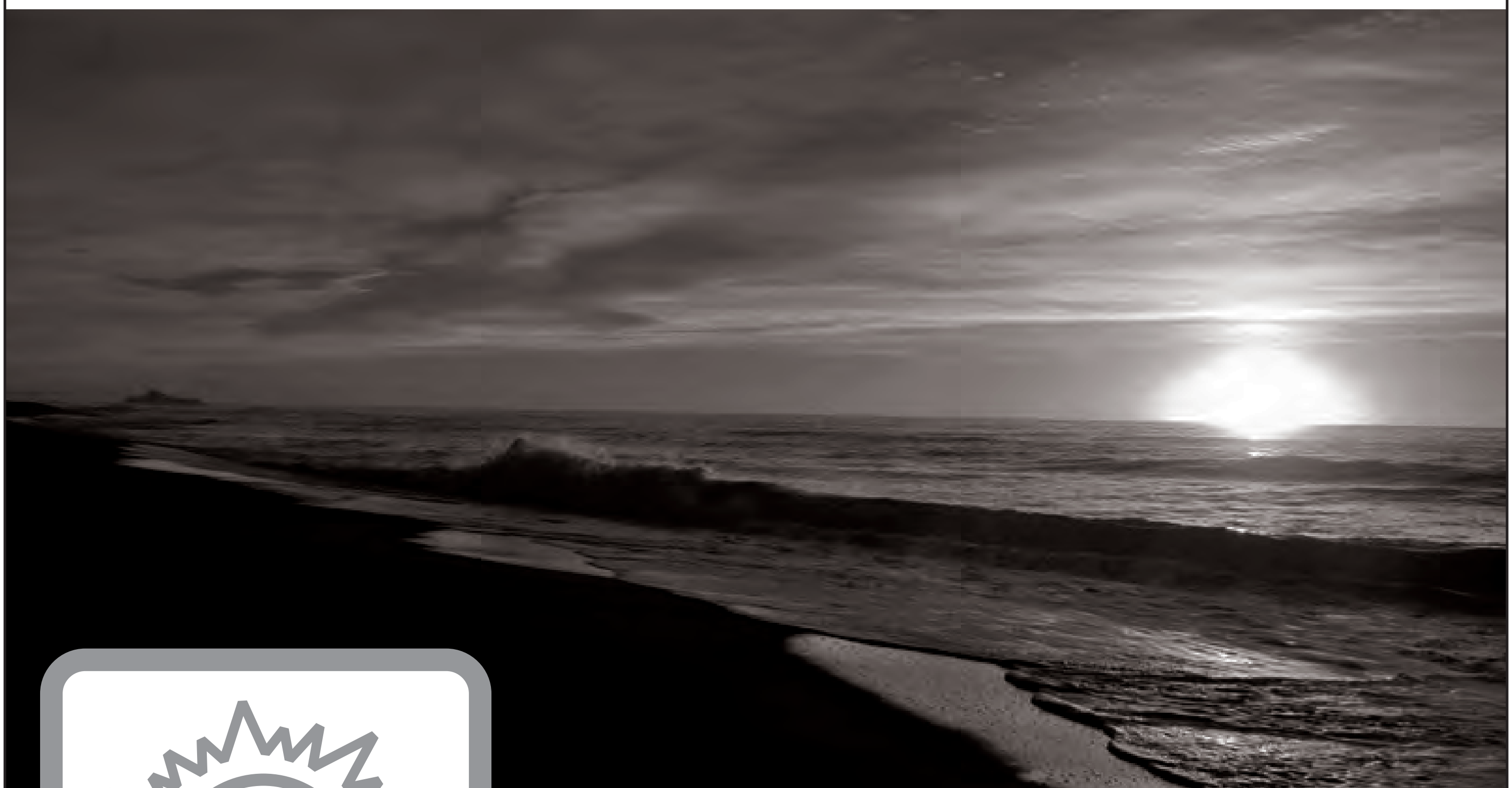
Exploring Solar Energy
Teacher Guide

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



ENERGY SOURCES

Grade Level:
- Intermediate

Subject Areas:
- Science
- Social Studies
- Math
- Language Arts

NEED
National Energy Education Development Project

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 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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Energy Data Used in NEED Materials

NEED believes in providing the most recently reported energy data available to our teachers and students. Most statistics and data are derived from the U.S. Energy Information Administration's Annual Energy Review that is published in June of each year. Working in partnership with EIA, NEED includes easy to understand data in our curriculum materials. To do further research, visit the EIA website at www.eia.doe.gov. EIA's Energy Kids site has great lessons and activities for students at www.eia.doe.gov/kids.

NEED
National Energy Education Development

1.800.875.5029
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Table of Contents

Materials in Solar Kit

- Class set of student guides
- 5 Radiation can kits
- 10 Thermometers
- 12 Concave mirrors
- 20 Plastic containers
- 5 Beakers
- 2 Solar balloons with string
- 5 Solar PV kits
- 1 Solar House kit
- Clay

Student thermometers in the kit are safety thermometers containing alcohol, not mercury.

Materials Needed

- 5 Metric rulers
- Bright light source
- Cardboard box
- Clear plastic wrap
- Cold and hot water
- Rubber bands
- Scissors
- Transparency film
- White and black construction paper

INTERSTATE RENEWABLE ENERGY COUNCIL

Correlations to National Science Education Standards: Grades 5-8

This book has been correlated to National Science Education Content Standards.
For correlations to individual state standards, visit **www.need.org**.

Content Standard A | *SCIENCE AS INQUIRY*

- **Abilities Necessary to do Scientific Inquiry**
  - Identify questions that can be answered through scientific investigations.
  - Design and conduct a scientific investigation.
  - Use appropriate tools and techniques to gather, analyze, and interpret data.
  - Develop descriptions, explanations, predictions, and models using evidence.
  - Think critically and logically to make the relationships between evidence and explanations.
  - Recognize and analyze alternative explanations and predictions.
  - Communicate scientific procedures and explanations.
  - Use mathematics in all aspects of scientific inquiry.

- **Understandings about Scientific Inquiry**
  - Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.
  - Mathematics is important in all aspects of scientific inquiry.
  - Science advances through legitimate skepticism. Asking questions and querying other scientists' explanations is part of scientific inquiry. Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations.
  - Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data. All of these results can lead to new investigations.

Content Standard B | *PHYSICAL SCIENCE*

- **Transfer of Energy**
  - Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.
  - Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.
  - Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object—emitted by or scattered from it—must enter the eye.
  - Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.
  - The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

Content Standard C | *LIFE SCIENCE*

- **Populations and Ecosystems**
  - For ecosystems, the major source of energy is sunlight. Energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis. That energy then passes from organism to organism in food webs.

Content Standard D | *EARTH AND SPACE SCIENCE*

- **Earth in the Solar System**
  - The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.
  - Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.
  - The sun is the major source of energy for phenomena on the earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. Seasons result from variations in the amount of the sun's energy hitting the surface, due to the tilt of the earth's rotation on its axis and the length of the day.

Correlations to National Science Education Standards: Grades 5-8

Content Standard E | *SCIENCE AND TECHNOLOGY*

- **Understandings about Science and Technology**
  - Scientific inquiry and technological design have similarities and differences. Scientists propose explanations for questions about the natural world, and engineers propose solutions relating to human problems, needs, and aspirations. Technological solutions are temporary; technologies exist within nature and so they cannot contravene physical or biological principles; technological solutions have side effects; and technologies cost, carry risks, and provide benefits.
  - Many different people in different cultures have made and continue to make contributions to science and technology.
  - Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.
  - Perfectly designed solutions do not exist. All technological solutions have trade-offs, such as safety, cost, efficiency, and appearance. Engineers often build in back-up systems to provide safety. Risk is part of living in a highly technological world. Reducing risk often results in new technology.
  - Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constraints limit choices in the design, for example, environmental protection, human safety, and aesthetics.
  - Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

Content Standard F | *SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES*

- **Populations, Resources, and Environments**
  - When an area becomes overpopulated, the environment will become degraded due to the increased use of resources.
  - Causes of environmental degradation and resource depletion vary from region to region and from country to country.

- **Science and Technology in Society**
  - Societal challenges often inspire questions for scientific research, and social priorities often influence research priorities through the availability of funding for research.
  - Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact. Technological changes are often accompanied by social, political, and economic changes that can be beneficial or detrimental to individuals and to society. Social needs, attitudes, and values influence the direction of technological development.
  - Science and technology have advanced through contributions of many different people, in different cultures, at different times in history. Science and technology have contributed enormously to economic growth and productivity among societies and groups within societies.

Content Standard G | *HISTORY AND NATURE OF SCIENCE*

- **Nature of Science**
  - Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.
  - In areas where active research is being pursued and in which there is not a great deal of experimental or observational evidence and understanding, it is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered. Different scientists might publish conflicting experimental results or might draw different conclusions from the same data. Ideally, scientists acknowledge such conflict and work towards finding evidence that will resolve their disagreement.

Teacher Guide

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

Background

Students use a backgrounder and hands-on explorations to develop an understanding of solar energy.

Concepts

- Nuclear fusion within the sun produces enormous amounts of energy, some in the form of radiant energy that travels through space to the Earth.
- Most of the energy on Earth comes from the sun. Only geothermal, nuclear, and tidal energy do not.
- The sun's energy makes life possible on Earth because of the greenhouse effect.
- We use the sun's energy to produce heat, light, and electricity.
- It is difficult to capture the sun's energy because it is spread out—not much is concentrated in any one place. We can capture solar energy with solar collectors that convert radiant energy into heat.
- Photovoltaic cells convert radiant energy directly into electricity.
- Concentrated solar power systems collect radiant energy from the sun and convert it into heat to produce electricity.

Time

Five 45-minute class periods.

Procedure

STEP ONE - PREPARATION

- Familiarize yourself with the Teacher and Student Guides, and with the materials in the kit. Make sure that the PV cell and motor work smoothly. If the motor doesn't spin immediately, 'jumpstart' it by touching the leads to the ends of a C or D battery.
- If the thermometers have been unused for a long time, they may need to be recalibrated. If they are not reading the same temperature, put them in ice water, then a few minutes later, in boiling water. This should recalibrate the thermometers to the same temperature.
- Download a PDF of the *Exploring Solar Energy Teacher Guide* from www.NEED.org so you can use the PV Cell explanation on page 11 with technology available in your classroom. Or, make a transparency of the graphic to use on an overhead projector.
- Collect the materials that are not included in the kit. See the Materials Needed list on page 3 for materials that are not in the kit.
- Review the Lab Safety Rules on page 14 .
- Divide the class into five groups.
- Set up five centers that have access to direct sunlight.

Teacher Information

What is Energy?

Energy is the ability to do work, the ability to make a change. Everything that happens in the world involves a change of some kind, the exchange of energy in some way. The total amount of energy in the universe remains the same. When we use energy, we do not 'use it up', we convert one form of energy into other forms. Usually the conversion of energy produces some heat, which is considered the lowest form of energy, since it dissipates into the surroundings and is difficult to capture and use again. Energy is categorized in many ways—by the forms it takes and by what it does—the changes it makes—the effects we can see or feel or measure.

What Energy Does: Energy is recognized in the following ways:

- Energy is light—energy produces light—the movement of energy in transverse waves or rays—radiant energy.
- Energy is heat—energy produces heat—the movement of atoms and molecules within substances—thermal energy.
- Energy is sound—energy produces sound—the back-and-forth vibration of substances in longitudinal waves.
- Energy is motion—energy produces motion—kinetic energy.
- Energy is growth—energy is required for cells to reproduce—chemical energy stored in the bonds of nutrients.
- Energy is electricity to run technology—the movement of electrons from atom to atom.

Forms of Energy: Energy is recognized in many forms, all of which are potential or kinetic:

- Thermal Energy (Heat)
- Mechanical Energy (Motion)
- Chemical Energy (Energy in Wood, Fossil Fuels)
- Electrical Energy (Electricity, Lightning)
- Nuclear Energy (Fission, Fusion)
- Radiant Energy (Light, X-rays)
- Sound (Motion)

Solar Energy

Solar energy is energy from the sun. The sun is a giant ball of hydrogen and helium gas. The enormous heat and pressure in the interior of the sun cause the nuclei of two hydrogen atoms to fuse, producing one helium atom in a process called fusion. During fusion, nuclear energy is converted into thermal (heat) and radiant energy. The radiant energy is emitted from the sun in all directions and some of it reaches Earth. Radiant energy is energy that travels in electromagnetic waves or rays. Radiant energy includes visible light, x-rays, infrared rays, microwaves, gamma rays, and others. These rays have different amounts of energy depending upon their wavelength. The shorter the wavelength, the more energy they contain.

Photovoltaic Cells

A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with an "n" dopant such as phosphorous. On the base of the slab a small amount of a "p" dopant, typically boron, is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side. Dopants are similar in atomic structure to the primary material. The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the electric field that motivate the energetic electrons out of the cell created when light strikes the PV cell.

The phosphorous gives the wafer of silicon an excess of free electrons; it has a negative character. This is called the n-type silicon (n = negative). The n-type silicon is not charged—it has an equal number of protons and electrons—but some of the electrons are not held tightly to the atoms. They are free to move to different locations within the cell.

The boron gives the base of the silicon a positive character, because it has a tendency to attract electrons. The base of the silicon is called p-type silicon (p = positive). The p-type silicon has an equal number of protons and electrons; it has a positive character but not a positive charge.

Where the n-type silicon and p-type silicon meet, free electrons from the n-type flow into the p-type for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the p-n junction.

When both sides of the silicon slab are doped, there is a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction due to movement of the electrons and "holes" at the junction of the two types of materials. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type silicon.

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-type silicon and repelled by the negative charge in the p-type silicon. Most photon-electron collisions actually occur in the silicon base.

A conducting wire connects the p-type silicon to an electrical application such as a light or battery, and then back to the n-type silicon, forming a complete circuit. As the free electrons are pushed into the n-type silicon 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-type to the p-type silicon.

In addition to the semi-conducting materials, solar cells 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 type to complete the electrical circuit.

See the PV Cell diagram on page 11 to explain how a PV cell works.

Activity 1: Introduction To Solar Energy

OBJECTIVES

- To learn about solar energy by reading the background information.
- To practice reading a thermometer with Fahrenheit and Celsius scales.
- To practice conversions between Fahrenheit and Celsius scales.

MATERIALS

- None

TIME

- 45 minutes

PROCEDURE

- Introduce solar energy as the topic of exploration and have the students make a list of the things they know and questions they have about solar energy.
- Distribute the Student Guides to the students and have them read the backgrounder. Have the students revise their list of the things they know and the questions they have. Discuss the questions they have and have them research specific questions as homework.
- Go to page 9 of the Student Guide. Have the students read and complete the Thermometer worksheet. Review the answers (see page 12 of Teacher Guide for answers).
- Go to page 10 of the Student Guide. Have the students read and complete the Fahrenheit/Celsius Conversion worksheet. Review the answers (see page 13 of Teacher Guide for answers).

Activity 2: Converting Radiant Energy To Heat

OBJECTIVE

- To learn that radiant energy can be reflected and absorbed by objects. When it is absorbed by objects, some is converted into heat.

MATERIALS

IN KIT: 5 Radiation can kits, 10 Thermometers, 5 Beakers

NEEDED: Cold and hot water, Bright light source

TIME

- 45 minutes

PROCEDURE

- Go to page 11 of the Student Guide. Place students in their groups and assign each group to a center. Explain the procedure and have the students complete the activity.
- Review the activity with the students to make sure they understand that:
    - radiant energy can be reflected or absorbed when it hits objects;
    - absorbed radiant energy can be converted into heat;
    - black objects tend to absorb radiant energy;
    - shiny objects tend to reflect radiant energy; and
    - radiant energy can be produced by the sun or by an artificial source.

Activity 3: Solar Concentration

OBJECTIVE

- To learn that radiant energy can be concentrated on an object with a concave mirror.

MATERIALS

IN KIT: 5 Radiation kits, 10 Thermometers, 12 Concave mirrors, Clay, 5 Beakers

NEEDED: Cold water, Metric rulers

TIME

- 45 minutes

PROCEDURE

- Go to page 12 of the Student Guide. Place students in their groups, assign them with A-E labels, and assign each group to a center with the corresponding number of concave mirrors. Explain the procedure and have the students complete the activity. They must get data from the other groups to complete the activity.
- While the students are waiting the 10 minutes, review the activity with the students to make sure they understand that:
  - a mirror reflects radiant energy; and
  - a concave mirror can concentrate solar radiation onto an object.

Activity 4: Solar Collection

OBJECTIVE

- To learn that radiant energy can be collected, converted into heat, and stored.

MATERIALS

IN KIT: 20 Plastic containers, 10 Thermometers, 5 Beakers, Rubber bands

NEEDED: Cold water, Plastic wrap, Black and white paper

TIME

- 45 minutes

PROCEDURE

- Go to page 13 of the Student Guide. Place students in their groups and assign each group to a center. Explain the procedure and have the students complete the activity.
- Review the activity with the students, using The Greenhouse Effect diagram on page 3 of the Student Guide, to make sure they understand that:
  - radiant energy can pass through transparent materials such as plastic wrap, but thermal energy (heat) does not;
  - black objects tend to absorb radiant energy; and
  - white objects tend to reflect radiant energy.
- Go to page 14 of the Student Guide. Play outside with the solar balloons on a sunny day.

Activity 5: Photovoltaic Cell

✪ OBJECTIVES

- To learn that radiant energy can be converted directly into electricity.
- To learn that a motor converts electricity into motion.

MATERIALS

IN KIT: 1 Solar house kit, 5 Solar energy kits with PV cells, Motors, Fans

NEEDED: Cardboard box, Transparency film, Bright light source

TIME

- 45 minutes

☑ PROCEDURE

- Go to page 15 of the Student Guide. Make a solar house using the Solar House Kit to demonstrate the uses of PV cells.
- Go to page 16 of the Student Guide. Place students in their groups and assign each group to a center. Explain the procedure and have the students complete the activity.
- Review the activity with the students, using the PV Cell Master on page 11 of the Teacher Guide, to make sure they understand that:
  - PV cells can convert radiant energy directly into electricity;
  - motors can convert electricity into motion; and
  - sunlight and artificial light are radiant energy.

Activity 6: Making Solar Ovens

✪ OBJECTIVE

- To make solar ovens and explore cooking with solar energy.

MATERIALS

NEEDED: see Materials List on page 17 of Student Guide

TIME

- Varies

☑ PROCEDURE

- Go to pages 17-18 of the Student Guide. Have the students make solar ovens and cook food in them on a sunny day.

Optional Activity 7: Photovoltaic Arrays On The School

✪ OBJECTIVE

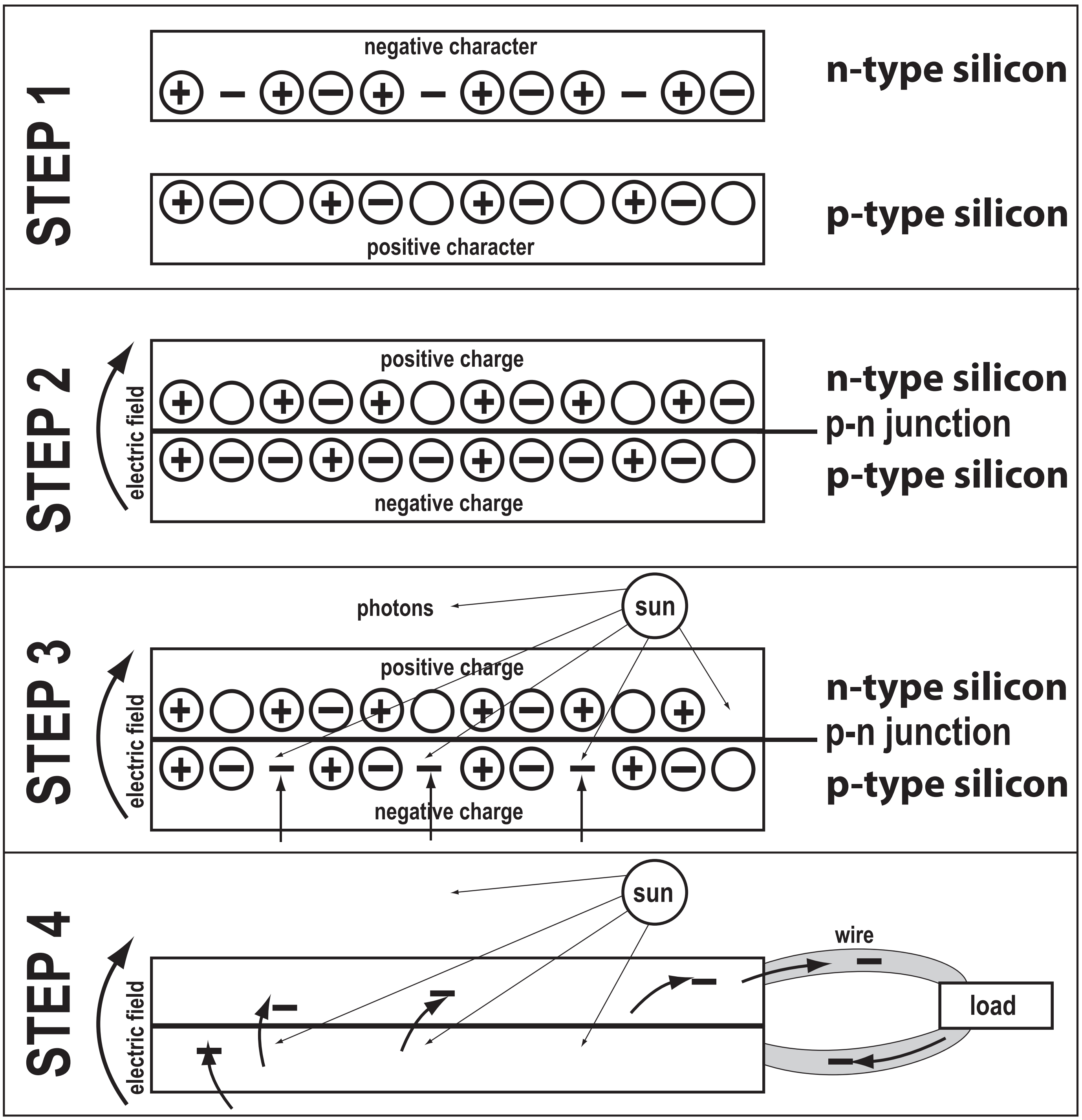
- To learn about and monitor the PV arrays on the school.

☑ PROCEDURE

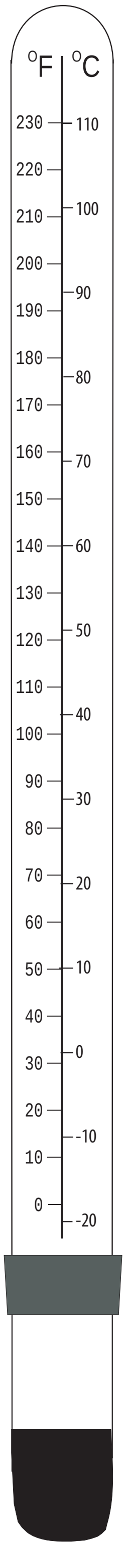
- Have the school's energy/facility manager or administrator speak to the students about the PV arrays on the school and show them how they work. If possible, have the students monitor the electrical output of the arrays and correlate the output to weather conditions. See NEED's *Monitoring and Mentoring* (Grades 5-6) and *Learning and Conserving* (Grades 7-8) activities for more information.

Photovoltaic Cell

- ⊕ proton
- ⊖ tightly-held electron
- – free electron
- ○ location that can accept an electron



Thermometer



A thermometer measures temperature. The temperature of an object or a substance shows how hot or cold it is. This thermometer is a long glass tube filled with a colored liquid. Liquids expand (take up more space) as they get hotter.

Temperature can be measured using many different scales. The scales we use most are:

Celsius

The Celsius (C) scale uses the freezing point of water as 0°C and the boiling point of water as 100°C.

Fahrenheit

The Fahrenheit (F) scale uses the freezing point of water as 32°F and the boiling point of water as 212°F.

In the United States, we usually use the Fahrenheit scale in our daily lives, and the Celsius scale for scientific work.

Answer These Questions

The temperature of the human body is 98-99°F. Looking at the drawing of the thermometer, what would that reading be on the Celsius scale?

37°C

A comfortable spring day is about 75°F. What would that reading be on the Celsius scale?

25°C

The temperature of a hot shower is about 105°F. What would that reading be on the Celsius scale?

42°C

Fahrenheit/Celsius Conversion

On the Fahrenheit scale, the freezing point of water is 32° and the boiling point of water is 212°—a range of 180°.

On the Celsius scale, the freezing point of water is 0° and the boiling point of water is 100°—a range of 100°.

To convert from Celsius to Fahrenheit, multiply the C number by $\frac{180}{100}$ or $\frac{9}{5}$, then add 32, as shown in the formula below.

$$F = (C \times \frac{9}{5}) + 32$$

If C = 5

$F = (5 \times \frac{9}{5}) + 32$

$F = 9 + 32$

$F = 41$

To convert from Fahrenheit to Celsius, subtract 32 from the F number, then multiply by $\frac{100}{180}$ or $\frac{5}{9}$ as shown in the formula below.

$$C = (F - 32) \times \frac{5}{9}$$

If F = 50

$C = (50 - 32) \times \frac{5}{9}$

$C = 18 \times \frac{5}{9}$

$C = 10$

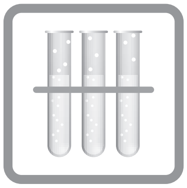
Answer These Questions

If C is 50°, what is the temperature in Fahrenheit?

122°F

If F is 100°, what is the temperature in Celsius?

37.78°C



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.
- 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 the tongs or protective gloves when handling hot objects. Do not touch hot objects with your hands.
- 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 their containers without specific instructions to do so.
- If a chemical accidentally touches your skin, immediately wash the area with water and inform your teacher.

Exploring Solar Energy Evaluation Form

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

1. Did you conduct the entire unit?	❑ Yes	❑ No
2. Were the instructions clear and easy to follow?	❑ Yes	❑ No
3. Did the activities meet your academic objectives?	❑ Yes	❑ No
4. Were the activities age appropriate?	❑ Yes	❑ No
5. Were the allotted times sufficient to conduct the activities?	❑ Yes	❑ No
6. Were the activities easy to use?	❑ Yes	❑ No
7. Was the preparation required acceptable for the activities?	❑ Yes	❑ No
8. Were the students interested and motivated?	❑ Yes	❑ No
9. Was the energy knowledge content age appropriate?	❑ Yes	❑ No
10. Would you teach this unit again? *Please explain any 'no' statement below*	❑ Yes	❑ No

How would you rate the unit overall?	❑ excellent	❑ good	❑ fair	❑ poor
How would your students rate the unit overall?	❑ excellent	❑ good	❑ fair	❑ poor

What would make the unit more useful to you?

____

____

____

____

Other Comments:

____

____

____

____

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Manassas, VA 20108
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U.S. Department of Energy–Hydrogen Program
U.S. Department of Energy–Wind Powering America
U.S. Department of Energy–Wind for Schools
U.S. Department of the Interior– Bureau of Land Management
U.S. Department of the Interior–Bureau of Ocean Energy Management, Regulation and Enforcement
U.S. Environmental Protection Agency
Van Ness Feldman
Virgin Islands Energy Office
Virginia Department of Education
Virginia Department of Mines, Minerals and Energy
Walmart Foundation
Washington and Lee University
Western Kentucky Science Alliance
W. Plack Carr Company
Yates Petroleum Corporation