reflection. Window glass and clear plastic sheeting should show the highest level of transmission. The mirror, aluminum foil, copper sheeting, wood, and construction paper should not transmit light energy.

Students should be expected to predict that the darker colored construction papers, black-painted copper sheeting, and wood will absorb the most light energy.

Figure 1: Template for solar panel 45-degree mount

Use this template to prepare a 45-degree solar panel mount for each team. Prepare each mount out of stiff cardboard. Each mount will be cut to the shape of the template. Cut out an opening for the solar panel wires as shown by the circle. Fold the wings of the mounts 90 degrees along the dashed lines. Students will use double-sided tape to hold the solar panel to the inside of the mount for the lab on reflection.



Review Questions:

1. Students should use mathematical reasoning and deduce that materials that perform poorly as reflectors and transmitters must be absorbing the radiation while materials that perform very well as reflectors or transmitters must not absorb much radiation. Students should cite the fact that reflected plus transmitted plus absorbed radiation must add up to the incident solar radiation.
2. Students should have noticed that smooth surfaces reflect more light than dull or rough surfaces and that a surface that reflects high levels of light absorbs less light.
3. Students should have noticed that materials having dark colors absorb more light than light-colored materials and that a material that absorbs high levels of light transmits less light.
4. Students should identify items such as distance between the material and the solar panel, consistent positioning of the material, and angle of incidence of the light source.
5. Answers will vary but they should accurately use information on how colors and materials affect the amount of solar radiation that is absorbed, reflected, or transmitted.
6. Answers will vary but they should accurately use information on how colors and materials affect the amount of solar radiation that is absorbed, reflected, or transmitted. Ideally a solar panel cover would look dull, indicating that very little light is reflected.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This lesson was adapted from *Renewable Energy Activities for Junior High / Middle School Science*, prepared for the U.S. Department of Energy by the Solar Energy Project in cooperation with the New York State Education Department and the State University of New York Atmospheric Sciences Research Center (out of print).

BACKGROUND INFORMATION

Radiation incident upon a surface is typically described as interacting with the surface in one or more of three ways: it will be absorbed into the material, transmitted through the material, or reflected off the material. The proportions of each will depend on the wavelengths of the radiation, the chemical composition and physical structure of the material, and the angle of incidence at which the radiation strikes the material.

Hard polished surfaces reflect light differently from rough textured surfaces. The amount of radiation reflected also depends on the angle of the incident light, with low angles of incidence typically reflecting more light than high angles of incidence. Radiation can reflect off a surface more or less equally in all directions at once or in only one direction as light reflects off a mirror. Radiation reflected in all directions is called "diffuse reflection" and radiation reflected as occurs off a mirror is called "specular reflection."

Materials that absorb many wavelengths of visible light look darker to us than those that absorb fewer wavelengths.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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 3: Critical thinking skills are used in the solution of mathematical problems.

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

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships.

Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data.

Key Idea 7: Students use patterns and functions to develop mathematical power, appreciate the true beauty of mathematics, and construct generalizations that describe patterns simply and efficiently.

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

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

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)

www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name(s) ________________________

Date ___________________________

Transmission, Reflection, and Absorption

What happens when solar energy strikes an object? Here are three possibilities: it may be transmitted through the object, the object may reflect the solar energy, or the object may absorb it. Most objects do all three, to a greater or lesser extent.

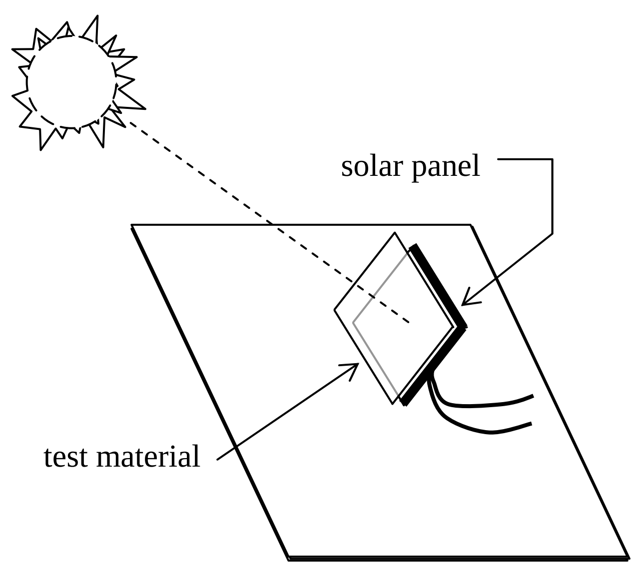
It is useful knowledge to understand how different materials transmit, reflect, and absorb solar radiation. For instance, in the case of a solar cell, it is important to coat the surface with a material that is a poor reflector—we want as much light as possible to enter the cell. Accordingly, creating comfortable, well-lit homes, schools, and offices requires an understanding of which building materials transmit, reflect, and absorb solar radiation. After experiencing this lesson you may even begin to select the color and texture of new clothing purchases depending on the strength of sunlight during the seasons.

You are now going to distinguish how well various materials reflect or transmit solar radiation. From the data obtained, you will then predict how well each material absorbs solar radiation.

Transmission

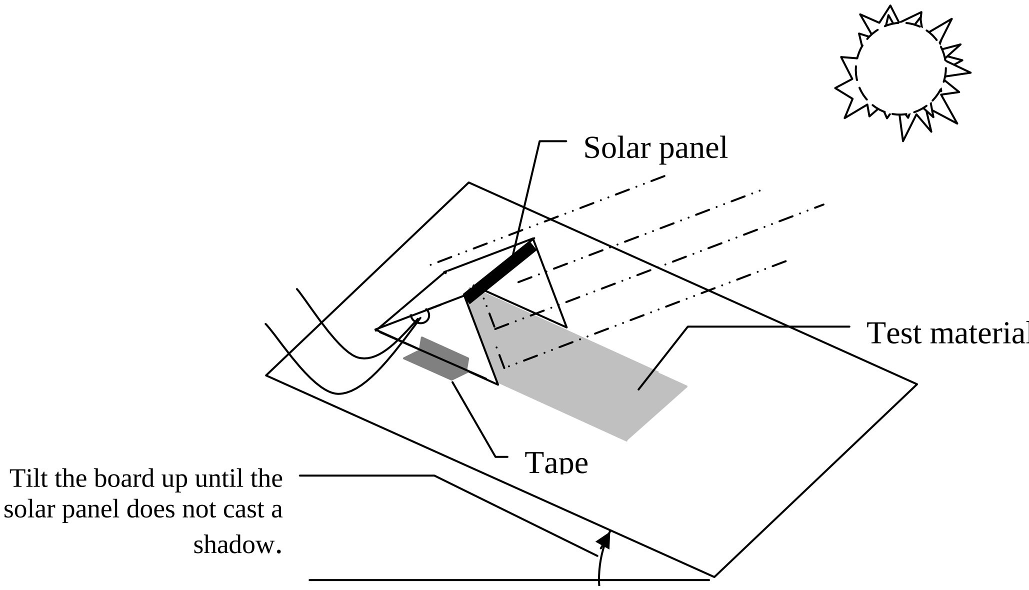
1. Tape one edge of the solar panel to a flat board such as a clipboard. Be careful not to cover any of the photovoltaic cells with tape. You should now be able to tilt the solar panel toward the Sun.

2. Connect an ammeter to the solar panel leads. Position the board and tilt the solar panel so the ammeter shows the highest reading possible. Prop the solar panel in this position with a heavy bulky object such as a text book and leave it this way for the rest of the transmission tests.



3. In turn, cover the solar panel with each piece of material. For each material, record the ammeter reading in milliamps (mA) under "As a Transmitter" in the Data Table.

4. When you have finished testing all materials, use the ammeter readings and the solar panel's calibration curve to calculate the intensity of light that was transmitted through each material. Record this as watts per square meter (W/m^2) under "As a Transmitter" in the Data Table.



5. On the basis of your observations, rate each test material's ability to transmit light. Record *excellent*, *good*, *fair, poor*, or *no ability* in the Data Table.

Reflection

6. Use double-sided tape on the back of the solar panel to secure it to the inside of the cardboard mount (the triangular wings wrap around the panel's sides) with the wire leads fed through the hole. Use tape to secure the cardboard mount (with solar panel) to the board as shown in the diagram so the face of the solar panel is directed toward the board.

7. Place the board on the table with the open side of the mount directed toward the Sun. Tilt the board until the solar panel does not show a shadow. (Or, if using an incandescent lamp, position the lamp so the solar panel does not cast a shadow.) You may have to tilt up either the front or the back of the board depending on where the Sun is in the sky. Secure the board in this position for the remainder of the reflection tests.

8. Place the mirror on the board in the test material location as shown in the diagram. Record the ammeter reading as "mA" under "As a Reflector" in the Data Table.

9. Remove the mirror and replace it in turn with each remaining test material. Make sure each test material is placed in the exact same position as the mirror. Record the ammeter reading for each test material in the Data Table.

10. For each material, use the ammeter reading and the solar panel's calibration curve to calculate the intensity of light that was reflected off the material. Record this as "W/m^2" under "As a Reflector" in the Data Table.

11. On the basis of your observations, rate each test material's ability to reflect light. Write *excellent*, *good*, *fair*, *poor*, or *no ability* in the Data Table.

Absorption

12. Review the data you collected and how you rated each material's ability to reflect and transmit light. For each test material, predict its ability to absorb light. Write *excellent*, *good*, *fair*, *poor*, or *no ability* in the Data Table.

13. Predict which of the materials would become the warmest and which the coolest if left lying out in the Sun. Use your sense of touch to test your prediction.

Review Questions:

1. What reasoning did you use to predict which materials would be the best or worst absorbers of light?

2. How did the texture of the material seem to affect its ability to reflect light? Absorb light?

3. How did the color of a material seem to affect its ability to transmit light? Absorb light?

4. What variables did you control to make sure that the material being tested was the only factor influencing the readings?

5. Using what you learned, what exterior and interior colors and materials would you want in a car if you lived in a hot sunny climate? What colors and materials would you pick if you lived in a cold sunny climate?

6. What properties of transmission, reflection, and absorption of light would you look for in a material used to cover a solar electric panel? Describe how you would expect this material to appear (such as dull, shiny, dark or light colored, etc.).

Name(s) ____

Date _____________

Data Log

Material	As a Transmitter			As a Reflector			As an Absorber
	mA	W/m^2	Description	mA	W/m^2	Description	Conclusion
Mirror							
Window Glass							
Frosted Glass							
Aluminum Foil							
Copper Sheeting: Unpainted							
Black-painted							
Wood							
Waxed Paper							
Clear Plastic Wrap							
Cellophane: Clear							
Yellow							
Red							
Blue							
Green							
Construction Paper: Black							
Yellow							
Red							
Blue							
Green							

Solar Education for NY
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Solar Kit Lesson #10
Properties of Solar Radiation: Direct and Diffuse Light

TEACHER INFORMATION

LEARNING OUTCOME
Students become habituated to observing conditions in the sky such as location of the Sun and types of clouds. They come to understand the patterns of cloud cover that affect solar energy production.

LESSON OVERVIEW
Students establish a long-term study of direct and diffuse solar radiation. They collect and display data, demonstrate the concept of percentage, interpret data, and make predictions. The data can readily be transferred to computer data-management software such as spreadsheets.

In this lesson, students:
- use an ammeter to collect data
- interpret data on direct and diffuse solar radiation
- display data in numerical and graphical forms
- use a graphical technique to determine and display percentage of direct versus diffuse solar radiation
- predict how factors such as differing weather conditions or times of day affect levels of direct and diffuse solar radiation
- adjust their predictions after interpreting new knowledge
- identify how differing weather conditions or times of day affect levels of direct and diffuse solar radiation

GRADE-LEVEL APPROPRIATENESS
This Level II Physical Setting lesson is intended for physical science and technology education classrooms, grades 6–9.

MATERIALS
If you choose to send a different team outdoors each day for the long-term study, you will need one of each of the following bulleted items. If you choose to have the class work in teams at the same time for the long-term data collection, you will need one of each of the following bulleted items per team.
- Two 1 V, 400 mA mini–solar panels* with alligator clip leads
- Digital multimeter or ammeter
- 11 x 17 inch sheet of dark-colored construction paper
- Tape

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

Per work group

- Student handouts
- Graph paper
- Scissors

SAFETY

Tell students not to look directly at the Sun. Permanent eye damage can result. Instead, direct them to use a maximum current reading to indicate when a solar panel faces the sun directly. Have them look at other parts of the sky, not at the Sun, to determine sky conditions.

TEACHING THE LESSON

This lesson includes an introductory discussion, a demonstration on how to collect data on solar radiation, a demonstration on how to graphically determine percentage, and a long-term student study. Each of the first three components could take a class period. The structure of the long-term class study is flexible and should be designed to address the needs and resources of your class.

Preparation: Form an 11-inch-deep box with a solar panel at the bottom by folding a sheet of 11 x 17 inch dark-colored construction paper around the edges of a mini–solar panel. Direct the face of the panel into the box. Tape the construction paper to the solar panel to form an open box with the panel as the bottom.

Remember, if you choose to have the class work in teams all at the same time for the long-term data collection, you will need one 11-inch-deep box for each team.

Opening Discussion: Discuss with students why, in a room having seven windows, it is bright enough to see even when no sunlight is shining directly into the room and the electric lights are not turned on. Define *direct light* and *diffuse light*. Ask students their estimation of how much light from the Sun reaches Earth's surface directly from the Sun (direct light) and how much light reflects off gases in the atmosphere before it arrives at Earth's surface (diffuse light). Manage to slip into the conversation various weather conditions such as days having heavily overcast skies (when hardly any direct radiation reaches Earth) or clear sunny days (when the direct radiation could be in the 90% range). Write on the chalkboard, chart, or overhead transparency phrases that students come up with, such as "hardly any" or "almost all."

Introduce the concept of percentage as a more accurate way of representing terms such as *hardly any*, *almost all*, *about half*, *none*, or *all of it*. Draw a scale on the board from 0% to 100% using 10% increments. Define *0%* as "none of it" and *100%* as "all of it." Work with the class to determine where phrases generated in the previous discussion might fit on the scale.

Tell the students that they will apply the concept of percentage as they study direct and diffuse light over the next month or two.

Measuring Direct and Diffuse Radiation: Distribute the handout "Direct and Diffuse Light – Data Sheet." Use a solar panel and ammeter as follows to demonstrate to students how to collect data. Asking a few students to assist, or rotating students through the process of taking measurements themselves, should be helpful.

Connect the ammeter to the leads of a mini–solar panel, positive to positive and negative to negative. Set the scale to read 0–500 mA. Explain that using the solar panel and meter in this manner provides a simple way of indicating how much light shines on the panel. Take the class outside to an open location.

Total or global radiation: Point the solar panel directly at the Sun. Adjust it until the ammeter reading is at a maximum. Have students record how many milliamps it produces. Explain that this number represents the total light energy shining on the panel. This is called global radiation.

Diffuse radiation*:* Point the solar panel toward the widest section of sky. Then use your hand to shade the solar panel. Hold your hand about one foot from the solar panel. Measure how many milliamps it produces. Have students record this information. Explain that this number represents only the light energy that has been reflected onto the solar panel. Ask students to name objects that reflected the light energy. They may mention trees, buildings, and gases in the atmosphere.

Direct radiation**:** Use the mini–solar panel in the 11-inch-deep box. Point the solar panel directly at the Sun so that there are no shadows on the panel. Have students record how many milliamps it produces. Explain that this number represents the light energy that came directly from the Sun.

Analyzing Data: Back in the classroom, help students make bar graphs of the data they collected. Discuss with students what their data reveals. How did the amount of direct light compare to the total amount of light? How did the amount of diffuse light compare to the total amount of light?

Draw a scale on the board from 0% to 100%, using 10% increments. Define *0%* as "no light" and *100%* as "all light." Tell students that the total or global radiation they measured is "all the light" (100%). Work with the class to determine where the amount of direct and diffuse light they measured should fit on the scale.

Determining percentage: Have students cut out the bar they drew to represent global radiation. Help them fold it into 10 equal parts. Have students unfold it and draw lines at each crease. Explain how their bar now represents a scale from 0% to 100%. Demonstrate how to place this next to the bars they drew for diffuse and direct light so that the bottom of each bar lines up. Have students mark on the global radiation bar where the tops of the direct and diffuse bars reach. Tell students to label each mark as "direct" or "diffuse."

Have students transfer these marks to the graph on their data sheet. Tell them to shade the column below each mark, using a different color for each column.

Student Predictions: Distribute the handout "Prediction Sheet I." Have teams of students predict the following:

The weather conditions and time of day that global radiation will come almost totally from

1) diffuse radiation and
2) direct radiation.

Save these diffuse radiation predictions for students to reference during the long-term study.

Long-Term Study: Set up a long-term study that meshes with the equipment you have available and your class and school schedules. You may wish to send a different team outdoors each day or at different times each day to take readings and then, on a daily or weekly basis, assign to the class some of the teams' data as practice for graphing and analysis. You could have the entire class work in teams and take readings on days having differing weather conditions, making sure to take readings at different times of the day as well.

In any situation, have students compare their predictions, in writing, to what the data is showing them. Have them write down adjustments they wish to make to their predictions. Keep these writings with the original team prediction sheet.

Final Data Analysis: Once the teams have collected all of the data, assemble and display all data sheets in a systematic manner. For instance, display morning and midday readings in different parts of the classroom with sunny conditions posted on the top and the worst weather conditions posted on the bottom. Pass out the handout "Prediction Sheet II" and have each team predict what portion of the total light the diffuse and direct radiation would contribute under the following conditions:

Early morning, clear blue skies
Early morning, hazy whitish skies
Early morning, heavily overcast skies
Midday, clear blue skies
Midday, hazy whitish skies
Midday, heavily overcast skies

Allow the teams time to review the displayed data and identify the accuracy of their predictions.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Results will vary due to light conditions. On heavily overcast days, students will measure hardly any direct radiation, while on clear sunny days the direct radiation could be in the 90% range. The percentage of direct radiation will be less in the morning than at midday under similar weather conditions.

Values for direct and diffuse radiation will add up to plus or minus 5% of 100% due to the inaccuracies in the measurement process.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This lesson is adapted from *Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*, Thames & Kosmos, LLC, Newport, RI, 2000.

BACKGROUND INFORMATION

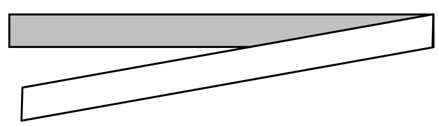
The sky provides light even where the Sun is not shining because the gases in the atmosphere reflect and scatter light. This portion of the light reaching us from the Sun is known as diffuse radiation. Light straight from the Sun is known as direct radiation.

On a clear day, the sky looks blue because the blue portion of sunlight is scattered most easily by gases in the atmosphere. The reds and yellows pass through these gases more easily, giving the impression that the Sun is yellow or red. Larger particles of dust and water vapor in the atmosphere cause more colors to be scattered. When these are present in the atmosphere, the sky becomes whitish or hazy.

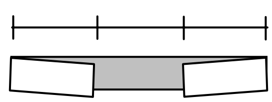
The term *percent* comes from the phrase *per centum*, meaning “by the hundred.” It refers to looking at a whole as being made of 100 equal parts where one part in a hundred is a percent.

Folding a strip of paper into 10 equal parts:

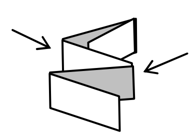
1) Fold the strip in half.



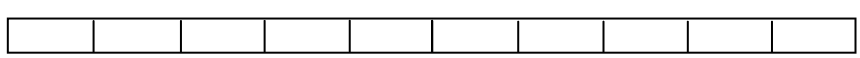
2) Fold each end toward the middle so you see three equal-size sections.



3) Fold creases on both sides of the middle section.



4) Unfold and mark the creases.



REFERENCES FOR BACKGROUND INFORMATION

Columbia On-line Encyclopedia. New York: Columbia University Press, 2002. New York: Bartleby.Com, 2002

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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. (elementary)

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions. (elementary and intermediate)

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems. (elementary and intermediate)

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (elementary and intermediate)

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. (elementary and intermediate)

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

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 1: Students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence, and construct an argument. (elementary and intermediate)

Key Idea 2: Students use number sense and numeration to develop an understanding of the multiple uses of numbers in the real world, the use of numbers to communicate mathematically, and the use of numbers in the development of mathematical ideas. (elementary and intermediate)

Key Idea 3: Students use mathematical operations and relationships among them to understand mathematics. (intermediate)

Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships. (elementary and intermediate)

Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data. (elementary and intermediate)

Key Idea 6: Students use ideas of uncertainty to illustrate that mathematics involves more than exactness when dealing with everyday situations. (elementary and intermediate)

Key Idea 7: Students use patterns and functions to develop mathematical power, appreciate the true beauty of mathematics, and construct generalizations that describe patterns simply and efficiently. (elementary and intermediate)

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

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

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

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

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful information. (elementary)

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 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. (elementary and intermediate)

Key Idea 3: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems. (elementary)

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions. (elementary and intermediate)

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Key Idea 1: The knowledge and skills of mathematics, science, and technology are used to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena. (elementary and intermediate)

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement,
please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name(s) ____

Date ___________________

Direct and Diffuse Light – Data Sheet

Time of day____________________________________

Condition of sky ____

Radiation Type   Ammeter Reading

Global radiation   ______________ (Point the solar panel at the Sun.)

Diffuse radiation   ______________ (Point the solar panel at the sky and shade it from the Sun.)

Direct radiation   ______________ (Point the solar panel in the box directly at the Sun.)

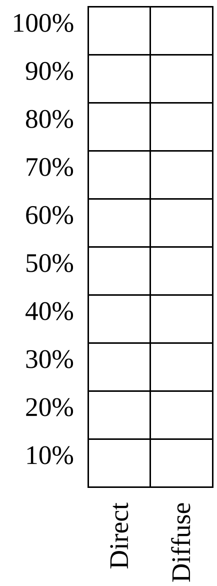
Data Analysis

1) On a separate sheet of paper, construct a bar graph showing your measurements for global, diffuse, and direct radiation.

2) Cut out the bar for global radiation and fold it into 10 equal parts. Draw lines at each crease.

3) Mark on the global radiation bar where the tops of the direct and diffuse bars reach.

4) Transfer these marks to the following graph. Shade the column below each mark. Use a different color for each column.

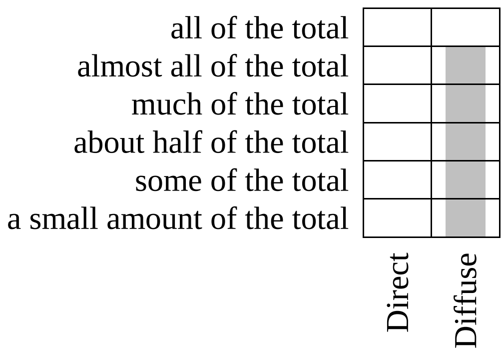


Name(s) ____

Date ____________________________________

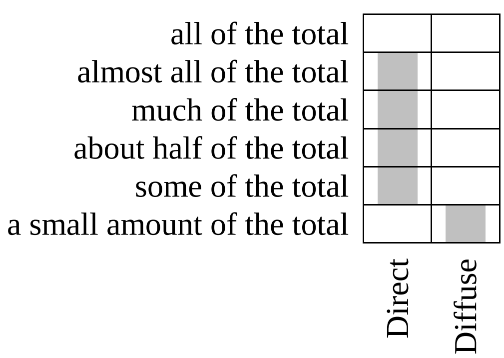
Direct and Diffuse Light – Prediction Sheet I

Graph 1



1) Predict two scenarios showing what time of day and under what weather conditions you will see the results in graph 1.

Graph 2



2) Predict two scenarios showing what time of day and under what weather conditions you will see the results in graph 2.

Name(s) ____

Date ______________________________

Direct and Diffuse Light – Prediction Sheet II

Early morning, clear blue skies

	Direct	Diffuse
all of the total		
almost all of the total		
much of the total		
about half of the total		
some of the total		
a small amount of the total		

Midday, clear blue skies

	Direct	Diffuse
all of the total		
almost all of the total		
much of the total		
about half of the total		
some of the total		
a small amount of the total		

Early morning, hazy whitish skies

	Direct	Diffuse
all of the total		
almost all of the total		
much of the total		
about half of the total		
some of the total		
a small amount of the total		

Midday, hazy whitish skies

	Direct	Diffuse
all of the total		
almost all of the total		
much of the total		
about half of the total		
some of the total		
a small amount of the total		

Early morning, heavily overcast skies

	Direct	Diffuse
all of the total		
almost all of the total		
much of the total		
about half of the total		
some of the total		
a small amount of the total		

Midday, heavily overcast skies

	Direct	Diffuse
all of the total		
almost all of the total		
much of the total		
about half of the total		
some of the total		
a small amount of the total		

Solar Kit Lesson #11
Power Maximum: An Electrical Determination

TEACHER INFORMATION

LEARNING OUTCOME
After standardizing test stations designed to measure a solar panel's maximum power output and working with output data for solar panels, students are able to

- identify variables that may affect test results,
- devise ways to control such variables so that comparable results can be obtained from each station, and
- identify construction considerations that might affect a solar panel's performance.

LESSON OVERVIEW
Students identify and implement methods to standardize testing stations that measure solar panel output power. After collecting electrical output data from several solar panels, they plot the current-voltage (I-V) and power curves. Working with the variable "amount of light," students identify voltage and current at maximum power output for several solar panels.

GRADE-LEVEL APPROPRIATENESS
This Level II Physical Setting, physical science, technology education lesson is intended for use in grades 6–9.

MATERIALS
Per work group
- two or three mini–solar electric panels*
- ten 0.5 ohm resistors
- multimeter capable of measuring milliamps, millivolts, and ohms to two decimal places
- a gooseneck lamp with 150 watt incandescent floodlight bulb
- masking tape
- handouts

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

Optional
- breadboard
- light meter

SAFETY
Warn students not to touch floodlight bulbs when they are on. The bulbs will be hot enough to cause a burn.

TEACHING THE LESSON

Planning and Preparation: Depending on your classroom resources, decide how students are to connect the resistors in series. You might have them twist wire leads together or, if you have breadboards available, instruct students how to make use of them.

Identify each mini–solar panel using an individual masking tape label such as *1* through *16* or *A* through *P*. Individual panels may be composed of two, three, or four solar cells. Prepare a set of panels for each team. To the extent possible, supply each set with panels made of differing numbers of cells.

A table such as the one shown in figure 1 is appropriate for teams to record their final data. Display such a table where students can access it. Provide a bulletin board or other space for teams to display their completed graphs.

Figure 1: Sample Class Data Table

Panel #	Pmax	V @ Pmax	A @ Pmax
1			
2			
3			
.			
.			
.			
16			

If your students do not know how to use a multimeter to measure electrical resistance, voltage, and current, demonstrate how to do this at the start of the lesson.

Suggested Approach: Introduce the lesson by revealing to students that, although all of the kit's 16 mini–solar electric panels are rated as 0.4 watt panels, each very likely produces a slightly different amount of power compared to the others. Tell students that they are to use electrical measurements to rate and rank the 16 panels from most to least powerful.

Describe how to set up the lab apparatus so that the floodlight is positioned at least 16 cm from the solar panel; otherwise, it might melt the panel's plastic cover. Form teams of two and distribute the materials and the handout "Standardizing Test Stations."

Have students contemplate how the class might ensure consistent results among lab setups. Allow the teams a few minutes to complete the handout "Standardizing Test Stations."

Guide the class as they identify one or more methods they believe will standardize test stations. If two likely methods are identified, have half the teams use one method and half the other method. (See the Acceptable Responses for Develop Your Understanding Section for sample standardization methods.)

Instruct students on how to connect the ten resistors in series. Distribute the remaining student handouts to each team and have students complete the instructions in them.

Once students have completed the data collection, have them perform the data analysis and post their findings.

Follow-up Discussion Points:

Review with students the data for all solar panels. Does any of the data lead to the belief that test results may have varied due to differences in test setups?

How might one test whether differences in individual teams' test setups influenced test results?

Are there construction details that may affect panel output?

What else might have an effect on the actual power output?

How do manufacturers ensure a quality product? Cite price differences between tested versus untested products.

Challenge students to propose other ways to test which mini–solar panel is the most powerful.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

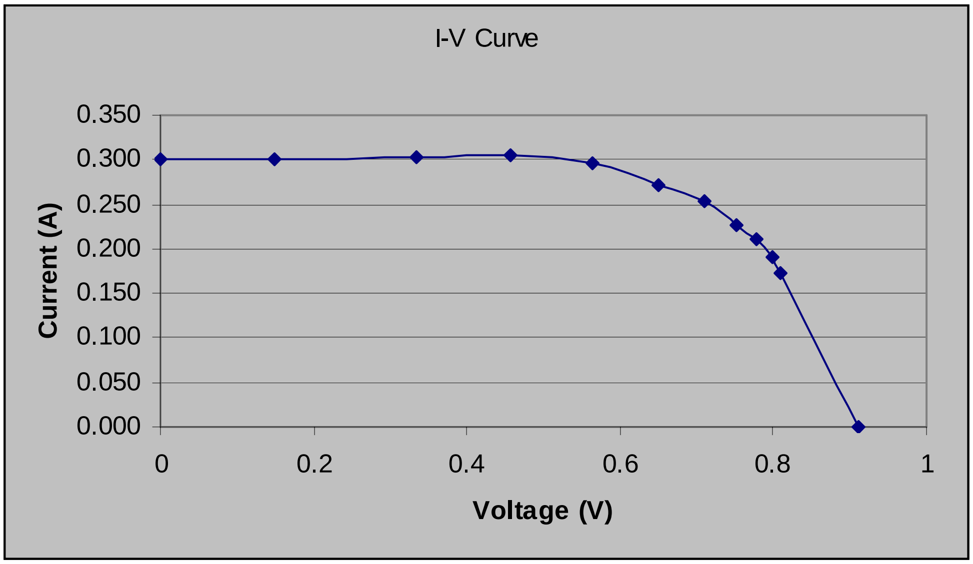
Standardizing Test Stations: Students should be aware that comparable results will not be possible unless all test stations are provided panels that receive the same level of light. Variables that affect this ideal situation are the

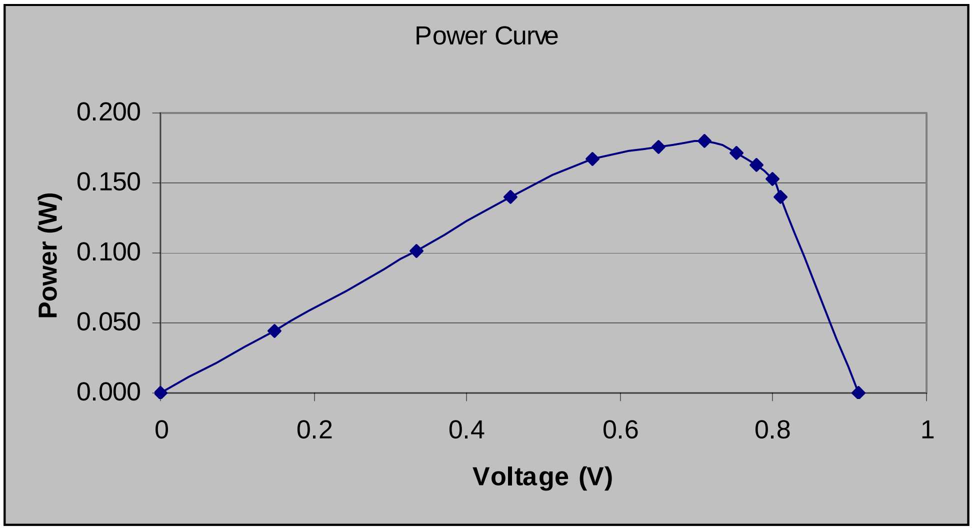
1) distance between a bulb and a solar panel,
2) the direction the bulb is facing,
3) the light output of the bulb, and
4) the position of the solar panel.

Some potential methods for standardizing testing stations include:

1) Use a standard and exact placement of the bulb and solar panel, although this ignores the potential difference in light output among bulbs.
2) Adjust each test station's lamp so it produces a standardized level of light for where the solar panels will be placed. Have a standard and exact placement of the solar panels.
    a. If a light meter is available to the class, students might use it to adjust the height of each lamp so that the solar panels at each test station are exposed to the same amount of light.
    b. Alternatively, students might use a mini–solar panel as a light meter. (See the Solar Kit lesson *Calibration Curve for a Radiation Meter*.)

Data Collection and Analysis: Students' data collection and analyses should result in a typical solar panel I-V and power graphs such as the one that follows. These sample graphs were obtained from a mini–solar panel rated for 1V, 400 mA illuminated by a 150 watt floodlight positioned 16 cm above the solar panel.





ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ACTIVITY

This is not an adapted lesson.

BACKGROUND INFORMATION

It doesn't matter if a solar cell breaks in two, because then you will have two working cells! Manufacturers of educational or small hobby solar panels rely on this fact and for reasons of economy purchase broken cells that are not acceptable to manufacturers of large solar panels.

Accordingly, it is typical to find that small hobby or educational solar panels are constructed from broken cells of a variety of sizes and shapes.

The cells in a solar panel are connected through soldered metal contacts. When a solar panel fails, the problem usually lies with the electrical connections, not the cells themselves. If a cell cracks and the two pieces are still fastened through the electrical contacts, the electrical performance of a panel might be nearly unchanged.

On the other hand, the electrical contacts between cells are susceptible to a variety of degradations from corrosion to mechanical failure. The grid of electrical contacts on the cell's surface is generally attached through a silkscreen process. The mechanical failure of the finger contacts is the most common cause of panel failure. Too high a temperature during soldering may loosen the fingers from the silicon; too low a temperature is likely to cause a "cold" solder joint. Either one, when present, causes an increase in the electrical resistance of contacts between cells.

REFERENCES FOR BACKGROUND INFORMATION

Practical Photovoltaics: Electricity from Solar Cells, Richard Komp, Ph.D., aatec publications, 2002

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Commencement Level

Standard 5—Technology Education: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms.

Key Idea 7: Project management is essential to ensuring that technology endeavors are profitable and that products and systems are of high quality and built safely, on schedule, and within budget.

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

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions.

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Key Idea 1: The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena.

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

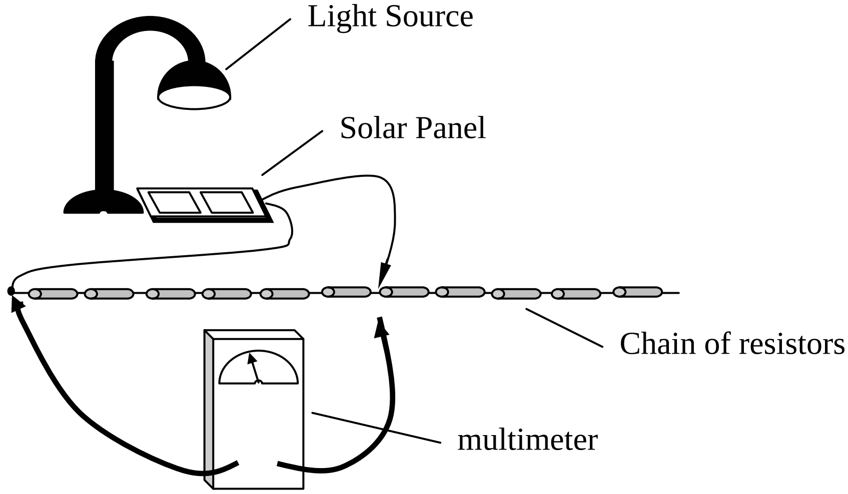
(STUDENT HANDOUT SECTION FOLLOWS)

Name ____________________________________

Date _____________________________________

Standardizing Test Stations

Each team is to use the test setup shown below to measure the power output of two to four solar panels.



In order to accurately rate and rank the 16 panels from most to least powerful, the results of each team's test setup must be comparable with all other test setups.

1) Identify variables that exist between individual teams' test setups that may affect test results.

2) Propose at least one way the class might work together to minimize or eliminate the effects these variables would have on the data to be collected.

Data Collection

1) Standardize your test setup as decided in class.

2) Follow your teacher's instructions on how to connect the ten 0.5 ohm resistors in series. Connect the negative (black) solar panel lead to one end of this resistor chain. Do not connect the red lead to the resistor chain at this time.

3) Set the multimeter to measure resistance values of around 5 ohms. Connect the negative (black) lead to the end of the resistor chain connected to the solar panel's negative lead. Measure the electrical resistance values between this point and each node of the resistor chain. (Measure the resistance of first one resistor, then two in series, and then three in series, and so on up to ten resistors in series.) Record these values in the Solar Panel Power Data Log.

4) Position the first mini–solar panel directly under the light source. Use tape to secure the panel in place, making sure not to cover any of the actual solar cells. Use tape to mark the solar panel's position on the table.

5) Set the multimeter to measure voltages of around 1 volt. Turn on the light source.

6) Keeping the negative lead of the solar panel connected to one end of the resistor chain, connect the solar panel's positive lead in turn to each node of the resistor chain and measure the solar panel's output voltage. (Start with the voltage over one resistor, then over two in series, and then over three in series, and so on up to ten resistors in series.) Record these values in the data log.

7) Measure the solar panel's output voltage with nothing but the voltmeter connected to the leads. Record this as the open circuit output voltage. (Voltmeters in effect have infinite resistance across their leads). Record this value in the data log. Why don't we bother to measure open circuit output current? What should you record in the data log for open circuit output current?

8) Set the multimeter to measure current of around 0.5 amps. Measure the solar panel's output current with nothing but the ammeter connected to the leads. Record this as the short circuit output current. (Ammeters have very low resistance across their leads). Record this value in the data log. Why don't we bother to measure short circuit output voltage? What should you record in the data log for short circuit output voltage?

9) In turn, replace the first mini–solar panel with each of the panels provided by your teacher and repeat steps 4 through 7.

Name ___________________________________

Date ____________________________________

Solar Panel Power Data Log

Mini–solar panel number: ______________

Resistance (ohms)	**Voltage (volts)**	**Current (amperes)**	**Power (watts)**
0 short circuit resistance	short circuit output voltage	short circuit output current	
one resistor			
two resistors			
three resistors			
four resistors			
five resistors			
six resistors			
seven resistors			
eight resistors			
nine resistors			
ten resistors			
infinite open circuit resistance	open circuit output voltage	open circuit output current	

Solar Panel Power Data Analysis

Complete the following for each solar panel tested.

1) Use Ohm's law to calculate the output current for each resistance value and enter those values in the data log.

Ohm's law: Voltage (V) = Resistance (Ω) x Current (A)

2) Plot current versus voltage on graph paper (provided below) to obtain the panel's I-V curve. Plot current (A) on the *y*-axis and voltage (V) on the *x*-axis. Label and show the scale of each axis. Sketch the shape of the curve.

Electric power is measured in watts (W) where:

Power (W) = Voltage (V) x Current (A)

3) Calculate the output power for each resistance value and enter those values in the data log.

4) Plot power versus voltage on graph paper (provided below) to obtain the panel's power curve. Plot power (W) on the *y*-axis and voltage (V) on the *x*-axis. Label and show the scale of each axis. Sketch the shape of the curve.

5) From the bottom graph, what is the value of maximum power and what is the voltage at maximum power? Record these values at the bottom of the graph paper.

6) From both graphs, what is the current at maximum power? (From the maximum power point on the power curve, trace upward parallel to the *y*-axis until you intersect the I-V curve. Trace left parallel to the *x*-axis until you reach the *y*-axis.) Record this value at the bottom of the graph paper.

7) Enter your results in the table of solar panel comparisons provided by your teacher and display your graph results as instructed.

8) Review and take notes on the following items and be prepared to discuss them as a class.

   a. Review data for all solar panels. Does anything in the data lead you to believe that test results varied due to differences in individual teams' test setups? Explain.

   b. How might you test whether differences in individual teams' test setups influenced test results?

c. Inspect several panels that showed noticeably different values for maximum power output. Does the power output seem to have anything to do with how each panel was constructed? What else might have an effect on the actual power output?

d. What might a manufacturer of solar panels do to ensure a consistent product? Would ensuring a consistent product have an effect on the price of a panel? Support your response.

e. Knowing that power is the rate at which work is done (amount of work completed per unit of time) can help you to propose other ways to judge which mini–solar panel is the most powerful.

Name ______________________________ **Panel number** _____________

Date ______________________________

I-V Curve

Power Curve

Maximum Power (Pmax)________ Voltage at Pmax __________ Current at Pmax _________

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Solar Kit Lesson #12
Calibration Curve for a Radiation Meter

TEACHER INFORMATION

LEARNING OUTCOME
After using measurement, students are able to link the concept of "brightness" to a graphical mathematical representation or, for more advanced students, an algebraic mathematical representation. Students ready for algebra are able to determine the slope-intercept equation for this linear relationship.

LESSON OVERVIEW
In this lesson students determine the relationship between the short circuit output current of a solar panel and the level of radiation striking the panel. They also:

- measure a solar panel output current as a function of the level of radiation striking the panel
- realize that there is a linear relationship present
- use a solar panel to process energy and information into a more useful form
- plot solar panel output current versus radiation to obtain a calibration curve for their panel
- may use this curve and the solar panel as a radiation meter in other SPN Solar Kit lessons

GRADE-LEVEL APPROPRIATENESS
This Level II physical science / technology education lesson is intended for use in grades 7–9.

MATERIALS
Per work group

- 60-watt bulb and lamp
- meterstick
- vertical stand for solar panel (this could be as simple as a cardboard box or block of wood with 90 degree corners)
- graph paper to plot curve
- 1 V, 400 mA mini–solar panel*
- digital multimeter

* Available in the provided Solar Education Kit, other materials are to be supplied by the teacher.

SAFETY
Warn students that the bulb will become hot enough to cause a burn if touched.

TEACHING THE LESSON

Students should work in groups of two or more. Carry out this lesson on a day of low humidity when students can access periods of unobscured sunlight preferably between 11:30 a.m. and 12:30 p.m. If objects such as clouds, buildings, snow, or haze can reflect diffuse radiation onto the solar panels, the outdoor readings may be high. You can avoid this by mounting the panels in a deep "well" or box with black interior sides before taking the outdoor reading. Of course, overcast days will produce low readings due to clouds blocking some of the incoming solar radiation.

Set out materials at the workstations.

Tell students that they will be learning how to use a solar panel as a light intensity meter. Demonstrate how to connect the multimeter to the solar panel leads and how to set the scale for reading milliamps. Position the panel near a light source such as an incandescent lamp or overhead projector, and show that the meter reading changes as the panel is held closer or farther from the light. Encourage students to practice by recording the meter reading as they hold the panel at different distances from the light.

Once students are comfortable with recording, relate how they will plot light intensity (radiation) versus short circuit output current of the solar panel. Explain that they will need to record the current at different known levels of light intensity and plot the results on the graph. For this activity, they will use the midday solar intensity (on a clear day), the light intensity at a set distance from a 60-watt incandescent light bulb, and darkness. They should use the values of light intensity given in table 1.

Have students follow the instructions on their handout. Once all teams have finished, discuss the sources of error in this procedure.

Extension activity for those students ready for algebra:

Have students determine the slope-intercept equation for the calibration curve.

Light intensity (W/m^2) = slope x current (mA) + y-intercept

where slope = change in intensity / change in current
y-intercept = 0 W/m^2

Once this equation is determined, students can calculate the light intensity for any given level of current. Keep the calibration equation with each solar panel for use with other SPN Kit activities.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

The following values were measured using a mini–solar panel rated for 1V, 400 mA.

Date: July 31	mA	W/m^2 *
Midday, outdoor reading	317	1029
Reading 10 cm from a 60-watt bulb	66	300
Darkness	0	0

* from table 1

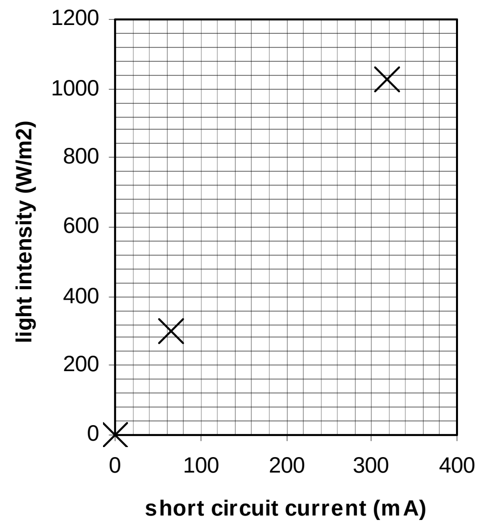

Figure 1: Calibration Curve

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This lesson is adapted from *Renewable Energy Activities for Junior High / Middle School Science*, prepared for the U.S. Department of Energy by the Solar Energy Project in cooperation with the New York State Education Department and SUNY Atmospheric Science Research Center, and also from *Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*, Thames & Kosmos, LLC, Newport, RI, 2001.

BACKGROUND INFORMATION

A solar cell's short circuit current is proportional to the number of photons absorbed by the cell.

The Sun delivers an average of 1,353 W/m^2 to the edge of Earth's atmosphere. This is known as the *solar constant*. Since the atmosphere reflects and absorbs some of this energy, the solar intensity at sea level is less—about 1,000 W/m^2 in the summer. The solar intensity at Earth's surface varies with the seasons. This variation is caused by the changing tilt of locations on Earth with respect to the Sun. Solar intensity at Earth's surface also varies with atmospheric conditions such as cloud cover and humidity.

REFERENCES FOR BACKGROUND INFORMATION

Exploring Solar Energy II: Activities in Solar Electricity. Allan Kaufman. Prakken Publications. 1995.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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.

Standard 3—Mathematics: Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.

Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data.

Key Idea 6: Students use ideas of uncertainty to illustrate that mathematics involves more than exactness when dealing with everyday situations.

Standard 4—Science: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Physical Setting

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

Standard 5—Technology Education: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms.

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Calibration Curve for a Radiation Meter

What does someone mean when they say “it is a bright day outside” or “that is a bright light”? How bright is “bright”? In this activity you devise a way to use a solar panel to measure how bright something is. To do so, you develop a calibration curve that will enable you to use a solar panel as a light intensity meter.

To do this, you plot on graph paper light intensity (W/m^2) versus a solar panel’s short circuit output current (mA) for three levels of known light intensity. This works because a solar cell’s short circuit current is proportional to the amount of light (number of photons) absorbed by the cell. Complete the following steps, using the values of light intensity given in table 1.

Table 1

	watts/meter^2
midday winter sun (Nov. 1 to Feb. 1)	868
midday fall or spring sun	952
midday summer sun (May 15 to Aug. 15)	1029
10 cm away from a 60 W incandescent bulb	300
darkness	0

Follow your teacher’s instructions on how to measure the short circuit output current of the solar panel.

1) Step outside and aim your solar panel at the Sun. Adjust the angle of the panel until the short circuit current reading is at its maximum. Record this value in your Calibration Data Table.

2) In the classroom, mount your solar panel on the vertical mount provided so it is centered at the height of the light bulb filament.

3) Turn on the light bulb and place a meterstick so its 0 mark is at the light bulb’s filament.

4) Place the solar panel at the 10 cm mark and turn the panel to face the light bulb directly. Measure the short circuit output current and record this value in your Calibration Data Table. Turn off the light.

5) Cover your solar panel so no light can get to the cells. Measure the short circuit output current and record this value in your calibration table.

6) Plot these three points on the graph paper provided.

7) Use a straightedge to connect, as closely as possible, all three points. The point *0 mA*, *0 W/m*^{2} should lie on the line; the other two points should lie as close as possible. Extend the line to the edge of the graph.

8) Consider some of the inherent sources of error in using this method to measure light intensity. Write down your ideas on a separate sheet of paper. Consider:

a) How might a nearby object such a snow-covered tree or a light-colored building affect your outdoor reading?

b) How might atmospheric conditions such as a hazy sky or scattered clouds affect your outdoor reading? How about an overcast sky?

c) Do all bright, clear summer, winter, spring, or fall days have the same level of light intensity as is shown in table 1?

d) Do all 60-watt light bulbs give off the exact same amount of light?

e) How would a slight change in the angle of the solar panel affect your results?

Calibration Data Table

Date: ______________	mA	W/m^2 *
Midday, outdoor reading		
Reading 10 cm from a 60-watt bulb		
Darkness		

* Fill in appropriate values from table 1.

To use the solar panel and calibration curve to find the intensity of a light source:

1) Measure the short circuit current.
2) Find that value on the horizontal axis.
3) Trace upward parallel to the vertical axis until you intersect the line.
4) Go left parallel to the horizontal axis until you reach the vertical axis.

The value at that point is the intensity of the light source.

Solar Kit Lesson #13
Solarize a Toy

TEACHER INFORMATION

LEARNING OUTCOME
After designing and constructing solar electric power sources for a selection of small electric toys, students are able to determine an electric toy or device's power requirements, design an alternate solar electric power supply, and appraise the effects of both variable lighting conditions and the size of the solar electric power supply on the operating performance of their toy or device.

LESSON OVERVIEW
Student working in teams

- select a low-power toy, game, or electrical device to "solarize," or convert to solar power;
- determine the operating voltage of their chosen device and design a solar array to provide this level of voltage;
- determine a series of conditions under which they will test their toy's performance and, if needed, adjust the size of their solar array to provide more current; and
- determine under what operating conditions their device draws the most power and evaluate how important it is to operate the device under these conditions.

GRADE-LEVEL APPROPRIATENESS
This Level II or III Physical Setting and technology education lesson is intended for use in physical science and technology education classes in grades 7–10.

MATERIALS
- At least sixteen 1 V, 400 mA mini–solar panels* with alligator clip leads
- Access to sunlight
- Toys selected by students
- Selection of DC power plugs and wire
- Student handout

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY

Do not let a student connect any toy or device directly to your school's AC power supply (a wall socket).

TEACHING THE LESSON

Preassignment: Divide the class into teams. Assign each team the task of identifying a DC-powered toy to solarize. Because of the small size of the mini–solar panels, each toy must either run on one or two AA batteries or operate at one to four volts with current requirements of less than 400 mA.

Procedure: Check the power requirements of the toys selected by students. Toys must all run on DC power. Because of the limited number of mini–solar electric panels available, make sure that the toys students select run on one to two watts. If a team has selected a toy that uses an AC adapter, help them find an appropriate DC power plug that can be wired to an array of mini–solar panels.

Distribute the student handout from *Solarize a Toy* and help student teams determine the operating voltage for their device. Hand out to each team the number of solar panels they need to produce the operating voltage for their device.

Have students write down a series of test conditions under which they want to test their toy. These should include adjusting lighting conditions, the size of their solar power arrays, and the operating conditions of the toy or device. Operating conditions refer to such variables as the level of backlit display, the level of volume, the speed of a toy car, or the ability of a small car to climb a ramp.

Teams should have access to direct sunlight to test their solarized toys.

Let students experiment with the amount of current that their solar arrays can provide. Hand out additional solar panels as needed. Teams may need to share limited numbers of panels between them as they experiment with higher current power supplies.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Test Conditions: Test conditions should fully exercise the device's functionality under reasonable lighting conditions. Lighting conditions should include reasonable long-term conditions, such as cloudy, hazy, or sunny days, as well as intermittent conditions, such as a short-term loss of sunlight.

Electrical Power Needs: Teams should correctly identify their device's operating voltage. Teams should connect an appropriate number of mini–solar panels in series to provide at least the operating voltage and no more than ½ volt above the operating voltage.

Teams should identify the minimum number of mini–solar panels needed to satisfactorily operate their device.

Performance of solarized toy: Teams should be able to describe in writing how well their device works with the various solar power supplies tested and under the various lighting conditions tested.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This lesson is not adapted.

BACKGROUND INFORMATION

Selection of Toys or Devices to "Solarize": Due to the low power output of the mini–solar panels and the limited number of panels, it will be most convenient to select toys or devices that run on one or two AA batteries or one to four volts and less than 400 mA DC power packs.

Maximum Power Needs of a Motorized Toy: To find the maximum power that will be drawn by an electric motor, multiply the measured current requirements when the motor is locked in place with the voltage specified by the power supply (battery pack or AC adapter).

To measure the current, place a small resistor (say 0.1 ohms) in series with the DC power supply and measure the voltage over this resistor when the motor is locked in place.

$$I_M = V_R/R = V_R/0.1$$

Where:
I_M = maximum current
V_R = voltage over the series resistor
R = series resistor

Maximum power (P_M) needed is

$$P_M = V_P * I_M$$

Where:
I_M = maximum current
V_P = voltage of power supply

Limiting Current Supply to a Motorized Toy: In situations where a motor does not need to produce a high level of torque, the motor's requirements for current during steady state operation are significantly less than at start-up. Because of this, a toy or motorized device may operate satisfactorily with an underpowered power supply, although it will take longer for the motor to come up to the steady state speed.

Encourage students to experiment with different power supplies recording how the toy performs with each.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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.

Scientific Inquiry 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. (intermediate)

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. (intermediate)

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

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

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints. (intermediate)

Key Idea 2: Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms. (commencement)

Key Idea 4: Technological systems are designed to achieve specific results and produce outputs, such as products, structures, services, energy, or other systems. (intermediate and commencement)

Key Idea 5: Technology has been the driving force in the evolution of society from an agricultural to an industrial to an information base. (intermediate)

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Solarize a Toy

Before you try to solarize a toy or electrical device, let your teacher check whether your selection runs on direct current (DC). If it does not, you will have to select a different device. Converting the direct current (DC) provided by a solar panel to alternating current (AC) goes beyond the scope of this activity.

Test Conditions:
Write down a series of conditions under which to test your device. These should include various lighting conditions and the operating conditions of the device.

Lighting conditions refer to the brightness and consistency of a light source. Think about long-term conditions, such as cloudy, hazy, or sunny days, as well as intermittent conditions, such as a short-term loss of sunlight.

Operating conditions may refer to such items as the brightness level of a backlit display, the level of volume, the speed of a toy car, or the ability of a small car to climb a ramp. Determine the operating conditions that pertain to your device.

After designing a solar power supply for your device, you will test your toy or device under these different conditions and write down how well your device performs in each situation.

Electrical Power Needs:
Determine the electrical power needs of the toy, game, or electrical device you have chosen to solarize.

Toys that require batteries

A. **Operating Voltage:** Determine the operating voltage from the number of batteries connected in series required by the device. Determine the number of mini–solar electric panels connected in series that are required to produce this voltage. If you need to exceed the normal operating voltage, do not do so by more than ½ volt.

B. **Operating Current:** Begin with a chain of panels connected in series so as to obtain the required operating voltage. Use this power supply to run your device. Test your toy or device under these conditions and write down how well your device performs under each test condition you have specified.

   If your device seems to be underpowered, add a second chain of mini–solar panels connected in parallel with the first chain. Again, record how well your device works at this increased power level. If your device still seems underpowered, add additional chains of mini–solar panels connected in parallel with the previous chains. Each time, write down how well your device responds to the different test conditions.

Toys that use motors

Motors draw their highest current when they are increasing speed (rpm) or are working to overcome a force that is working to slow them down. For applications where the motor is often changing speed or is often working to overcome a force (such as a toy electric car running up a steep ramp), the need to provide this high level of current may be critical to the satisfactory operation of the device. In cases where this type of performance is not required, it may be acceptable to reduce the level of current available to the motor. This may allow you to reduce the number of solar panels in parallel needed to power the device.

Toys with AC adapters—those black "bricks" that plug into electric wall sockets

Some toys include AC adapters that convert the AC power provided by an electric wall socket into the DC power needed to operate the toy or device. The DC power is generally provided to the device through a thin cable with a round electric jack known as a DC power plug that plugs into the device. The DC operating voltage and current are often specified on the AC adapter or on the device itself where the DC power plug plugs into the device.

A. **Operating Voltage:** Determine the number of mini–solar electric panels connected in series that are required to produce the specified voltage. If you need to exceed the normal operating voltage, do not do so by more than ½ volt.

B. **Operating Current:** Determine the number of mini–solar electric panels connected in parallel that are required to produce the specified current. It is OK to provide more current than specified because the device will not draw more current than it needs. On the other hand, this may end up using more solar panels than you need to.

   You may want to begin with one chain of panels and see how well your device works. Test your toy or device and write down how well your device performs under each test condition you have specified.

   If your device seems to be underpowered, add a second chain of mini–solar panels connected in parallel with the first chain. Again, record how well your device works at this increased power level. If your device still seems underpowered, add additional chains of mini–solar panels connected in parallel with the previous chains. Each time, write down how well your device responds to the different test conditions.

Minimizing power requirements

Try to determine which function of your device uses the most power. Is this function critical to the satisfactory operation of the toy? Can this function be turned off or turned down in order to reduce the power requirements of your device?

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Solar Kit Lesson #14
Solar Cells as Control Devices

TEACHER INFORMATION

LEARNING OUTCOME
Students complete a design project using a solar cell as a control device or as part of a feedback circuit.

LESSON OVERVIEW
Students identify, research, design, construct, test, and evaluate a device whose function is to respond in some way to changes in the intensity or the direction of sunlight. This device must demonstrate a design concept that could be used in a real-world, practical application.

GRADE-LEVEL APPROPRIATENESS
This Level III Educational Technology lesson is intended for use in technology education classes in grades 11–12.

MATERIALS
Materials needed may vary greatly as this is an open-ended design project.

- Small electric motor attached to a small fan blade
- One or two 400 mA, 1V mini–solar electric panels* per workgroup depending on design project

* Available in the provided Solar Education Kit; other materials are to be supplied by the teacher. Any materials supplied by students must be examined by the teacher before they are used.

SAFETY
Safety considerations, if any, will vary depending on design projects selected by students.

TEACHING THE LESSON
Preparation:
Connect a mini–solar electric panel to a motor having an attached fan blade.

Fill in due dates on each step of the student handout and make sufficient copies for all student teams. Alternatively, have students plan their own work schedule, in which case they would fill in the due dates on their own handout.

Suggested Approach:
Show students that a solar cell can be used as a switch by demonstrating the solar-powered fan. Explain that, in this case, the fan can be used for cooling when the Sun is shining. Also show that in addition to providing the circuit with power, the solar panel can act as a switch to turn the device on or off under desired conditions.

Challenge each team to demonstrate a design concept that could be applied to a practical, real-world application. Students may come up with their own ideas for design concepts or choose from the four suggestions provided in the student handout. Approve any student-proposed design concepts or student-provided materials before allowing the construction phase to begin.

Have students work in teams to accomplish the tasks described on the student handout.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Although a satisfactory level of detail, clarity, neatness, and completeness is required for each step of the design process, it is more important that the approach to each step enables the teacher and the student teams to communicate in a way that helps guide students to a successful completion of the design.

Step 1: Students complete notes and drawings to a satisfactory level of detail, clarity, and neatness for the skill level of the class. Sources are cited.

Step 2: For each test, students prepare a step-by-step description that includes details on the position of the device being tested, the level of light required, and the position of the light source with respect to the device.

Step 3: Students complete schematics and drawings to a satisfactory level of detail, clarity, and neatness for the skill level of the class.

Step 4: Students prepare a list of parts that are available at the school or can be obtained using school resources.

Step 5: This step will entail the iterative design process of construction, testing, redesign, reconstruction, and retesting. Students provide documented changes to their original ideas with notes, schematics, and/or drawings completed to a satisfactory level of detail, clarity, and neatness for the skill level of the class.

Step 6: Students give a clear presentation or demonstration that includes the team's conclusions on the success of their design, suggestions on modifications for improvement, and information on how to apply the design concept to a real-world application.

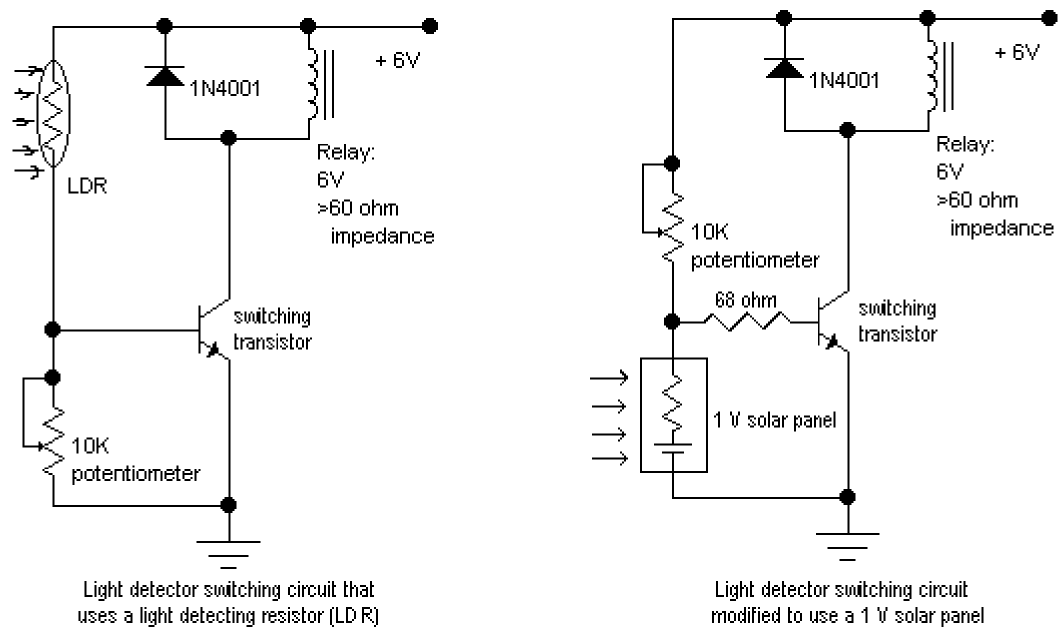
ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This is not an adapted lesson.

BACKGROUND INFORMATION

Photodiodes, phototransistors, or photoresistors are the optoelectronic (solar electric) devices typically used in circuits requiring a light sensor. During their research, students will most likely find examples of circuits that use these devices and will have to modify the circuits, or design their own circuit, to instead use mini–solar panels.



Example of a light-detecting switching circuit modified to use a 1 V solar panel instead of a photoresistor.

Photodiodes, phototransistors, and photoresistors only change electrical resistances when exposed to light versus dark conditions. Solar cells also provide a power source when exposed to light. In the example shown above, under dark conditions the solar panel's low resistance shorts the transistor's base to ground and shuts off the relay. When light falls on the solar panel, it produces a high enough voltage to saturate the transistor and turn the relay on. Note that a 68-ohm current limiting resistor was added to the base of the transistor.

Sample Design Rubric

Following is a sample rubric (from New York State Curriculum for Advanced Technology Education) that you may want to use with your students. If so, copy it and go over it with them ahead of time so that they are aware of your evaluation criteria. If you know the students are unfamiliar with the informed design process, copy pages 5 and 6 and have them complete "The Informed Design Cycle" activity (from New York State Curriculum for Advanced Technology Education). Some students may have been involved in design projects before, but keep in mind that informed design stresses avoiding trial-and-error methods by researching and investigating a topic before and during design and construction. The cycle of steps can provide a general guide for student work as well, should you choose to take a less structured approach.

RUBRIC FOR SOLAR KIT LESSON

The Design Solution

A. An accurate sketch of your final design, as built, was drawn.

4. Drawing was on graph paper to scale with all elements included. Isometric view or multiple views (top, side, and front) were shown.
3. Drawing was on graph paper to scale with all elements included. Drawing showed the design in two dimensions (a flat view).
2. Drawing was on graph paper approximately to scale with most elements included.
1. Drawing was not to scale and important elements were missing.

B. Materials and tools were planned and used appropriately in constructing project.

4. Listed materials and tools are present, as well as a description of how they should be used.
3. Prepared complete list of materials required and tools necessary to fabricate with these materials.
2. List of materials was essentially complete; some tools required were not mentioned.
1. Mentioned only a few materials and no tools.

C. The solution worked. It met the design specifications and constraints.

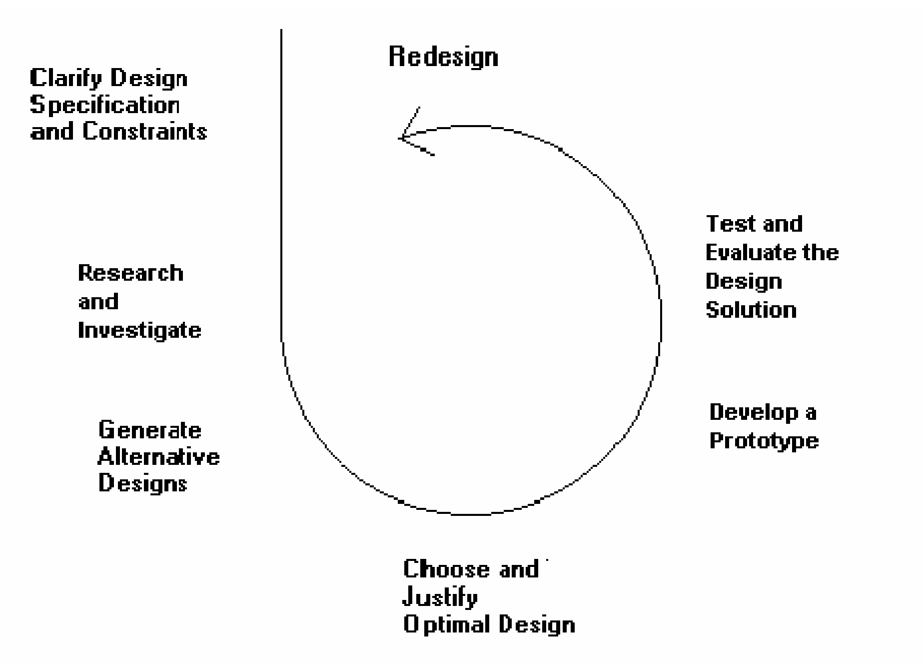
4. The solution solved the problem statement; this was explained in the write-up along with how the specifications and constraints were addressed and/or how the design was modified to assure their being met.
3. The solution solved the problem statement and the constraints and specifications were met.
2. The solution solved the problem but not all constraints and specifications were met in doing so.
1. The solution did not solve the problem; constraints and specifications were not met.

D. The design was creative.

4. The solution was unique; never or seldom has this design been formulated.
3. The solution was functional, but not unique. Similar solutions were common.
2. The solution was similar to others; it may have been a modification or interpretation of someone else's solution.
1. The solution appears to have been copied from someone else's work.

The Informed Design Cycle

A method is shown (see informed design loop below) to achieve informed technological design. The cycle includes several phases. In this model, the phases together are referred to as the design cycle. The model involves repeatable phases that engage you in the design process.



You are to work in a manner similar to that of adult professionals who do engineering design for a living. Engineers and other designers rarely follow these phases in order. Instead, they move back and forth from one phase to another as needed. You also are not expected to go through the phases in the same order each time you design something. Additionally, some decisions are made without complete knowledge and as a result phases must be revisited later on. The designer arrives at solutions, monitoring performance against desired results and making changes as needed. Usually, following design criteria leads to trade-offs taking place. Seldom is true perfection obtained.

Further information on the phases of the informed design cycle follows:

- *Clarify design specifications and constraints.* Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements the solution must meet.

- *Research and investigate the problem.* Search for and discuss solutions that presently exist to solve this or similar problems. Identify problems, issues, and questions that relate to addressing this Design Challenge.

- *Generate alternative designs.* Don't stop when you have one solution that might work. Continue by approaching the challenge in new ways. Describe the alternative solutions you develop.

- *Choose and justify optimal design.* Defend your selection of an alternative solution. Why is it the optimal choice? Use engineering, mathematical, and scientific data, and employ analysis techniques to justify why the proposed solution is the best one for addressing the design specifications. This chosen alternative will guide your preliminary design.

- *Develop a prototype.* Make a model of the solution. Identify possible modifications that would lead to refinement of the design, and make these modifications.

- *Test and evaluate the design solution.* Develop a test to assess the performance of the design solution. Test the design solution, collect performance data, and analyze the data to show how well the design satisfies the problem constraints and specifications.

- *Redesign the solution with modifications.* In the redesign phase, critically examine your design and note how other students' designs perform to see where improvements can be made. Identify the variables that affect performance and determine which science concepts underlie these variables. Indicate how you will use science concepts and mathematical modeling to further enhance the performance of your design.

Develop your understanding

1. Review the informed design cycle and explain how you might use the various phases to guide your design efforts. Identify any procedural changes you would add, delete, or change. Defend your recommendation(s).

2. Pick one example of a product or system that was poorly designed. Explain possible reasons why the manufacturer might have allowed it to be produced with design flaws. Explain consequences (both positive and negative) that might result from a less-than-optimal design.

3. Provide an example of a product or system that you think could benefit from an improved design.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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.

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

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.

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

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.

Standard 5—Technology: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints.

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.

Systems Thinking 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.

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

Equilibrium and Stability Key Idea 4: Equilibrium is a state of stability due either to a lack of changes (static equilibrium) or a balance between opposing forces (dynamic equilibrium).

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Strategies Key Idea 2: Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.

Produced by the Northeast Sustainable Energy Association in coordination with the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Solar Cells as Control Devices

The challenge for your team is to use a mini–solar panel to demonstrate a design concept that could be applied to a practical, real-world application.

Step 1: Carry out an investigation using such sources as the Internet* and a library to determine how others may have accomplished tasks similar to those described in the table below. Document your findings through notes and drawings and cite your sources. Then, select one of the following design concepts to implement, or propose one of your own. You will need to obtain your teacher's approval of any personally proposed design concepts.

Design Concept Your design concept must use a mini–solar panel as a light sensor, switch, and/or part of a feedback circuit in a device that can:	**Potential Application** Each design concept must be useful in demonstrating a practical real-world application such as:
1) Turn a light off under bright conditions and turn it on under dark conditions.	Automatically turn a street lamp on at dusk and off at dawn.
2) Cause a light to dim as the room grows brighter and cause a light to brighten as the room grows dimmer.	Automatically adjust the brightness of room lights depending on the level of natural light available from a window.
3) Keep an object facing a light source such as the Sun as the light source moves.	Keep a PV (solar electric) array facing the Sun throughout the day.
4) Hold an object in one position under bright light conditions and in a second, different, position under dim or no-light conditions.	Open window shades under bright outdoor conditions and close them under dim outdoor conditions.
Describe in writing other design concepts you can think of.	*Describe a practical real-world application that could use each design concept you describe.*

*Search on terms such as *hobby* and *circuit* together to find likely sources of circuits on the Internet.

Step 2: Develop a detailed test or set of tests to run on a device designed to demonstrate your chosen design concept. Include specific descriptions of how to position a device being tested, what level of light is required, and how to position the light source with respect to the device.

Due date ________________

Step 3: Generate ideas on how to construct a device that will demonstrate your chosen design concept. Select a potential solution and develop a set of schematic(s) and drawing(s) of your proposed device. Your solution must be one that can be constructed in a classroom setting.

Due date ________________

Step 4: In consultation with your teacher, develop a parts list and a plan for obtaining the materials necessary to construct the proposed design. Obtain the required materials.

Due date ________________

Step 5: Construct and test your design using the test(s) developed in step 2. Document changes to your original ideas with notes, schematics, and/or drawings. Record and portray graphically and/or through a written report the test results so as to show the level of success of the design.

Due date ________________

Step 6: Prepare and give a presentation or demonstration of the design. This must include your conclusions on the success of the design, suggestions on modifications for improvement, and information on how to apply your design concept to a real-world application.

Due date ________________

Solar Education for NY
SchoolPower ...Naturally

Solar Kit Lesson #15
Solar-Powered Electrolysis of Water and the Hydrogen Economy

TEACHER INFORMATION

LEARNING OUTCOME
After producing hydrogen and oxygen gases through the electrolysis of water and studying the process, students realize that hydrogen can act as an energy carrier and that as an energy carrier it has many properties that are useful to humankind.

LESSON OVERVIEW
Students complete a short reading on hydrogen as an energy carrier, and use solar electric panels to produce hydrogen and oxygen gases from the electrolysis of water. They then test for the presence of flammable gases and propose and balance the chemical reaction for the process of the electrolysis of water.

GRADE-LEVEL APPROPRIATENESS
This Level III Physical Setting lesson is intended for use in chemistry and technology education classrooms in grades 10–12.

MATERIALS
Per work group
- beaker (250 ml)
- two aluminum electrodes (electrical tape and 8 cm long, small-diameter aluminum rods)
- metric ruler
- two small test tubes (13 x 100 mm to 18 x 150 mm) or (10 mL to 20 mL).
- five 1 V, 400 mA mini–solar panels* mounted on a board
- two pieces of wire (30–40 cm)
- stirring rod
- candle
- wooden splint
- matches
- ring stand
- two clamps
- graduated cylinder (10–20 mL)
- teaspoon
- two teaspoons of sodium carbonate (washing soda) or sodium bicarbonate (baking soda)
- safety goggles
- clear plastic tape (optional)
- grease pencil
- water and paper towels

* Available in the provided Solar Education Kit; other materials are to be supplied by the teacher

SAFETY
As with all lab work, try this lab yourself before having the students perform it. Hydrogen gas is explosive and oxygen gas can promote rapid burning of flammable materials. The amount of hydrogen and oxygen gases produced in this lab, however, is small enough that there should be no safety hazard. To be on the safe side, instruct students not to displace so much water that bubbles begin to escape from the test tubes. This will reduce opportunities for the mixing of the two gases. Have students wear safety goggles during the lab work.

The amount of hydrogen gas produced when ignited will explode, making a “pop” or “whoosh” sound. If large test tubes are used (this will produce a larger explosion of hydrogen gas), wrap the tubes first in clear plastic tape.

TEACHING THE LESSON
Preparation: For each lab setup, use double-sided tape to attach five mini–solar panels to a piece of wood or cardboard roughly 125 cm by 15 cm.

Prepare two aluminum electrodes for each lab setup. For each electrode, bend an aluminum rod into a j-shape with the turned end bent up far enough to form the bottom of the j at the end of the rod. Wrap tightly with electrical tape all except 5 mm of the two ends of the aluminum rod.

Suggested Approach: The Solar Kit contains sufficient mini–solar panels to run three lab setups at a time. Because of this, you should run this lab each time with six to nine students divided into three teams that investigate while the remainder of the class is occupied with other projects such as completing the required reading.

Alternatively, the electrolysis lab can be conducted as a class demonstration with limited student participation. If that approach is used, the rate of electrolysis can be increased by using all 16 solar panels at once. Connect pairs of panels (eight pairs in all) in parallel. Then connect the eight pairs in series to produce an 8-volt, 800 mA digital power source.

Before beginning the lab work, conduct a discussion to find out what your students already know about the topics hydrogen power, “hydrogen economy,” and fuel cells. Then have students bring in and share news articles and other information from books, newspapers, magazines, TV, and the Internet that pertain to these topics. Distribute the student reading, “Hydrogen: An Energy Carrier,” or assign that reading for homework. When students have completed the reading, discuss as a class what they have learned about hydrogen from the assigned reading and the other sources they obtained.

Distribute the lab instructions, “Solar-Powered Electrolysis of Water,” to the first three student teams and have students follow the instructions. Supervise and assist students as needed during the investigation. Repeat as needed when the remaining students perform their lab work.

Follow-up Discussion: Go over with students the overall and simplified chemical equations for electrolysis of water. Elicit from them why this process produced H_2 at twice the rate it produced O_2.

Discuss the tests for the two gases, one resulting in an explosive sound and the other in increased flammability. See that students can not only identify test results for each gas, but also why each produces its particular outcome.

Find out whether any students can cite from their pre-lab research other methods for producing hydrogen. If they can't do so, relate for them how hydrogen is produced commercially today.

Describe why hydrogen might someday become the ideal and predominant energy carrier.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION
Students should be encouraged to accurately follow directions for all steps of the procedure.

Step 8: **Observation:** Bubbles form on both electrodes. The negative electrode appears to be more reactive yet produces smaller bubbles than the positive electrode.
Analysis: Students may correctly infer that in order to give off hydrogen, water must be reduced and the negative electrode is supplying the electrons necessary for that process to take place.

Step 13: **Observation:** Students hear a "pop" or "whoosh" sound and see a flash of flame inside the test tube.
Analysis: Since hydrogen is the only explosive gas that could be produced, this test confirms that hydrogen is produced at the negative electrode.

Step 17: **Observation:** Students see the splint glow brighter for a moment. The splint may even burst briefly back into flame.
Analysis: The presence of high concentrations of oxygen promotes more rapid oxidation (burning) of the splint material. The gas collected should be inferred to be oxygen.

Step 18: **Observation:** By volume, twice as much hydrogen as oxygen is produced.
Analysis: Students can surmise that in this electrolysis procedure, all of the hydrogen and oxygen atoms in a water molecule are released as hydrogen gas and oxygen gas. Since there are twice as many hydrogen atoms as oxygen atoms per molecule of water, twice the volume of hydrogen gas was produced, as expected.

Step 19: $2\ H_2O \rightarrow 2\ H_2 + O_2$

Step 20: Radiant energy → [solar cell] → electrical energy → [water] → chemical energy

Through the photovoltaic effect, the energy of solar radiation is converted into electrical energy. Through electrolysis, electrical energy is converted into chemical energy stored in hydrogen gas.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

The electrolysis of water lab is adapted from *Hydrogen: An Energy Carrier*, Chris Mason, Northeast Sustainable Energy Association, 2004, and from the following lesson plans from the World Wide Web:

- *Electrolysis of Water* at the Siraze Chemistry Club website, www.chemistry.lmt.md
- *Electrolysis of Water and Salts* at the Collaborative Pre-University Science Projects website, www.science-projects.com
- *Electrolysis of Water* at the Resources For Chemistry Teachers and Students website, http://129.93.84.115/#NSF.

BACKGROUND INFORMATION

Hydrogen: The U.S. government lists hydrogen as an alternative fuel for transportation even though very little hydrogen gas (H_2) exists naturally on Earth. Hydrogen (H), however, is the most abundant *element* in the universe. It is

- a major component of biomass, making up about 14% by weight of such carbon-based organic materials;
- one of two primary components of water (H_2O); and
- the 10^{th} most abundant element in Earth's crust, where it is mainly present in water (H_2O), but also is present in such hydrocarbons as coal, petroleum, and natural gas.

For information on the abundance of hydrogen, see John Emsley, *Nature's Building Blocks*, Oxford University Press. 2001.

Electrolysis: Electrolysis is a process by which a chemical reaction is carried out by means of the passage of an electric current. For the electrolysis of water, water is oxidized at the anode (positive) and reduced at the cathode (negative).

In the electrolysis of water, the reaction at the cathode is:
$4H_2O + 4e- \rightarrow 2H_2 + 4OH^-$
The reaction at the anode is:
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$
The net reaction is:
$6H_2O \rightarrow 4OH^- + 4H^+ + 2H_2 + O_2$
The simplified balanced chemical reaction is:
$2 H_2O \rightarrow 2 H_2 + O_2$

This last equation reveals why the rate of hydrogen gas production is twice that of oxygen during the electrolysis of water. Be aware that hydrogen is much less dense than air. This becomes important when students cover the test tubes to prevent gas from escaping. Accordingly, the tubes should be held up-side-down rather than upright. Oxygen is slightly more dense than air, but, for simplicity sake, both test tubes can be held up-side down.

Given the contents of the water molecule, the only possible explosive gas that can form is hydrogen.

Production of Hydrogen: The United States produces approximately three billion cubic feet of hydrogen gas annually. The most common source for hydrogen production is natural gas. Natural gas is heated in the presence of steam to around 1,000^oC ($CH_4 + H_2O \rightarrow 3\ H_2 + CO$). In a second reaction using steam, the carbon monoxide and water are converted into carbon dioxide and hydrogen, ($H_2O + CO \rightarrow CO_2 + H_2$).

Passing steam over red-hot coals produces a mixture of equal parts hydrogen and carbon monoxide. This mixture is known as synthesis gas, a useful fuel that can be converted into methanol. Ethanol reacts with water in the presence of a rhodium catalyst, producing hydrogen and some heat. The electrolysis of water is not yet an economical process, although it has been suggested as a feasible way to store the energy from excess electricity derived from nuclear power plants or hydroelectric dams.

Hydrogen also can be obtained from some kinds of bacteria and algae—the ones that give off hydrogen as they ferment the sugar glucose producing acetic acid.

Using Solar Energy to Produce Hydrogen: When steam is "superheated" to about 1,400^oC, the water molecule literally begins to break apart into hydrogen and oxygen. This can be accomplished by mirrors focusing sunlight on a single location wherein steam is present. This method currently is considered impractical because of the amounts of energy needed to initiate the process and the expense of producing special containers that can withstand such high temperatures.

When water is heated to 300^oC–1,000^oC in the presence of powdered iron oxide, the iron rusts, tying up the oxygen and leaving behind hydrogen gas. This process also can be brought about by the focusing of sunlight by mirrors. The focused light reaches a location containing water and, in this case, powdered iron oxide. This method is considered practical because the production temperature for it is relatively low.

Electrolysis of water can be accomplished by passing DC current from a solar electric panel through an alkaline solution. Although this is not yet an economical process, improvements achieved include such methods as

- the electrolysis of steam inside porous electrodes of zirconium oxide
- the use of fuel cells for achieving electrolysis

The latter method is a newly rediscovered technology having potential efficiencies of 80%–90% and corrosive alkaline solutions are not necessary for this process to occur.

For additional information on producing hydrogen from solar energy sources, refer to Francisco Fantes, *Solar Hydrogen Energy: Mining the Oceans for the Holy Grail*, Winter 2003 issue of Harvard Science Review, *Climate and the Environment*, Vol. 16, No. 1. September 2002–January 2003. http:/hcs.harvard.edu/~hsr/winter2003.html

REFERENCES FOR BACKGROUND INFORMATION

John Emsley, *Nature's Building Blocks*, Oxford University Press. 2001.
Francisco Fantes, *Solar Hydrogen Energy: Mining the Oceans for the Holy Grail*, Winter 2003 issue of Harvard Science Review, *Climate and the Environment*, Vol. 16, No. 1. September 2002–January 2003. http:/hcs.harvard.edu/~hsr/winter2003.html

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

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.

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

Standard 4—Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

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

Standard 5—Technology Education: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Key Idea 6: Technology can have positive and negative impacts on individuals, society, and the environment and humans have the capability and responsibility to constrain or promote technological development.

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(STUDENT HANDOUT SECTION FOLLOWS)

A Reading

Hydrogen: An Energy Carrier

The U.S. government lists hydrogen as an alternative fuel for transportation even though very little hydrogen gas (H_2) exists naturally on Earth. Hydrogen (H), however, is the most abundant *element* in the universe. It is

- a major component of biomass, making up about 14% by weight of such carbon-based organic materials;
- one of two primary components of water (H_2O); and
- the 10^{th} most abundant element in Earth's crust, where it is mainly present in water (H_2O), but also is present in such hydrocarbons as coal, petroleum, and natural gas.

Energy is required to isolate hydrogen, in the form of hydrogen gas (H_2), from the elements present on Earth that combine chemically with H. Once separated, hydrogen gas has the potential to release energy in a controlled and useful manner. Because of this, it is said that hydrogen acts as an energy carrier; much of the energy used to produce hydrogen gas can later be extracted in a separate location for a useful purpose.

Many scientists/technologists believe hydrogen gas is likely to be the clean fuel of the future. When burned, it produces only heat and water resulting in almost no pollution. When fed into a fuel cell along with oxygen, the fuel cell produces electricity, water, and heat—no dangerous emissions. The U.S. space program has made use of this technology for decades to supply both electric power for spaceships and drinking water for crews.

Hydrogen gas and the useful energy it contains, when used as an energy source, are potentially

- storable
- transportable
- pollution-free
- useful in transportation systems, homes, and industry.

Also, hydrogen gas can be produced from a wide selection of abundant resources including biomass, water, and hydrocarbons. Yet, scientific and technological advances in storage, transportation, and fuel cell technologies will be needed before hydrogen gas can be economically used on a widespread basis.

How environmentally friendly hydrogen power ultimately will be is heavily dependent on where the hydrogen gas is obtained and what energy source is used to obtain it. For example, when hydrogen is obtained from a fossil fuel, a powerful greenhouse gas (carbon dioxide) is released. On the other hand, when hydrogen is obtained from water, it is the gas oxygen that is released

When fossil fuels are used as an energy source to isolate hydrogen gas, the process produces the same harmful emissions that we are familiar with today. The amount of emission, however, may be reduced if the production, transportation, and use of hydrogen gas turns out to be more efficient than the production, transportation, and use of a petroleum product such as gasoline or heating oil. Alternatively, when a renewable energy source such as solar electric, hydro, or wind power is used to isolate hydrogen gas, there are almost no emissions, although there are other environmental impacts that certainly should be considered.

Name ___________________________________

Date ____________________________________

Solar-Powered Electrolysis of Water

In this investigation you experience a way to use solar electric power to isolate hydrogen (and oxygen) from water. You make use of the process known as electrolysis.

Vocabulary terms:

Electrolysis (e·lec·trol·y·sis) n. The decomposition of an electrolyte by an electrical current.

Electrolyte (e·lec·tro·lyte) n. Any substance which in solution or in a liquid form ionizes to produce an electrically conductive medium.

In electrolysis, electricity is applied to a liquid electrolyte by means of metals called electrodes that are immersed in the liquid. In this investigation the electrolyte used is water.

Most tap water conducts electricity poorly because tap water contains very few positive and negative ions; it is a very weak electrolyte. To increase conductivity, you add a small amount of sodium carbonate (Na_2CO_3) to the tap water. Sodium carbonate molecules dissolve in water into charged particles called ions. An ion having a negative charge, such as CO_3^{-2}, is called an anion because it moves through its solution to the positive charge on the anode. A particle having a positive charge, such as Na^+, is called a cation. It moves through the same solution to the cathode.

PROCEDURE

1. Fill the beaker half full of water.

2. Add a teaspoon of sodium carbonate to the water and help dissolve it by stirring the resulting solution.

3. Completely fill the test tubes with water from the beaker. Close the mouth of the first test tube, using a finger to prevent air from entering the test tube, and invert the tube into the remaining water in the beaker. Leave the tube inverted in the water. Repeat the procedure for the second test tube.

4. Hook the bottom of the j-shaped electrodes into the mouths of the test tubes.

5. Using the clamps, secure each test tube and electrode in place. See that the mouths of the test tubes are located below the surface of the water in the beaker and the electrodes are hooked in the mouths of the test tubes.

6. Connect five 1 V, 400 mA mini–solar panels in series and place them facing the sun in direct sunlight.

7. Use the alligator clips and extra wire to connect the positive lead (red) of the string of solar panels to one electrode and the negative lead (black) to the other.

8. Observe and record the changes that take place on the surface of the electrodes. What do you infer has been forming at

   - the cathode or negative electrode (black wire)?

   - the anode or positive electrode (red wire)?

9. Continue until you notice that one of the test tubes is 2/3 full of gas, and then disconnect the solar panels from the electrodes.

Throughout the next step, make sure the mouths of the test tubes remain below the surface of the water within the beaker.

10. Loosen the clamp holding one of the test tubes and electrodes. Position the tube up or down so the meniscus inside the tube is even with the level of the liquid in the beaker. Using a grease pencil, mark the position of the meniscus. Reposition the test tube and electrode, retightening the clamp. Repeat the procedure for the second test tube.
11. Reconnect the solar panels and continue electrolysis. Make sure to connect the negative and positive wires to the same electrodes as originally. Continue to collect gas until one of the test tubes is just about full of gas, and then disconnect the solar panels from the electrodes.
12. Position a lighted candle next to your setup. Slip your finger under water and cover the opening of the full-of-gas tube to stopper it. Release the clamp holding that tube and lift the tube out of the water. Towel off most of the water on the outside of the tube and on your hand.

The next step is best completed in a somewhat darkened room.

13. Keeping the test tube positioned mouth down, remove your finger as a stopper and slowly move the mouth of the test tube over the candle flame. Observe what happens. Record what you see and hear. Was the gas in the tube explosive? What caused you to reach this conclusion? If you observed that the gas was explosive, use a grease pencil to mark the test tube with the letter *E* for explosive.
14. Fill the test tube with water and add a pinch of sodium carbonate. Close the mouth of the test tube with your finger and invert it into the water in the beaker. Secure the test tube and electrode as before.
15. Reconnect the solar panels to continue the electrolysis. Make sure to connect the negative and positive wires to the same electrodes as before. Continue the gas collection until the second test tube is more than 2/3 full of gas, and then disconnect the solar panels from the electrodes.

16. As before, slip your finger under water and cover the opening of the second tube to stopper it. Release the clamp holding the second tube and lift the tube out of the water. Let the last of the water in the tube slip out by loosening your finger slightly. Towel off most of the water on the outside of the tube and on your hand. Label the tube.

17. Light the wooden splint and then blow out the flame present on the splint. Immediately insert the glowing splint into the test tube and observe what happens. Record what you see and hear. What gas do you infer caused this reaction? What caused you to come to this conclusion?

18. Remove and empty both test tubes. Fill each test tube with water up to the grease pencil mark. Using the graduated cylinder, measure the volume of water in each test tube. By volume, what ratio (larger volume to smaller volume) do the two gases form? What conclusions do you draw on the basis of this ratio?

At the negative electrode, there were two elements that might be reduced, H^+ to H_2 and/or Na^+ to Na°. If the gas H_2 is produced it bubbles away, and if Na° is produced, it reacts with water to form H_2 and soluble NaOH. So at the negative electrode, it always has to be the gas H_2 that is seen bubbling up.

At the positive electrode, the carbon in carbonate cannot be oxidized any more than it already has been oxidized. So, the only oxidation product possible is from O^{-2} becoming the gas O_2. The oxygen gas essentially bubbles away because of its low solubility in water (8ppm).

19. Write the balanced simplified chemical reaction for the electrolysis of water.

20. Draw a diagram, and provide written explanations, of the energy conversions carried out in this investigation.