PHOTOVOLTAICS

Teacher Guide

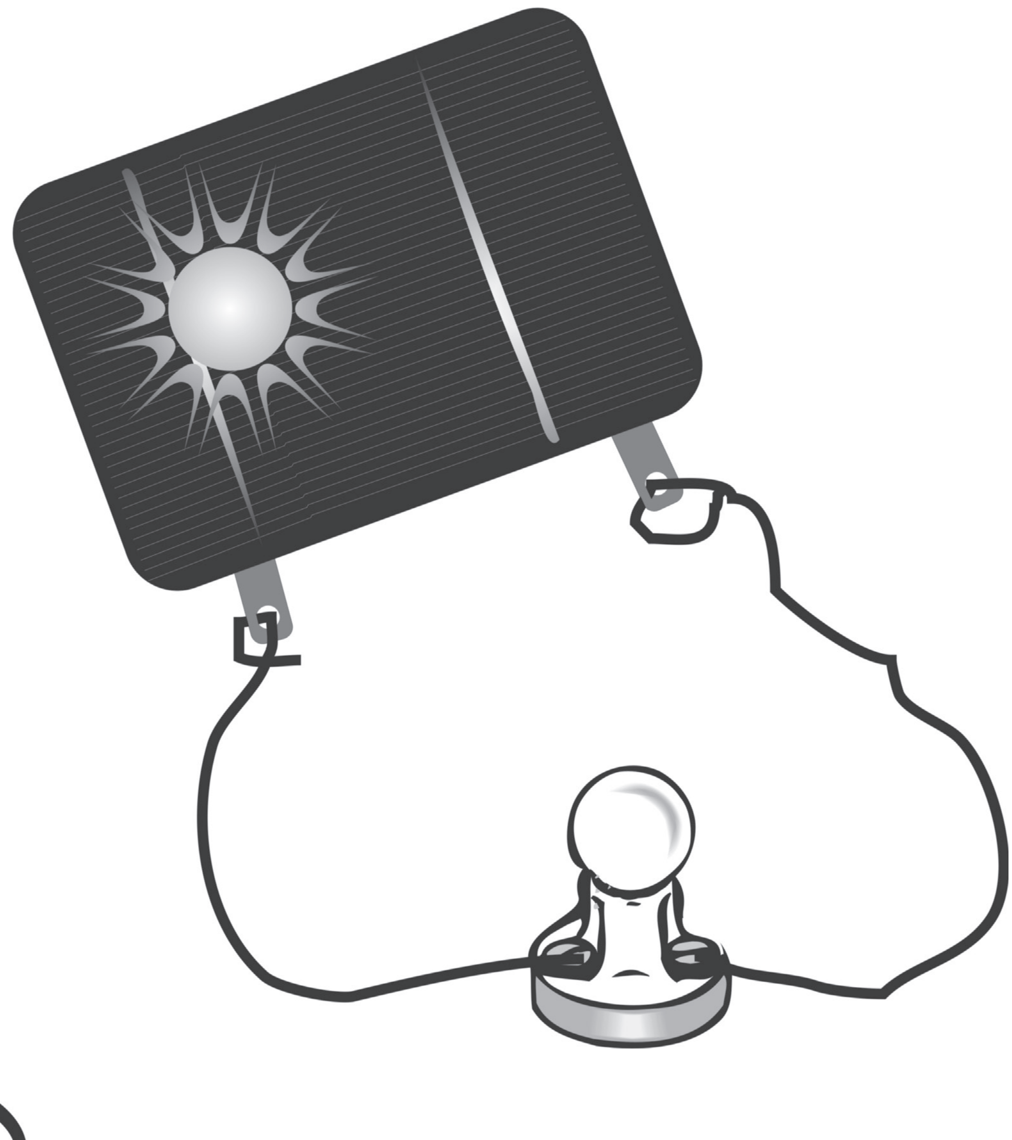
Hands-on explorations that teach scientific concepts of solar energy and photovoltaics to secondary students.

GRADE LEVEL

Secondary

SUBJECT AREAS

Science
Social Studies
Math
Language Arts



NEED

2006-2007

Putting Energy into Education

NEED Project PO Box 10101 Manassas, VA 20108 1-800-875-5029 www.NEED.org

Teacher Advisory Board

NEED Mission Statement

The mission of the NEED Project is to promote an energy conscious and educated society by creating effective networks of students, educators, business, government and community leaders to design and deliver objective, multi-sided energy education programs.

Teacher Advisory Board Vision Statement

In support of NEED, the national Teacher Advisory Board (TAB) is dedicated to developing and promoting standards-based energy curriculum and training.

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MATERIALS NEEDED

6 AA, C & 9-Volt Batteries
6 Protractors
6 Lab Thermometers
6 Reflecting Lamps*
6 Tape Measures

** Reflecting lamps are optional but helpful if you have limited time to conduct the unit and don't want to depend on the cooperation of the sun. If you plan to use lamps, have 60W and 40W bulbs available to compare light intensity.*

MATERIALS IN KIT

Class Set of Student Guides
6 PV Cell Kits
6 Multimeters
6 Magnifiers
6 Sets of Alligator Connectors
6 Sets of Color Filters
Learning & Conserving Guides

COST OF KIT: $350.00

Acknowledgment: Many of the content and graphic explanations in this activity were developed by Robi Robichaud at the National Renewable Energy Laboratory.

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IREC
INTERSTATE RENEWABLE ENERGY COUNCIL

National Science Content Standards

UNIFYING CONCEPTS & PROCESSES

1. Systems, Order, and Organization

a. The goal of this standard is to think and analyze in terms of systems, which will help students keep track of mass, energy, objects, organisms, and events referred to in the content standards.

b. Science assumes that the behavior of the universe is not capricious, that nature is the same everywhere, and that it is understandable and predictable. Students can develop an understanding of order—or regularities—in systems, and by extension, the universe; then they can develop understanding of basic laws, theories, and models that explain the world.

c. Prediction is the use of knowledge to identify and explain observations, or changes, in advance. The use of mathematics, especially probability, allows for greater or lesser certainty of prediction.

d. Order—the behavior of units of matter, objects, organisms, or events in the universe—can be described statistically.

e. Probability is the relative certainty (or uncertainty) that individuals can assign to selected events happening (or not happening) in a specified time or space.

f. Types and levels of organization provide useful ways of thinking about the world.

2. Evidence, Models, and Explanation

a. Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.

3. Change, Constancy, and Measurement

a. Although most things are in the process of change, some properties of objects and processes are characterized by constancy; for example, the speed of light, the charge of an electron, and the total mass plus energy of the universe.

b. Energy can be transferred and matter can be changed. Nevertheless, when measured, the sum of energy and matter in systems, and by extension in the universe, remains the same.

c. Changes can occur in the properties of materials, position of objects, motion, and form and function of systems. Interactions within and among systems result in change. Changes in systems can be quantified and measured. Mathematics is essential for accurately measuring change.

d. Different systems of measurement are used for different purposes. An important part of measurement is knowing when to use which system.

4. Evolution and Equilibrium

b. Equilibrium is a physical state in which forces and changes occur in opposite and offsetting directions.

c. Interacting units of matter tend toward equilibrium states in which the energy is distributed as randomly and uniformly as possible.

SECONDARY (GRADES 9-12) CONTENT STANDARD–A: SCIENCE AS INQUIRY

1. Abilities Necessary to do Scientific Inquiry

a. Identify questions and concepts that guide scientific investigation.

b. Design and conduct scientific investigations.

c. Use technology and mathematics to improve investigations and communications.

d. Formulate and revise scientific explanations and models using logic and evidence.

e. Recognize and analyze alternative explanations and models.

f. Communicate and defend a scientific argument.

SECONDARY–B: PHYSICAL SCIENCE

1. Structure of Atoms

a. Matter is made of minute particles called atoms, which are composed of even smaller components. These components have measurable properties, such as mass and electrical charge.

b. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.

c. The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called isotopes of the element.

d. The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart.

e. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions.

f. Fission is the splitting of a large nucleus into smaller pieces.

g. Fusion is the joining of two nuclei at extremely high temperature and pressure and is the process responsible for the energy of the sun and other stars.

2. Structure and Properties of Matter

a. Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.

b. An element is composed of a single type of atom.

c. A compound is formed when two or more kinds of atoms bind together chemically.

4. Motions and Forces

c. The electrical force is a universal force that exists between two charged objects.

5. Conservation of Energy and the Increase in Disorder

a. The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.

6. Interactions of Energy and Matter

a. Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

b. Electromagnetic waves—including radio waves, microwaves, infrared radiation, ultraviolet radiation, x-rays, and gamma rays—result when a charged object is accelerated or decelerated.

c. Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and, thus, can absorb and emit light only at wavelengths corresponding to these amounts.

d. In some materials, such as metal, electrons flow easily, whereas in insulating materials such as glass, they can hardly flow at all.

SECONDARY STANDARD–D: EARTH AND SPACE SCIENCE

1. Energy in the Earth System

a. **Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation.**

c. **Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents.**

d. Global climate is determined by energy transfer from the sun at and near the earth's surface.

4. The Origin and Evolution of the Universe

a. **Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium.**

SECONDARY STANDARD–E: SCIENCE AND TECHNOLOGY

1. Abilities of Technological Design

a. Identify a problem or design an opportunity.

b. Propose designs and choose between alternative solutions.

c. Implement a proposed solution.

d. Evaluate the solution and its consequences.

e. Communicate the problem, process, and solution.

2. Understandings about Science and Technology

a. Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations. New disciplines—such as geophysics—often emerge at the interface of two older disciplines.

b. Science often advances with the introduction of new technologies.

c. Creativity, imagination, and a good knowledge base are required in science and engineering.

d. Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design by the need to meet human need and solve human problems.

SECONDARY STANDARD–F: SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

3. Natural Resources

a. Human populations use resources in the environment to maintain and improve their existence.

b. The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and depletes those resources that cannot be renewed.

c. Humans use many natural systems as resources. Natural systems have the capacity to reuse waste but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

5. Natural and Human-induced Hazards

d. Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards—ranging from those with minor risk to a few people to major catastrophes with major risk to many people.

6. Science and Technology in Local, National, and Global Challenges

a. Science and technology can indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge.

b. Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science and technology related challenges. However, understanding science alone will not resolve local, national, and global challenges.

c. Individuals and society must decide on proposals involving new research and the introduction of new technologies into society.

Teacher Guide

HANDS-ON INVESTIGATIONS TO TEACH SECONDARY STUDENTS THE SCIENTIFIC CONCEPTS OF PHOTOVOLTAICS.

BACKGROUND

Students use a backgrounder and hands-on investigations to develop an understanding of photovoltaics.

TIME

Five 45-minute class periods plus homework. (For schools with PV arrays, the unit will be extended as students investigate and monitor the output of the array.)

PROCEDURE

Preparation

- Familiarize yourself with the **Teacher** and **Student Guides**, and with the materials in the kit. Be sure you read the backgrounder in the **Student Guide** and understand the information.
- Make transparencies of the PV Cell and Multimeter explanations on pages 9-10.
- Collect the materials that are not included in the kit. See the Materials List on page 3 for a list of these materials.
- Review the Lab Safety Rules on page 22.
- Divide the class into six groups.
- Set up six centers that have reflecting lamps or access to direct sunlight. You can also conduct the investigations outside.

Day 1—Learning About Solar Energy

- Distribute the **Student Guides** to the students and have them read the background information in class or as homework. Have the students outline the materials in their science notebooks and answer the questions on page 14.
- Review and discuss the information with the class, using the PV Cell transparency (see page 11).
- Place the students in their groups at the six centers.
- Using the Multimeter transparency, explain how to use the multimeter. (See page 11).
- Review the Lab Safety Rules on page 22 and any other lab rules you have with your students.
- Instruct the students to familiarize themselves with the equipment and practice using the multimeters by measuring the output of the PV cells (Solar 1). (See pages 15- 16 of the **Student Guide**.)
- For homework, have the students design investigations for Solar 2, 3, and 4 in their science notebooks following the format in the **Student Guide**. (See pages 17-19 of the **Student Guide**.)

NOTE: Sample designs are included for the Solar Investigations on pages 12-19 of this guide. These are examples only and are not intended to be the only correct designs. Possible expected results are included.

Day 2—Investigating PV Cells

- Place the students in their groups at the six centers.
- Instruct each group to review and discuss their individual designs for the investigations and to develop a group design for each investigation.
- Instruct the students to conduct the investigations and record the results as group work, but to complete the conclusion sections individually, then discuss in their groups.
- Review and discuss the results , conclusions, and challenges as a class.
- For homework, have the students design the investigations for Solar 5-8. (See pages 20-23 of the **Student Guide**.)

Day 3—Investigating PV Cells

- Place the students in their groups at the six centers.
- Instruct each group to review and discuss their individual designs for the investigations and to develop a group design for each investigation.
- Instruct the students to conduct the investigations and record the results as group work, but to complete the conclusion sections individually, then discuss in their groups.
- Review and discuss the results , conclusions, and challenges as a class.
- For homework, have the students design the investigations for Solar 9-10. (See pages 24-25 of the **Student Guide**.) In addition, have each student design an individual investigation using the materials provided at the center, using their science notebooks. (See pages 26-27 of the **Student Guide**.)

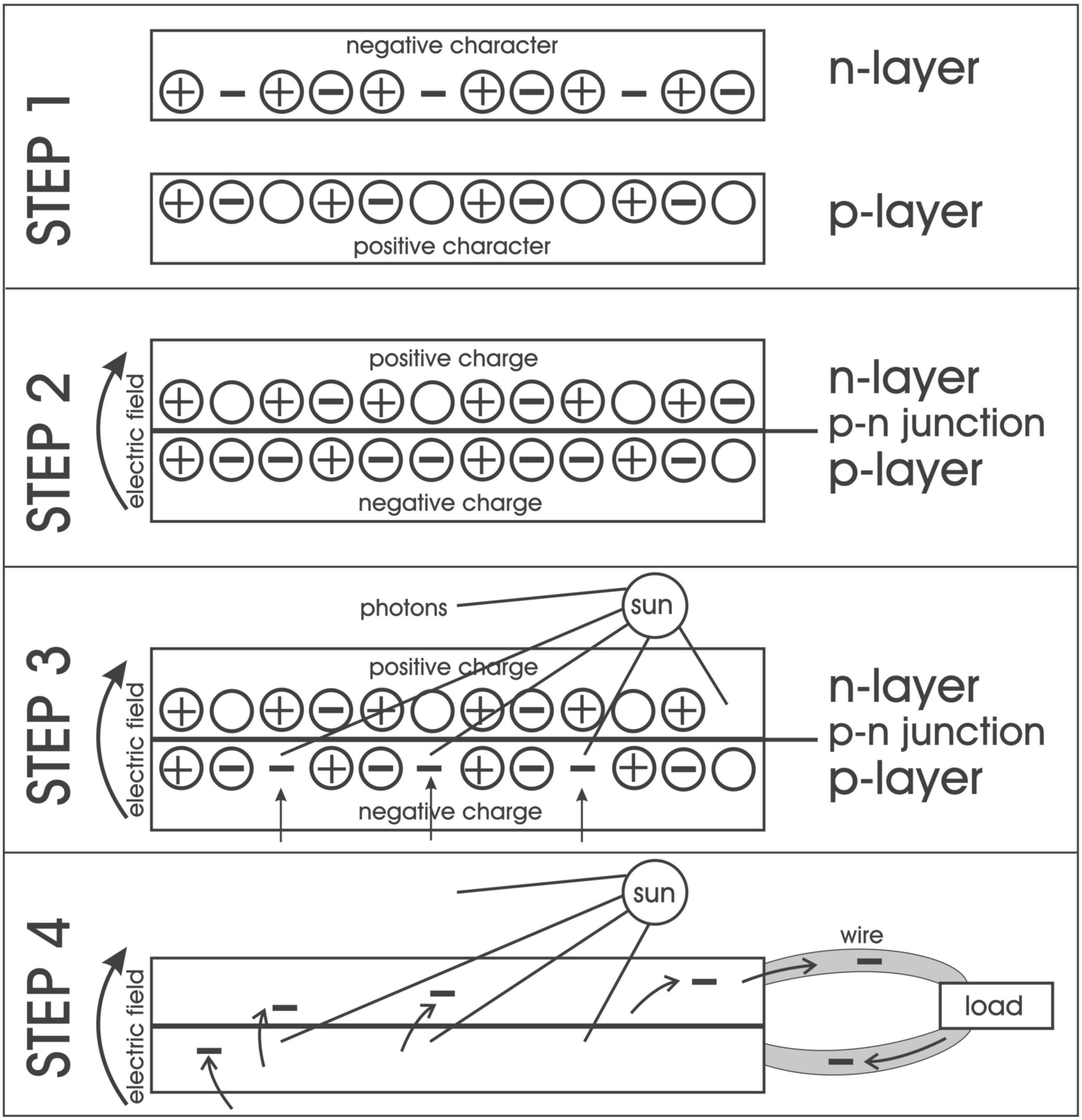
Day 4—Investigating PV Cells

- Place the students in their groups at the six centers.
- Instruct each group to review and discuss their individual designs for Solar 9-10 and to develop a group design for each investigation.
- Instruct the students to conduct the investigations and record the results as group work, but to complete the conclusion sections individually, then discuss in their groups.
- Review and discuss the results , conclusions, and challenges as a class.
- Have the students discuss their individual investigation designs with their groups, revise them as necessary, and begin conducting the investigations as groups.

Day 5—Investigating PV Cells & Evaluation

- Allow the students to complete their individual investigations.
- Review and discuss the results , conclusions, and challenges as a class.
- Evaluate the unit using the evaluation form on page 23 of the **Teacher Guide**.
- Evaluate student performance using the students' science notebooks.

PHOTOVOLTAIC CELL

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VΩmA
750VAC
1000VDC
200m A max
COM
500V max
KT-820B
DIGITAL
MULTIMETER

How a PV Cell is Made and How It Works

Pure silicon is used to form very thin wafers. In half of the wafers, a small amount of the element phosphorous is added. In the other wafers, a small amount of the element boron is added. The phosphorous gives the wafer of silicon an excess of free electrons; therefore, it has a negative character. This wafer with the phosphorous is called the **n-layer** (n = negative). The n-layer is not a charged wafer—it has an equal number of protons and electrons—but some of the electrons are not held tightly to the atoms in the wafer. They are free to move to different locations within the layer. The boron gives its wafer of silicon a positive character, because it has a tendency to attract electrons. The layer has an equal number of protons and electrons; it has a positive character but not a positive charge. This wafer with boron is called the **p-layer** (p=positive).

When the two wafers are placed together, the free electrons from the n-layer are attracted to the p-layer. At the moment of contact between the two wafers, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between layers. This point of contact and barrier is called the **p-n junction**. Once the layers have been joined, there is a negative charge in the p-layer section of the junction and a positive charge in the n-layer section of the junction. This imbalance in electrical charge at the p-n junction produces an electric field between the p-layer and the n-layer.

If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-layer and repelled by the negative charge in the p-layer.

If the n-layer is attached by a conducting wire to the p-layer, a circuit is formed. As the free electrons are pushed into the n-layer, they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that can power a load, such as a calculator or other device, as it travels through the circuit from the n-layer to the p-layer.

Solar cells also consist of a top metallic grid or other electrical contact to collect electrons from the semi-conductor and transfer them to the external load, and a back contact layer to complete the electrical circuit.

How To Use the Multimeter

An ammeter is a device that measures the amount of electric current flowing in a circuit. A voltmeter is a device that measures the voltage potential across the terminals of a source of electromotive force. A multimeter is a device that combines the features of an ammeter and voltmeter to measure current, DC and AC voltage, and resistance in an electric circuit or in parts of a circuit.

For every measurement, the black lead **ALWAYS** goes in the black terminal labeled COM (**B**).

To measure voltage, the red lead goes into the red terminal to the left of the black terminal (**A**). This terminal is labeled VΩ. To measure the voltage of the solar cells, the dial must be turned to DCV (Direct Current Voltage). The number the dial should point to in this section depends on the amount of voltage you are measuring. If the voltage is less than two volts, the dial should point to the 2. If the voltage is between 2 and 20, the dial should point to the 20.

To measure current, the red lead goes into one of the two red terminals to the right of the black terminal. The red terminal on the far right (**D**), labeled 10A, is to measure current of 10 amps or less. The red terminal immediately to the right of the black terminal (**C**), labeled mA, is to measure small currents less than one amp. This measurement is in milliamps. To measure current, the multimeter must be connected as part of the circuit. To measure the current of the solar cells, set the dial to DCA (Direct Current Amperage). For most of the measurements in this unit, the dial should point to 200m/20m and the red lead should be placed in the mA terminal (C).

To measure the voltage of a battery, set the dial to DCV (Direct Current Voltage). The voltage of AAA, AA, C, and D batteries is less than two volts, so set the dial at 2. For a 9-volt battery, set the dial at 20. Place the red lead onto the positive terminal (+) and the black lead onto the negative terminal (-). The voltage of a charged AAA, AA, A, C, or D battery should read between 1.55 - 1.63 V. If the voltage of the battery is below 1.5 V, the battery may need to be recharged (if it is a rechargeable battery) or replaced.

SOLAR 1: Do Similar PV Cells Produce Similar Electrical Output?

HYPOTHESIS:

MATERIALS: 8 PV cells
multimeter

PROCEDURE:

1. Measure the current and voltage of each PV cell under identical external conditions.

RESULTS:

PV Cell 1 Output: _____ A x _____ V = _____ W

PV Cell 2 Output: _____ A x _____ V = _____ W

PV Cell 3 Output: _____ A x _____ V = _____ W

PV Cell 4 Output: _____ A x _____ V = _____ W

PV Cell 5 Output: _____ A x _____ V = _____ W

PV Cell 6 Output: _____ A x _____ V = _____ W

PV Cell 7 Output: _____ A x _____ V = _____ W

PV Cell 8 Output: _____ A x _____ V = _____ W

CONCLUSION:

The PV cells should produce similar, though perhaps not identical results.

SOLAR 2: How Does Light Intensity Affect the Electrical Output of a PV Cell?

HYPOTHESIS:

MATERIALS:
- multimeter
- PV cell
- bright light source
- dim light source

PROCEDURE:

1. Attach the multimeter to a PV cell.
2. Place the PV cell in bright sun or in bright light.
3. Measure the current & voltage produced by the PV cell.
4. Place the PV cell in bright sun and cover it with a piece of notebook paper or in dim light.
5. Measure the current & voltage produced by the PV cell.
6. Conduct several trials with different PV cells.

RESULTS: ***(Both voltage and current should increase with light intensity.)***

Trial 1: V x A = W

Trial 2: V x A = W

Trial 3: V x A = W

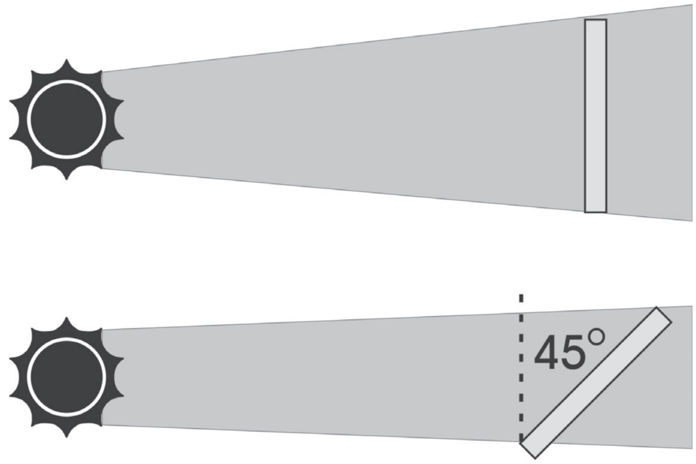
CONCLUSION:

The greater the light intensity, the greater the electrical output.

CHALLENGES:

Students may find it a challenge to vary the light intensity without changing other factors that could affect the results.

SOLAR 3: How Does the Angle of the PV Cell to the Light Source Affect the Electrical Output?



HYPOTHESIS:

MATERIALS:
- PV cell
- multimeter
- light source
- protractor*

PROCEDURE:

1. Connect the multimeter to a PV Cell.
2. Measure the current & voltage when the PV cell is perpendicular to the light.
3. Tilt the PV cell 15 degrees from perpendicular. Measure the output.
4. Tilt the PV cell 30, 45, 60, 75 degrees from perpendicular. Measure the output at each angle.
5. Conduct several trials with different PV cells.

RESULTS:

Current should decrease as the angle increases.

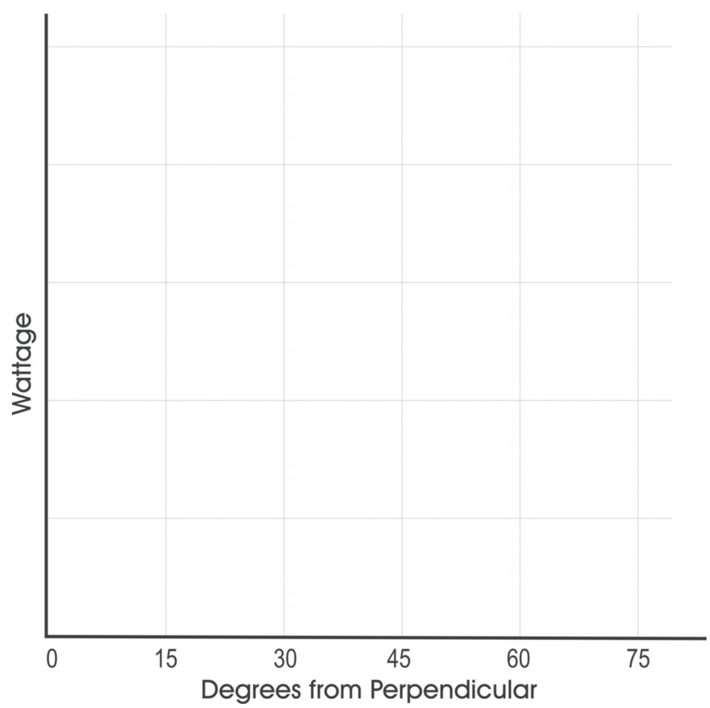
Voltage should remain relatively constant, since voltage is a property of the cell itself.

CONCLUSION:

The greater the angle from perpendicular, the less the electrical output. As the angle increases, the amount of light hitting the PV cell decreases, reducing the wattage. See the diagram above.

CHALLENGES:

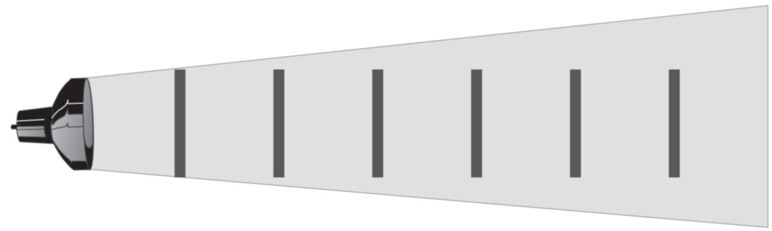
Measuring precise angles; determining how to graph the results.



SOLAR 4: How Does the Distance from the Light Source Affect the Electrical Output of a PV Cell?

HYPOTHESIS:

MATERIALS:
- PV Cell
- Multimeter
- Lamp
- Tape Measure



PROCEDURE:

1. Connect the multimeter to a PV cell.
2. Place the PV cell at increasing distances from the lamp and measure the current & voltage.
3. Conduct several trials with different PV cells.

RESULTS:

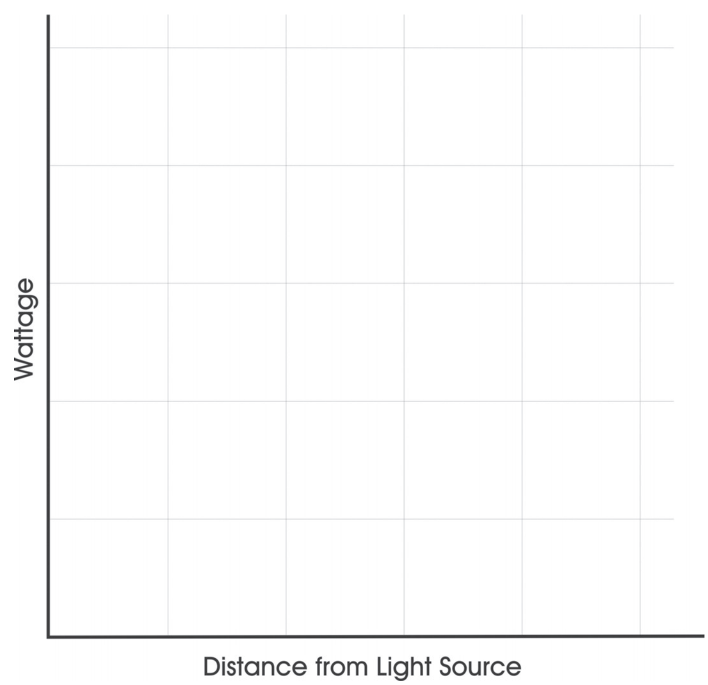
Current should decrease as the distance from the light increases. Voltage should remain relatively constant, since voltage is a property of the cell itself.

CONCLUSION:

As the distance from the light source increases, the wattage produced by the PV cell decreases. Less light is hitting the PV cell.

CHALLENGES:

This experiment can only be done with a light source, not the sun.



SOLAR 5: How Does Placing Part of a PV Cell in Shadow Affect Its Electrical Output?

HYPOTHESIS:

MATERIALS: PV cell
multimeter
piece of dark paper

PROCEDURE:

1. Connect a PV cell to the multimeter and place in the sun.
2. Place increasing sections of the PV cell in shadow, holding the dark paper at a distance from the PV cell between the cell and the light source, and measure the current & voltage.
3. Conduct several trials with different PV cells.

RESULTS:

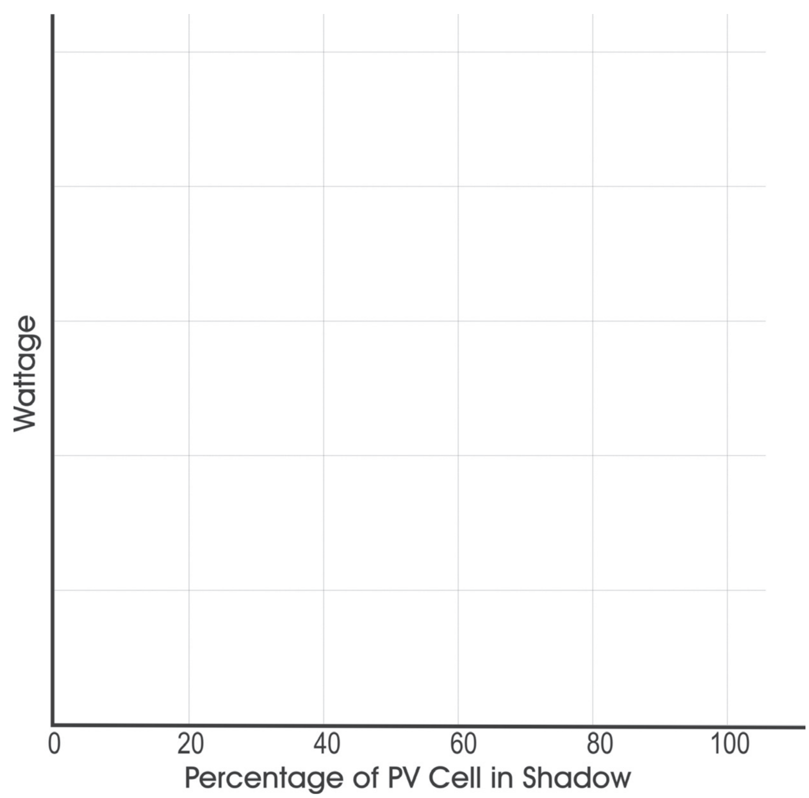
Current should decrease as the percentage in shadow increases. Voltage should remain relatively constant, since voltage is a property of the cell itself.

CONCLUSION:

The wattage decreases in proportion to the increase in the percentage of the PV cell in shadow.

CHALLENGES:

Determining with a reliable degree of precision the percentage of the PV cell in shadow.



SOLAR 6: How Does the Color of the Light Affect the Electrical Output of a PV Cell?

HYPOTHESIS:

MATERIALS:
- PV cell
- multimeter
- color filters
- lamp - optional

PROCEDURE:

1. Connect a PV cell to the multimeter and place in the sun.
2. Measure the current & voltage.
3. Place each of the color filters in turn between the sun and the PV cell so that all of the light hitting the PV cell is filtered. Measure the output with each filter.
4. Conduct several trials with different PV cells.

RESULTS:

Current should decrease when the light is filtered.

Voltage should remain relatively constant, since voltage is a property of the cell itself. The blue should filter most, the red least.

No Filter: V x A = W

Blue Filter: V x A = W

Green Filter: V x A = W

Red Filter: V x A = W

CONCLUSION:

All of the filters decrease the electrical output to differing degrees, because they are filtering out part of the light hitting the PV cell.

CHALLENGES:

Determining if any decrease in current is a result of the color of the light or another variable, such as a decrease in the amount of light hitting the PV cell.

SOLAR 7: How Does Concentrating the Light from a Light Source Affect the Electrical Output of a PV Cell?

HYPOTHESIS:

MATERIALS:
- PV cell
- multimeter
- magnifying lens

PROCEDURE:

1. Connect a PV cell to the multimeter and place in the sun.
2. Measure the current & voltage.
3. Use a magnifying lens to concentrate light on the PV cell.
4. Measure the current and voltage.
5. Conduct several trials with the lens at different distances from the PV cell and with different PV cells.

RESULTS:

Current should increase with the light concentration. Voltage should remain relatively constant, since voltage is a property of the cell itself.

With No lens: V x A = W

With Lens at ___ distance: V x A = W

With Lens at ___ distance: V x A = W

CONCLUSION:

Concentrating light on a PV cell increases the electrical output of the cell.

CHALLENGES:

Determining the focal length of the magnifying lens to concentrate light on the PV cell effectively. Making precise measurements of distances and maintaining precise distances.

SOLAR 8: How Does Air Temperature Affect the Electrical Output of a PV Cell?

HYPOTHESIS:

MATERIALS:

PV cell

multimeter

thermometer

*light source and hair dryer**

PROCEDURE:

1. Connect a PV cell to the multimeter.
2. Measure the current & voltage produced by the sun outside on a clear sunny day, recording the exact time of day and air temperature.
3. On the next two clear sunny days, at the same time of day, record the PV output and air temperature at the same location.
4. Conduct several trials using different PV cells.

** Because it is difficult to design a procedure to conduct this experiment in one day or control all of the variables, as an alternative procedure you can conduct the experiment inside using a light source and a hair dryer to raise the temperature of the PV cell.*

RESULTS:

As temperature increases, there can be an increase in resistance, decreasing the current.

Temperature 1 _____ V x A = W

Temperature 2 _____ V x A = W

CONCLUSION:

Minor changes in air temperature do not affect the output of a PV cell. Major increases in temperature decrease the electrical output.

CHALLENGES:

Controlling the variables in this experiment may be difficult.

SOLAR 9: How Does Combining PV Cells in Parallel Affect the Electrical Output of the PV Cells?

HYPOTHESIS:

MATERIALS:

- **4 PV cells**
- **multimeter**
- **alligator connectors**

PROCEDURE:

1. **Connect one PV cell to the multimeter and measure current and voltage.**
2. **Connect two PV cells in parallel to the multimeter and measure the current & voltage.**
3. **Connect three, then four, PV cells in parallel to the multimeter and measure the current & voltage of each circuit.**

RESULTS:

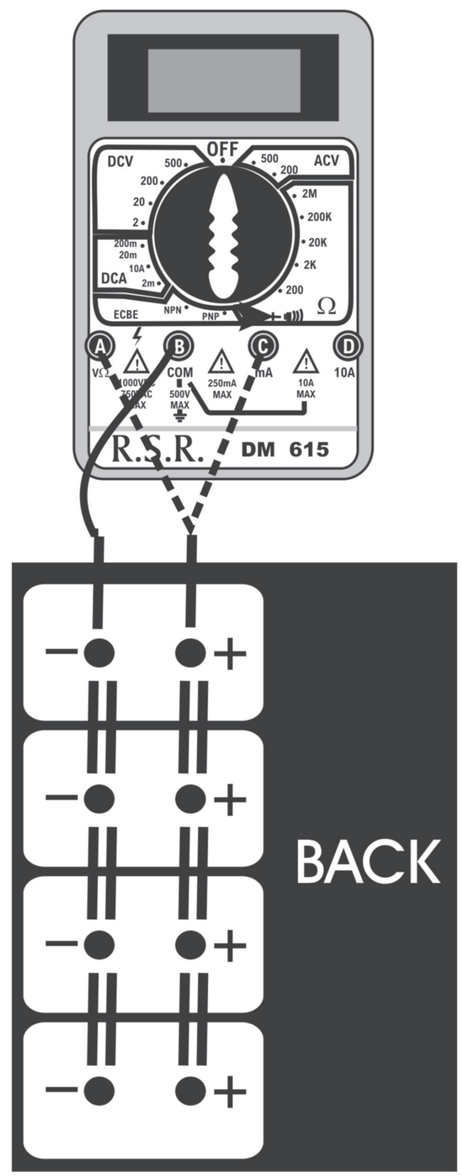
The current should increase in direct proportion to the number of PV cells in the circuit and the voltage should remain constant.

CONCLUSION:

Combining PV cells in parallel increases the current produced in proportion to the number of cells combined, but the voltage remains the same.

CHALLENGES:

Determining how to connect the PV cells in a parallel circuit.



SOLAR 10: How Does Combining PV Cells in Series Affect the Electrical Output of the PV Cells?

HYPOTHESIS:

MATERIALS: 4 PV cells
multimeter
alligator connectors

PROCEDURE:

1. Connect one PV cell to the multimeter and measure the current and voltage.
2. Connect two PV cells in series to the multimeter and measure the current & voltage.
3. Connect three, then four, PV cells in series to the multimeter and measure the current & voltage of each circuit.

RESULTS:

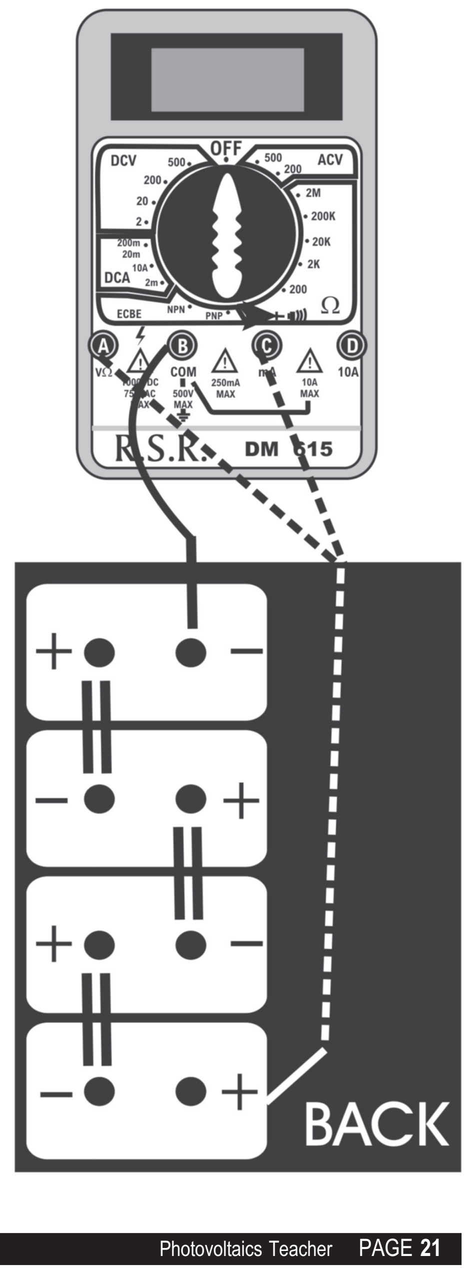
The voltage should increase in direct proportion to the number of PV cells in the circuit and the current should remain constant.

CONCLUSION:

Combining PV cells in series increases the voltage produced in direct proportion to the number of PV cells and the current remains the same.

CHALLENGES:

Determining how to connect the PV cells in a series circuit.



Lab Safety Rules

EYE SAFETY

Always wear safety glasses when performing experiments.

FIRE SAFETY

Do not heat any substance or piece of equipment unless specifically instructed to do so.

Be careful of loose clothing. Do not reach across or over a flame.

Keep long hair pulled back and secured.

Do not heat any substance in a closed container.

Always use the tongs or protective gloves when handling hot objects. Do not touch hot objects with your hands.

Keep all lab equipment, chemicals, papers, and personal effects away from the flame.

Extinguish the flame as soon as you are finished with the experiment and move it away from the immediate work area.

HEAT SAFETY

Always use tongs or protective gloves when handling hot objects and substances.

Keep hot objects away from the edge of the lab table—in a place where no one will come into contact with them.

Do not use the steam generator without the assistance of your teacher.

Remember that many objects will remain hot for a long time after the heat source is removed or turned off.

GLASS SAFETY

Never use a piece of glass equipment that appears cracked or broken.

Handle glass equipment carefully. If a piece of glassware breaks, do not attempt to clean it up yourself. Inform your teacher.

Glass equipment can become very hot. Use tongs if glass has been heated.

Clean glass equipment carefully before packing it away.

CHEMICAL SAFETY

Do not smell, touch, or taste chemicals unless instructed to do so.

Keep chemical containers closed except when using them.

Do not mix chemicals without specific instructions.

Do not shake or heat chemicals without specific instructions.

Dispose of used chemicals as instructed. Do not pour chemicals back into container without specific instructions to do so.

If a chemical accidentally touches your skin, immediately wash the area with water and inform your teacher.

PHOTOVOLTAICS
Evaluation Form

State: ____________ Grade Level: ____________ Number of Students: ___________

1. Did you conduct the entire activity?	Yes	No
2. Were the instructions clear and easy to follow?	Yes	No
3. Did the activity meet your academic objectives?	Yes	No
4. Was the activity age appropriate?	Yes	No
5. Were the allotted times sufficient to conduct the activity?	Yes	No
6. Was the activity easy to use?	Yes	No
7. Was the preparation required acceptable for the activity?	Yes	No
8. Were the students interested and motivated?	Yes	No
9. Was the energy knowledge content age appropriate?	Yes	No
10. Would you use the activity again?	Yes	No

How would you rate the activity overall (excellent, good, fair, poor)?

How would your students rate the activity overall (excellent, good, fair, poor)?

What would make the activity more useful to you?

Other Comments:

Please fax or mail to:

NEED Project
PO Box 10101
Manassas, VA 20108
FAX: 1-800-847-1820

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