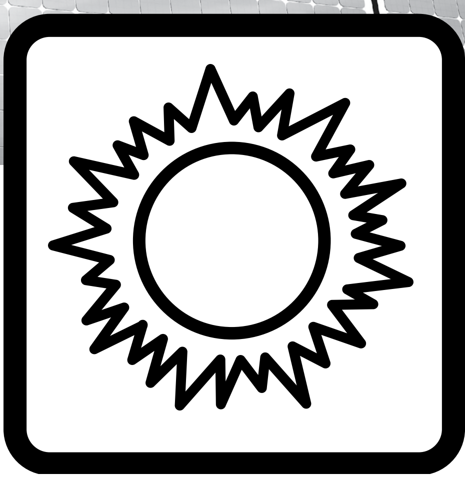
Exploring Photovoltaics

Teacher Guide

Hands-on investigations to teach secondary students how electricity is generated using photovoltaics and other systems. Students will explore the variables affecting photovoltaic cells.



Grade Level:

Sec Secondary

Subject Areas:

Science

Language Arts

Social Studies

Technology

Math

NEED National Energy Education Development Project

Dominion Energy SOLAR FOR STUDENTS

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.

Permission to Copy

Teacher Advisory Board

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

Energy Data Used in NEED Materials

NEED believes in providing teachers and students with the most recently reported, available, and accurate energy data. Most statistics and data contained within this guide are derived from the U.S. Energy Information Administration. Data is compiled and updated annually where available. Where annual updates are not available, the most current, complete data year available at the time of updates is accessed and printed in NEED materials. To further research energy data, visit the EIA website at www.eia.gov.

NEED
National Energy Education Development

1.800.875.5029
www.NEED.org

Exploring Photovoltaics
Teacher Guide

NEED would like to express gratitude to the National Renewable Energy Laboratory and the Interstate Renewable Energy Council who helped develop this curriculum.

PROUD MEMBER OF

IREC Interstate Renewable Energy Council

Exploring Photovoltaics Kit

- 6 PV cell kits
- 12 Multimeters
- 6 Fresnel lenses
- 12 Sets of alligator clips
- 24 Ping pong balls
- 30 Student Guides

Table of Contents

Standards Correlation Information

www.NEED.org/curriculumcorrelations

Next Generation Science Standards

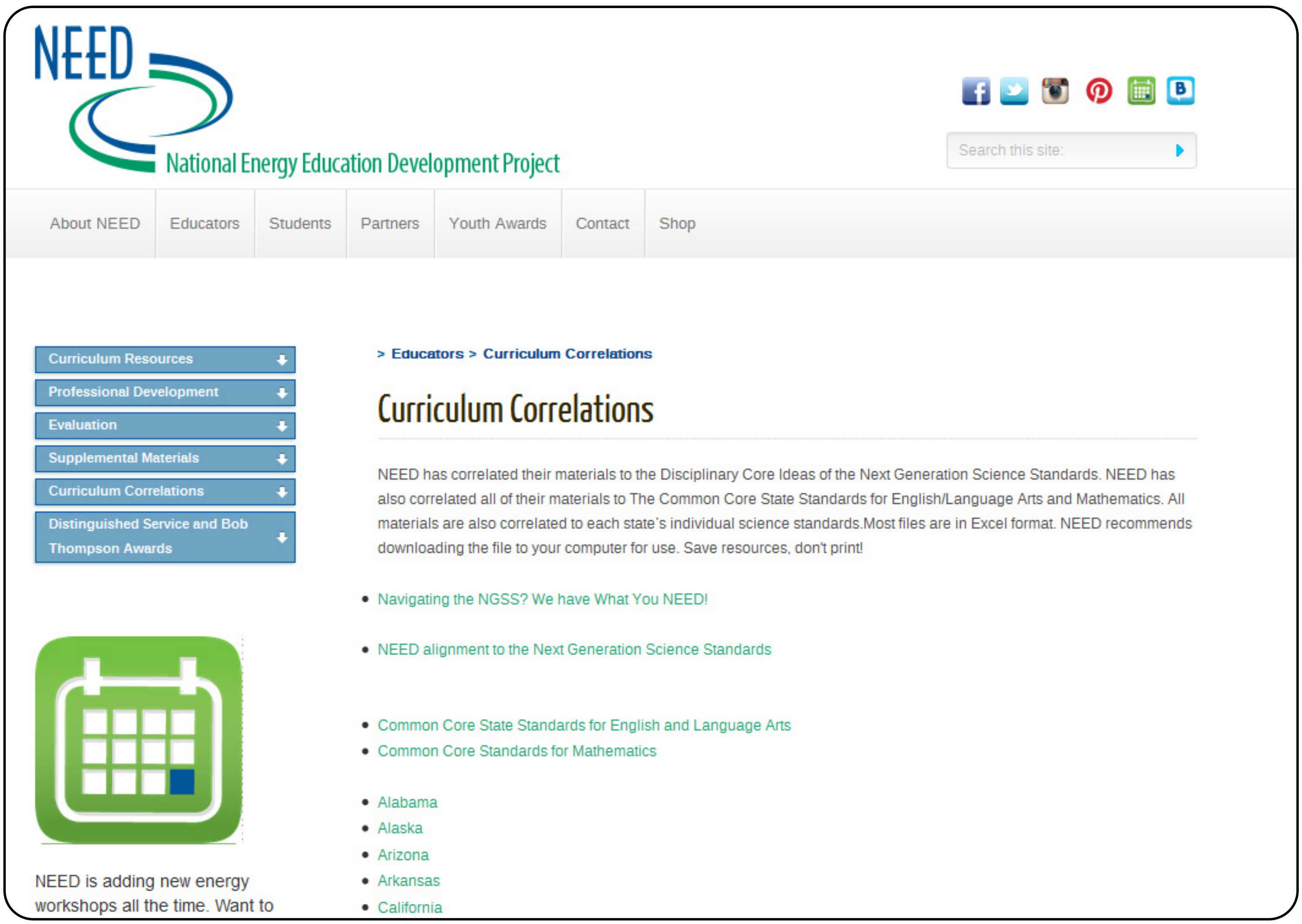
- This guide effectively supports many Next Generation Science Standards. This material can satisfy performance expectations, science and engineering practices, disciplinary core ideas, and cross cutting concepts within your required curriculum. For more details on these correlations, please visit NEED's curriculum correlations website.

Common Core State Standards

- This guide has been correlated to the Common Core State Standards in both language arts and mathematics. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED curriculum correlations website.

Individual State Science Standards

- This guide has been correlated to each state's individual science standards. These correlations are broken down by grade level and guide title, and can be downloaded as a spreadsheet from the NEED website.



Exploring Photovoltaics Materials

ACTIVITY	MATERIALS IN KIT	ADDITIONAL MATERIALS NEEDED
PV Ping Pong	▪24 Ping pong balls	▪Flashlight ▪Colored tape ▪Sticky name tags
Solar 1	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Light source*
Solar 2	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Light source*
Solar 3	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Light source (bright and dim)*
Solar 4	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Protractors ▪Light source*
Solar 5	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Measuring tape or meter stick ▪Light source*
Solar 6	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Cardboard ▪Light source*
Solar 7	▪Alligator clips ▪PV cell kits ▪Multimeters ▪Fresnel lenses	▪Ruler ▪Light source*
Solar 8	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Ice water ▪Stopwatch ▪Light source*
Solar 9	▪Alligator clips ▪PV cell kits ▪Multimeters	▪Light source*
Extensions	▪Alligator clips ▪PV cell kits (fan motors and arrays) ▪Multimeters	▪Light source*

NOTE: Consider the bulbs used with the PV cell kits when using lamps for artificial light. It may be necessary to check the light source's compatibility with the panels, as newer energy-efficient light bulbs emit different wavelengths of light that may not be adequate for the cells in the panels. A traditional 60-watt incandescent bulb works best, but bulbs labelled "work bulb," and heat lamps may also work. It also may be necessary to substitute a different load into the setup, based on the light source. Call NEED for help with bulbs and troubleshooting concerns.

Teacher Guide

Grade Level

- Secondary, grades 9-12

Note

This unit focuses on solar energy as it relates to photovoltaic cells and electricity. For information on solar energy and heating, you may wish to copy the *Solar Space Heating* article on pages 25-26 for your students to read.

Internet Resources

American Solar Energy Society
www.ases.org

Lawerance Berkely Lab Traking the Sun
https:// emp.lbl.gov/tracking-the-sun/

Energy Information Administration
www.eia.gov

EIA Energy Kids
www.eia.gov/kids

Energy Schema Solar Energy Animations
www.NEED.org/solarmaterials

Interstate Renewable Energy Council
www.irecusa.org

Interstate Renewable Energy Council Solar Career Map
http://irecsolarcareermap.org/about-this-map

National Renewable Energy Laboratory Open PV Project
http://openpv.nrel.gov/

Solar Energy Industries Association
www.seia.org

U.S. Department of Energy, Solar Energy Technologies Office
https://www.energy.gov/eere/solar/solar-energy-technologies-office

U.S. Department of the Interior Bureau of Land Management
www.blm.gov

Background

The *Exploring Photovoltaics* unit focuses on how solar energy is used to generate electricity. The student informational text has information on photovoltaic cells, concentrated solar power, and emerging solar technologies.

Time

Five to six 45-minute class periods

Preparation

- Familiarize yourself with the Teacher and Student Guides, and with the materials in the kit. Be sure you read the informational text in the Student Guide and understand the information associated with each activity you choose to conduct.
- Review the teacher masters on pages 16, and 19-24. Make copies or download digital files to project as needed.
- Collect the materials that are not included in the kit. See the *Additional Materials Needed* list on page 5. It is suggested that you test the equipment and read the operating manuals prior to instruction.
- Set up six centers that each have 2 multimeters, one PV cell kit, 2 sets of alligator clips, and a reflecting lamp or access to direct sunlight. Investigations can be conducted outside.

Science Notebooks

Throughout this curriculum, science notebooks are referenced. If you currently use science notebooks or journals, you may have your students continue using them. A rubric to guide assessment of student notebooks can be found on page 9.

In addition to science notebooks, student worksheets have been included in the Student Guide. Depending on your students' level of independence and familiarity with the scientific process, you may choose to use these instead of science notebooks. Or, as appropriate, you may want to make copies of worksheets and have your students glue or tape the copies into their notebooks.

Activity 1: Introduction to Solar Energy

Objectives

- Students will be able to describe how a PV cell converts radiant energy into electricity.
- Students will be able to calculate power in watts using a PV module and compare several module outputs.

✔ Procedure

1. Distribute the Student Guides to the students and have them read the informational text in class or as homework. Students should answer the review questions on page 14 of the Student Guide.
2. Play *Solar Energy Bingo* and/or *Solar Energy in the Round* as an introductory activity to gauge student comfortability with solar energy vocabulary. Instructions are found on pages 13-15. Play these games throughout the unit as formative asessments.
3. Review and discuss a PV cell and its function with the class using the *Photovoltaic Cell* master on page 16.
4. Assign students to roles and set up and run the *PV Ping Pong Simulation* as written on page 17.
5. Discuss answers to the review questions with the students. Answers are provided on page 10 of the Teacher Guide.

CONTINUED ON NEXT PAGE

6. Place the students in their groups at the six centers.
7. Using the *Digital Multimeter* master on page 19 (also found on page 17 of the Student Guide) and the operating manual, explain how to use the multimeter. Remind students that when assembling their investigations, their set up may require extra lengths of wiring than the diagrams demonstrate, due to work space and lengths of connections. As long as the connections follow the general setup of the diagram, a longer line of wires will not matter.
8. Remind students that the diagrams include dashed and solid lines to represent different sets of wiring. One set of alligator clips is represented by the dashed line, while the other set is represented by the solid line so as to avoid confusion in the diagrams.
9. Review any lab safety rules you have with your students.
10. Instruct the students to familiarize themselves with the equipment and complete the first investigation, *Solar 1* on page 18 of the Student Guide.

***NOTE*:** The diagrams in the solar activities suggest using the fan from the PV cell kit as the load. Other loads can be substituted in these activities such as the buzzer/music box or light bulb. Under many lamps, the buzzer/music box often works best. If using the light bulb as your load, please note that due to the incandescent bulb and potential resistance of the pathway, the bulb may not light reliably, unless extremely close to the light source. As a substitution, a small LED or Christmas light bulb can work well in place of the light in the PV cell kit.

Activity 2: Investigating PV Cells, Part 1

✪ Objectives

- Students will be able to assemble a series circuit.
- Students will be able to describe how light intensity and the angle of the panel will affect a PV panel's output.

✔ Procedure

1. Place the students in their groups at the six centers.
2. Review series circuits using the masters on pages 20-21. Let students know that many of the investigations will require the PV cells to be wired in a series circuit.
3. Have groups work through investigations 2-4. Instruct the students to conduct the investigations and record the results as group work, but to complete the conclusion and reflections sections individually, then discuss in their groups. Reference the expected outcomes, if needed, on page 11 when observing group discussions.

Activity 3: Investigating PV Cells, Part 2

✪ Objectives

- Students will be able to assemble a series circuit.
- Students will be able to describe how distance from a light source and obstructions will affect a PV panel's output.

✔ Procedure

1. Place the students in their groups at the six centers.
2. Instruct the students to conduct investigations 5-8 and record the results as group work, but to complete the conclusion and reflections sections individually, then discuss in their groups.
3. Review and discuss the results, conclusions, reflections, and challenges as a class. Reference the expected outcomes, if needed, on page 11 when discussing overall results and challenges as a class.

Activity 4: Investigating PV Cells, Part 3

✪ Objective

- Students will be able to describe how the electrical output of a PV panel is affected when wired in series and in parallel.

✔ Procedure

1. Introduce *Solar 9* to the class. Direct students to individually design an experiment to answer the question.
2. Place the students in their groups at the six centers.
3. Instruct each group to review and discuss their individual experimental designs for *Solar 9* and come up with a group design. Once groups have tested their array wired in parallel, students can re-test some of the previous investigations, this time using parallel circuits, to see if their reflections based on *Solar 9* are correct.
4. As students re-test previous investigations, they should record observations and data in Student Guides or science notebooks.
5. Review and discuss the results, conclusions, reflections, and challenges as a class.

Extensions

1. PV Investigation Extensions

- Combine groups so you have three large groups that will share equipment.
- Have the students conduct the extension investigations (1-4) on pages 27-30 of the Student Guide.
- Review and discuss the results, conclusions, reflections, and challenges as a class. Answer suggestions for *Extension 4* can be found on page 12 of the Teacher Guide.

2. Can Solar Meet Your Electricity Demands?

- Have the students analyze their electricity usage and peak sun hours to determine whether or not solar energy can meet their demands. Students should use their own electric bill to determine their family's electricity usage. If they do not have access to an electricity bill, students can use the national average of 867 kWh a month for electricity consumption. Have students complete page 31 of the Student Guide.
- A full page *U.S. Solar Resource Map* is included on page 24 of the Teacher Guide and on page 32 of the Student Guide. For color maps and more information about solar resources in the U.S., visit the National Renewable Energy Laboratory website at www.nrel.gov/gis/solar.html.
- As a further extension, have your students analyze the payback period in cities that have different peak solar hours than your city.

3. Your Solar-Powered Cabin

- Have students work in pairs or individually to power "Uncle Ed's" cabin on pages 33-34 of the Student Guide.
- Have students present or discuss their plans with the class.

4. Data Collection

- Download NEED's *Schools Going Solar* guide from shop.NEED.org for data collection activities for solar installations.

☑ Evaluation and Asessments

There are a variety of assessment opportunities provided in this module. These include:

- Conduct the *Solar-Powered Cabin* activity as an assessment.
- Revisit the *Review Questions* on page 14 of the Student Guide.
- Play *Solar Energy Bingo* or *Solar Energy in the Round* as review activities before an assessment. Instructions can be found on pages 13-15.
- Evaluate student work and group work using the rubrics on page 9.
- Evaluate the unit with the class using the *Evaluation Form* on page 31.

Rubrics for Assesment

Inquiry Explorations Rubric

This is a sample rubric that can be used with inquiry investigations and science notebooks. You may choose to only assess one area at a time, or look at an investigation as a whole. It is suggested that you share this rubric with students and discuss the different components.

	SCIENTIFIC CONCEPTS	SCIENTIFIC INQUIRY	DATA/OBSERVATIONS	CONCLUSIONS
4	Written explanations illustrate accurate and thorough understanding of scientific concepts.	The student independently conducts investigations and designs and carries out his or her own investigations.	Comprehensive data is collected and thorough observations are made. Diagrams, charts, tables, and graphs are used appropriately. Data and observations are presented clearly and neatly with appropriate labels.	The student clearly communicates what was learned and uses strong evidence to support reasoning. The conclusion includes application to real life situations.
3	Written explanations illustrate an accurate understanding of most scientific concepts.	The student follows procedures accurately to conduct given investigations, begins to design his or her own investigations.	Necessary data is collected. Observations are recorded. Diagrams, charts, tables, and graphs are used appropriately most of the time. Data is presented clearly.	The student communicates what was learned and uses some evidence to support reasoning.
2	Written explanations illustrate a limited understanding of scientific concepts.	The student may not conduct an investigation completely, parts of the inquiry process are missing.	Some data is collected. The student may lean more heavily on observations. Diagrams, charts, tables, and graphs may be used inappropriately or have some missing information.	The student communicates what was learned but is missing evidence to support reasoning.
1	Written explanations illustrate an inaccurate understanding of scientific concepts.	The student needs significant support to conduct an investigation.	Data and/or observations are missing or inaccurate.	The conclusion is missing or inaccurate.

Culminating Project Rubric

This rubric may be used with the extensions or for any other group work you ask the students to do.

	CONTENT	ORGANIZATION	ORIGINALITY	WORKLOAD
4	Project covers the topic in-depth with many details and examples. Subject knowledge is excellent.	Content is very well organized and presented in a logical sequence.	Project shows much original thought. Ideas are creative and inventive.	The workload is divided and shared equally by all members of the group.
3	Project includes essential information about the topic. Subject knowledge is good.	Content is logically organized.	Project shows some original thought. Work shows new ideas and insights.	The workload is divided and shared fairly equally by all group members, but workloads may vary.
2	Project includes essential information about the topic, but there are 1-2 factual errors.	Content is logically organized with a few confusing sections.	Project provides essential information, but there is little evidence of original thinking.	The workload is divided, but one person in the group is viewed as not doing a fair share of the work.
1	Project includes minimal information or there are several factual errors.	There is no clear organizational structure, just a compilation of facts.	Project provides some essential information, but no original thought.	The workload is not divided, or several members are not doing a fair share of the work.

Answer Key

STUDENT GUIDE REVIEW QUESTIONS

1. Identify and explain the nuclear reaction in the sun that produces radiant energy. *Smaller hydrogen nuclei fuse together to create larger helium atoms. During the process, some of the matter is converted and emitted as radiant energy.*
2. Define renewable energy. Explain why solar energy is considered renewable. *Renewable energy sources are resources that are continuously replenished by nature and never run out. Fusion reactions that power the sun will generate light for billions of years to come.*
3. Explain why a car parked in the sun becomes hot inside. *Light passes through the windows of a car and is absorbed by the interior fixtures, where it is converted and trapped as heat. The car is a solar collector.*
4. Why is a solar cell called a PV cell? What does the word photovoltaic mean? *A solar cell is called a PV cell because it uses light or solar energy to create electricity. "Photo" refers to light and "volt" is a measure of electricity.*
5. Explain the conversion efficiency of a PV cell. How efficient are PV cells today? *Conversion efficiency is the proportion of radiant energy the cell is able to convert to electricity. Current PV cells convert approximately 13-30 percent of the radiant energy striking them into electricity.*
6. How do new thin-film technologies compare to conventional PV cells? *New technologies and designs have produced conversion efficiencies as high as 46 percent, but with limitations to their uses.*
7. Explain briefly how a PV cell converts radiant energy into electricity. *A PV cell is made of silicon with layers. Each layer has a different "dopant" applied to it creating positive and negative characters. When these layers meet, free electrons from the n-type layer flow into the p-type layer creating an electric field at their junction. As radiant energy hits the electrons in the junction, the electrons are knocked free and attracted to the n-type layer. A conducting wire allows the free electrons to travel away from each other in a complete circuit, creating an electric current.*
8. Do PV modules produce AC or DC current? Which type of current do most appliances use? What device converts DC to AC current? *PV modules produce direct current. Most appliances and electronics require alternating current to run, thus an inverter may be required to convert DC to AC.*
9. Define the following electrical measures and the unit of measurement for each.

   voltage*: the amount of pressure applied to make electrons move, strength of the current in a circuit. Units = volts (V)*

   current: *electrons flowing between two points with a difference in voltage. Units = amperes or amps (A)*

   resistance*: slowing the flow of electrons. Units = ohms (Ω)*

   power: *the amount of electric current flowing based on voltage applied, amount of electricity required to start or operate a load. Units = watts (W)*
10. What is the average cost of a kilowatt-hour of electricity for U.S. residential customers? *The average cost of a kWh for U.S. residents is about 12.9 cents.*

Expected Outcomes

SOLAR INVESTIGATIONS

Solar 1

Question: How do similar PV modules in an array vary in electrical output? Think about which varies more, current or voltage.

Conclusion: The PV modules should produce similar, though perhaps not identical, results.

Solar 2

Question: How does a PV array wired in series affect the electrical output? Think about what will happen to current and voltage output.

Conclusion: Combining PV modules in series increases the voltage produced in direct proportion to the number of PV cells in the circuit, and the current should remain constant.

Solar 3

Question: How does light intensity affect the electrical output of a PV array wired in series?

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

Solar 4

Question: How does the angle of a PV array (wired in series) relative to the light source affect the electrical output?

Conclusion: The greater the angle from perpendicular, the less the electrical output. As the angle increases, the amount of light hitting the PV cells decreases, reducing the wattage.

Solar 5

Question: How does the distance from a light source affect the electrical output of a PV array wired in series?

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

Solar 6

Question: How does covering different parts of the PV array wired in series affect its electrical output?

Conclusion: The wattage decreases in proportion to the increase in the percentage of the PV panel in the shadow.

Solar 7

Question: How does concentrating the light from a light source affect the electrical output of a PV array wired in series?

Conclusion: Concentrated light will increase the voltage and amps, individually, thus increasing the overall output (watts) of the PV array.

Solar 8

Question: How does surface temperature affect the electrical output of a PV array wired in series?

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

Solar 9

Question: How does a PV array wired in parallel affect the electrical output? Think about what will happen to current and voltage output.

Conclusion: Wiring PV arrays in parallel increases the current produced in proportion to the number of cells combined, but the voltage remains the same.

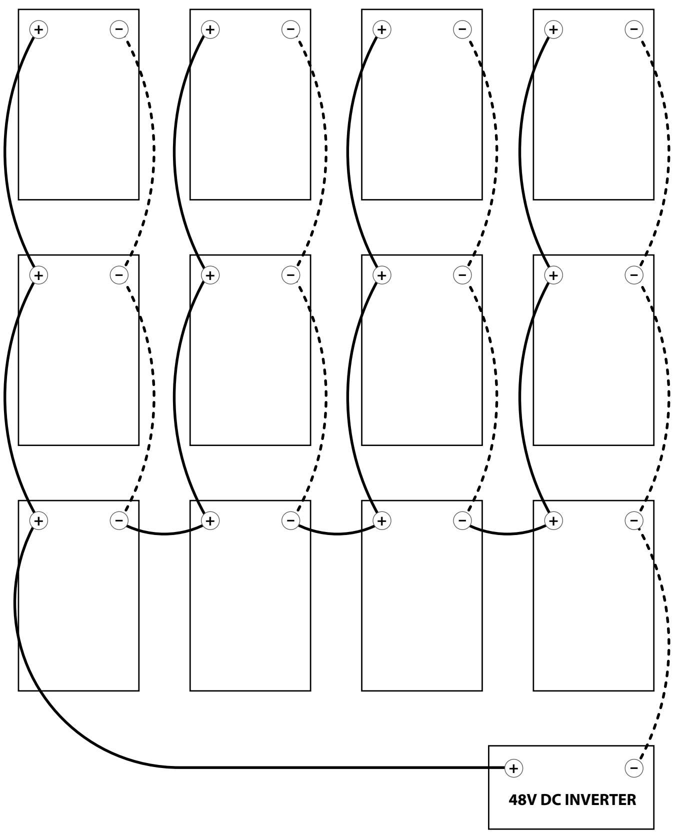
NOTE: The diagrams in the solar activities suggest using the fan from the PV cell kit as the load. Other loads can be substituted in these activities such as the buzzer/music box or light bulb. Under lamps that are not incandescent, the buzzer/music box often works best. If using the light bulb as your load, please note that due to the incandescent bulb and potential resistance of the pathway, the bulb may not light reliably, unless extremely close to the light source. As a substitution, a small LED or Christmas light bulb can work well in place of the light in the PV cell kit.

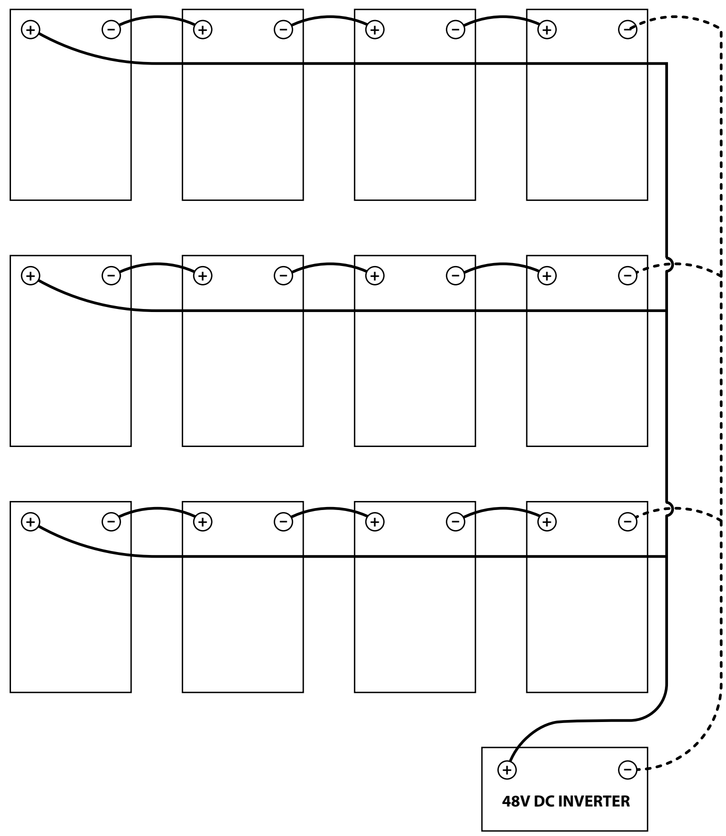
Answer Key

EXTENSION 4

Below are twelve 12-volt photovoltaic modules rated at 80 watts each. Design an array to deliver 48 volts to the inverter by using a combination of series and parallel circuits. Use dashed lines to represent the black (-) wires, and solid lines to represent the red (+) wires.

Below are two possible wiring configurations.





Solar Energy BINGO Instructions

Get Ready

Duplicate as many *Solar Energy Bingo* sheets (found on page 27 of the Teacher Guide) as needed for each person in your group. In addition, decide now if you want to give the winner of your game a prize and what the prize will be.

Get Set

Pass out one *Solar Energy Bingo* sheet to each member of the group.

Go

PART ONE: FILLING IN THE BINGO SHEETS

Give the group the following instructions to create bingo cards:

- This bingo activity is very similar to regular bingo. However, there are a few things you'll need to know to play this game. First, please take a minute to look at your bingo sheet and read the 16 statements at the top of the page. Shortly, you'll be going around the room trying to find 16 people about whom the statements are true so you can write their names in one of the 16 boxes.
- When I give you the signal, you'll get up and ask a person if a statement at the top of your bingo sheet is true for them. If the person gives what you believe is a correct response, write the person's name in the corresponding box on the lower part of the page. For example, if you ask a person question "D" and he or she gives you what you think is a correct response, then go ahead and write the person's name in box D. A correct response is important because later on, if you get bingo, that person will be asked to answer the question correctly in front of the group. If he or she can't answer the question correctly, then you lose bingo. So, if someone gives you an incorrect answer, ask someone else! Don't use your name for one of the boxes or use the same person's name twice.
- Try to fill all 16 boxes in the next 20 minutes. This will increase your chances of winning. After the 20 minutes are up, please sit down and I will begin asking players to stand up and give their names. Are there any questions? You'll now have 20 minutes. Go!
- During the next 20 minutes, move around the room to assist the players. Every five minutes or so tell the players how many minutes are remaining in the game. Give the players a warning when just a minute or two remains. When the 20 minutes are up, stop the players and ask them to be seated.

PART TWO: PLAYING BINGO

Give the class the following instructions to play the game:

- When I point to you, please stand up and in a LOUD and CLEAR voice give us your name. Now, if anyone has the name of the person I call on, put a big "X" in the box with that person's name. When you get four names in a row—across, down, or diagonally—shout "Bingo!" Then I'll ask you to come up front to verify your results.
- Let's start off with you (point to a player in the group). Please stand and give us your name. (Player gives name. Let's say the player's name was "Joe.") Okay, players, if any of you have Joe's name in one of your boxes, go ahead and put an "X" through that box.
- When the first player shouts "Bingo," ask him (or her) to come to the front of the room. Ask him to give his name. Then ask him to tell the group how his bingo run was made, e.g., down from A to M, across from E to H, and so on.

***Solar Energy Bingo* is a great icebreaker for a NEED workshop or conference. As a classroom activity, it also makes a great introduction to an energy unit.**

Preparation

- 5 minutes

Time

- 45 minutes

Bingos are available on several different topics. Check out these resources for more bingo options!

- Biomass Bingo—*Energy Stories and More*
- Change a Light Bingo—*Energy Conservation Contract*
- Coal Bingo—Coal guides
- Energy Bingo—*Energy Games and Icebreakers*
- Energy Efficiency Bingo—*School Energy Managers* and *School Energy Experts*
- Hydropower Bingo—Hydropower guides
- Hydrogen Bingo—*H_2 Educate*
- Nuclear Energy Bingo—Nuclear guides
- Oil and Natural Gas Bingo—Oil and Natural Gas guides
- Science of Energy Bingo—*Science of Energy* guides
- Wind Energy Bingo—Wind guides

- Now you need to verify the bingo winner's results. Ask the bingo winner to call out the first person's name on his bingo run. That player then stands and the bingo winner asks him the question which he previously answered during the 20-minute session. For example, if the statement was "can name two renewable sources of energy," the player must now name two sources. If he can answer the question correctly, the bingo winner calls out the next person's name on his bingo run. However, if he does not answer the question correctly, the bingo winner does not have bingo after all and must sit down with the rest of the players. You should continue to point to players until another person yells "Bingo."

SOLAR ENERGY BINGO

ANSWERS

A. Has used a solar clothes dryer

B. Knows the average conversion efficiency of PV cells

C. Knows the nuclear process in the sun's core

D. Knows how radiant energy travels through space

E. Can explain how solar energy drives the water cycle

F. Has used a photovoltaic cell

G. Rides in a solar collector

H. Can explain how solar energy produces wind

I. Knows how plants convert solar energy into chemical energy

J. Uses passive solar energy at home

K. Has seen a solar water heater

L. Has cooked food in a solar oven

M. Can name two advantages of solar energy

N. Knows the energy conversion that a PV cell performs

O. Can explain why dark clothes make you hotter in the sun

P. Owns solar protection equipment

A Has hung clothes outside to dry	**B** 13-30%	**C** Fusion	**D** In electromagnetic waves (or transverse waves)
E Sun evaporates water in lakes and oceans, water vapor rises and becomes clouds, rains to replenish	**F** ask for location/description	**G** Car without tinted windows is a solar collector-like a greenhouse	**H** Sun heats the Earth's surface unevenly-hot air rises and cooler air moves in
I Photosynthesis	**J** Allows sun to enter through windows for light and heat-has materials that retain heat (masonry, tile, etc.)	**K** ask for location/description	**L** ask for description
M Solar energy systems do not produce air pollutants or carbon dioxide, minimal impact on environment, sun's energy is free	**N** radiant energy to electrical energy	**O** Dark colors absorb more radiant energy and turn it into thermal energy	**P** Sun screen, sunglasses, etc.

Solar Energy in the Round

Get Ready

- Copy the *Solar Energy in the Round* cards on pages 28-30 onto card stock and cut into individual cards.
- Make an additional copy to use as your answer key. These pages do not need to be cut into cards.
- Have the *Exploring Photovoltaics* Student Guides or NEED's *Secondary Energy Infobooks* available for quick reference. Infobooks can be downloaded from shop.NEED.org.

Get Set

- Distribute one card to each student. If you have cards left over, give some students two cards so that all of the cards are distributed.
- Have the students look at their bolded words at the top of the cards. Give them five minutes to review the information about their words.

Go

- Choose a student to begin the round and give the following instructions:
  - Read the question on your card. The student with the correct answer will stand up and read the bolded answer, "I have _____."
  - That student will then read the question on his/her card, and the round will continue until the first student stands up and answers a question, signaling the end of the round.
- If there is a disagreement about the correct answer, have the students listen to the question carefully looking for key words (forms versus sources, for example) and discuss until a consensus is reached about the correct answer.

Alternative Instructions

- Give each student or pair a set of cards.
- Students will put the cards in order, taping or arranging each card so that the answer is directly under the question.
- Have students connect the cards to fit in a circle or have them arrange them in a column.

***Solar Energy in the Round* is a quick, entertaining game to reinforce vocabulary and information about solar energy and photovoltaics.**

Grades

- 5–12

Preparation

- 5 minutes

Time

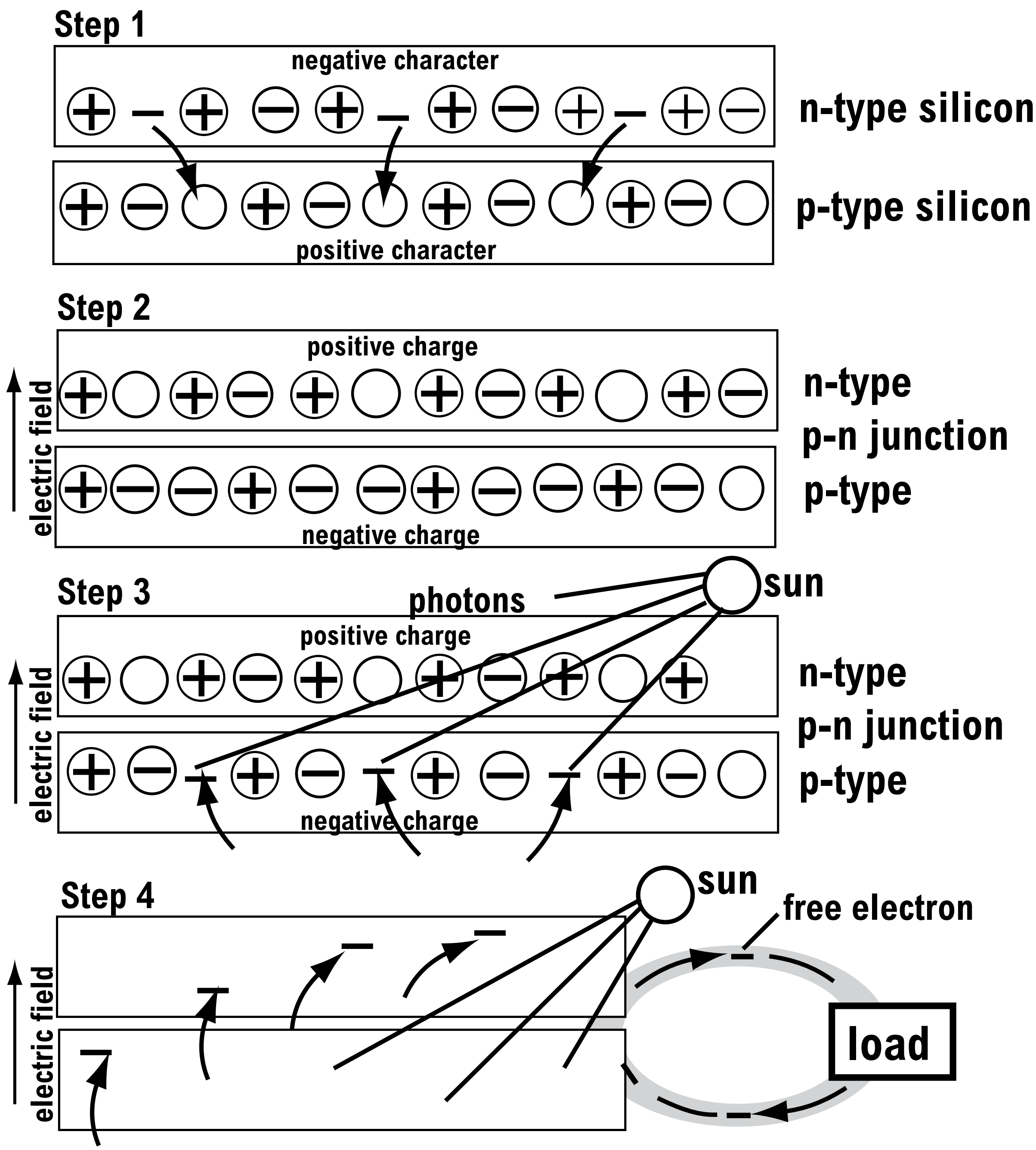
- 10–20 minutes

"In the Rounds" are available on several different topics. Check out these guides for more, fun "In the Round" examples!

- Coal in the Round—Coal guides
- Conservation in the Round—*School Energy Managers, School Energy Experts*
- Energy in the Round—*Energy Games and Icebreakers*
- Forms of Energy in the Round—*Science of Energy* guides
- Hydrogen in the Round—*H_2 Educate*
- Oil and Natural Gas Industry in the Round—*Fossil Fuels to Products*, *Exploring Oil and Natural Gas*
- Uranium in the Round—Nuclear guides

Photovoltaic Cell

○	A location that can accept an electron
–	Free electron
⊕	Proton
⊖	Tightly-held electron



PV Ping Pong Simulation

Background

Solar energy can be used to produce electricity without any chemical reaction. This process, known as the photoelectric effect, allows electrons to be ejected or emitted from the surface of a material when photons of light strike the material. Solar panels, or photovoltaic cells, are the devices we use to collect radiant energy from the sun and turn it directly into electricity to power our homes, schools, and businesses. This process, however, can be somewhat mystifying to students. In this simulation, students will act as the layers of a solar cell within a solar panel, photons of light, and electrons on the move.

Materials

- 20 – 25 Foam or tennis balls
- Flashlight
- Colored tape
- Sticky name tags
- *Photovoltaic Cell* master

Preparation

- Set up two lines of tape on the floor for students to stand on. The lines should be facing each other with a few feet between them.
- Create a circle behind one of the tape lines. This will be the photon home.
- Write out name tags for each of the roles. This can also be done by the students once roles are assigned. You may choose to get "fancy" giving name tags or props that resemble roles as well (i.e., N-layers=N, photons=light bulbs, etc.).

✔ Procedure

1. Show students the digital PV cell simulations on NEED's website:

   Overview of Solar Cells - http://www.need.org/content.asp?contentid=157

   Single Junction Silicon Solar Cells - http://www.need.org/content.asp?contentid=158
2. Assign students to roles.
3. Ask the P-layer students to stand on one line and the N-layer students to stand on the other line so that they are facing each other. Tell them the P-N junction is between them. Have the students on each line hold hands "wiring" themselves together.
4. The electrical load(s) should stand at the end of two lines. Students on the end of each line should hold hands with the electrical load, forming an open loop from P-layer through electrical load and on to N-layer.
5. Ask the photons to congregate in the photon circle, their "light source".
6. Give each N-layer student a ball. Tell students these are electrons. P-layer students should have none but should want to receive them.
7. When you signal, have the N-layer students toss their electrons to P-layer students, who will catch them.
8. When you signal, photons must leave the light source circle and tap a P-layer student (student with a ball) on the shoulder. They should then return to the circle and repeat the process.
9. When a P-layer student with a ball feels a tap, he or she should pass their electron down to the next person in line towards the electrical load to start the flow of current (or balls) toward the electrical load student.
10. When the electrical load student receives an electron, he or she should turn on his or her flashlight and yell "WOOO HOO," and turn it off as they pass the electron to the other side.
11. As electrons come to the N-layer from the load, they should immediately be tossed to the P-layer again.
12. Simulate darkness by having photon students sit in their circle, not moving. P-layer students should stand, holding electrons, ready to receive photons.

PV Ping Pong Simulation and Roles

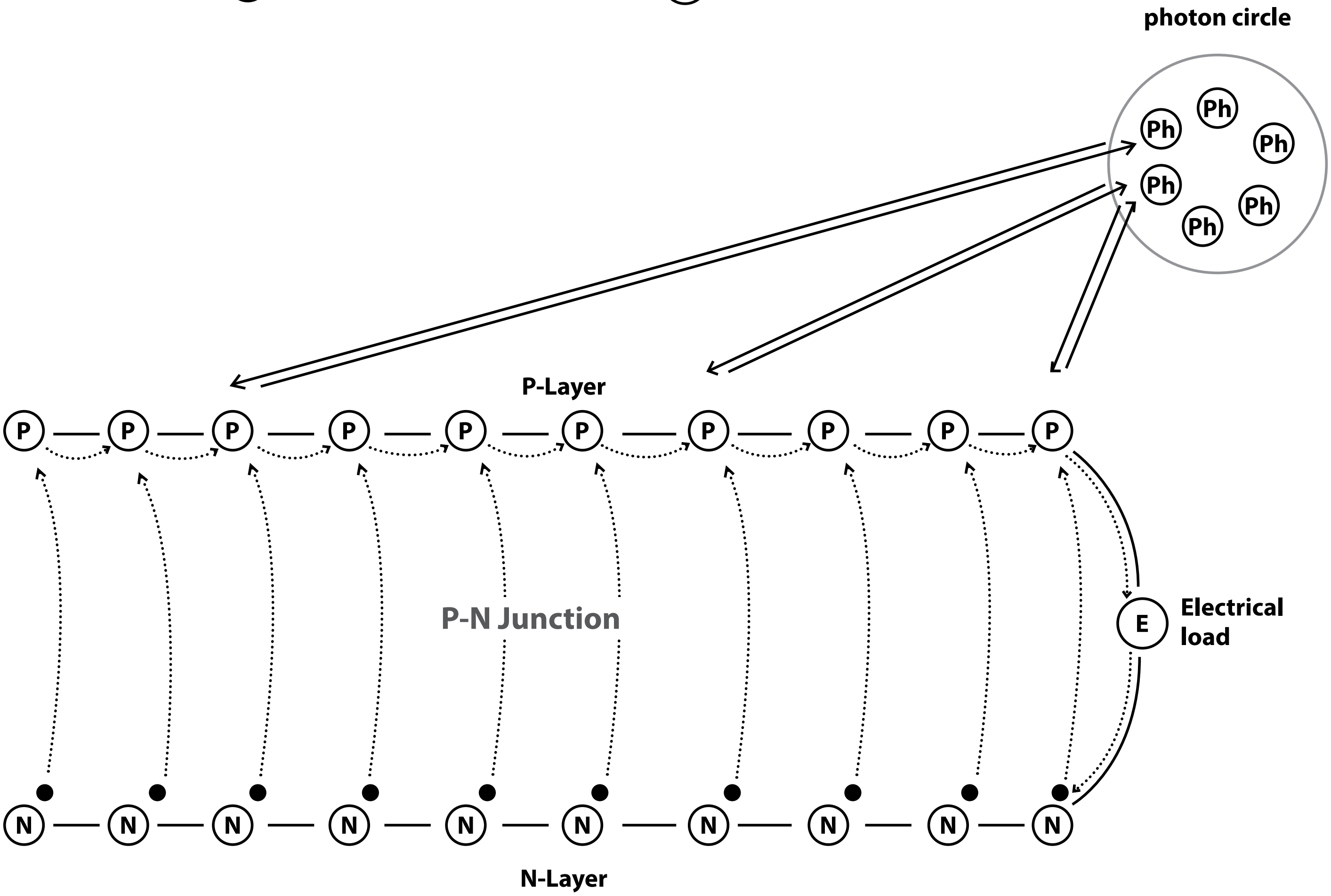
N-layer students – 17 N

P- layer students – 17 P

Photon students – 10 Ph

Electrical load students – 1-2 E

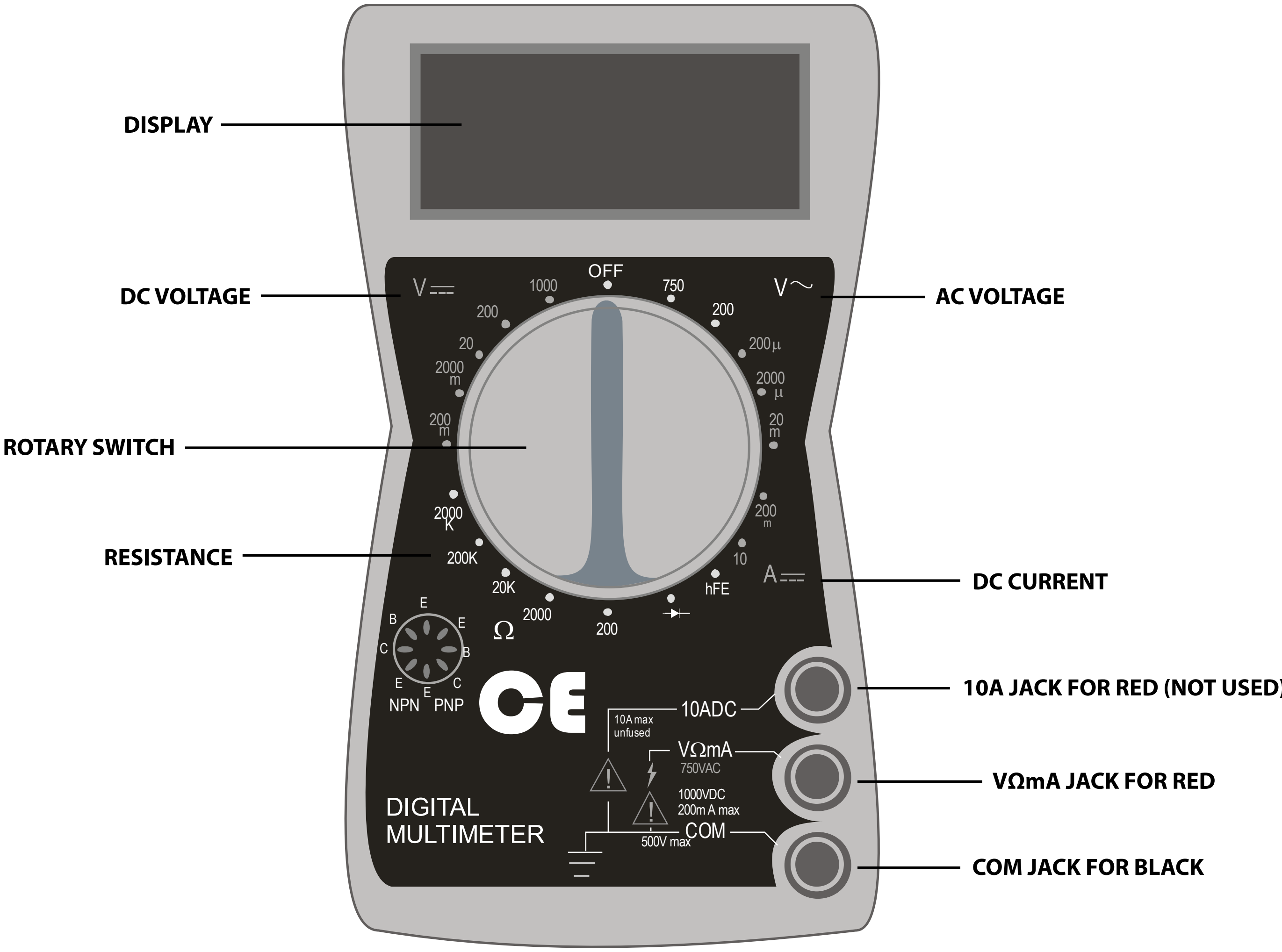
● Ball



Extensions

- Have students determine how they would extend the simulation to include more solar arrays and devices into the circuitry.
- Have students write a description of how PV cells work.
- Have students design a simulation to showcase how a concentrated solar power (CSP) facility operates.

Digital Multimeter



Directions

DC Voltage (V⎓)

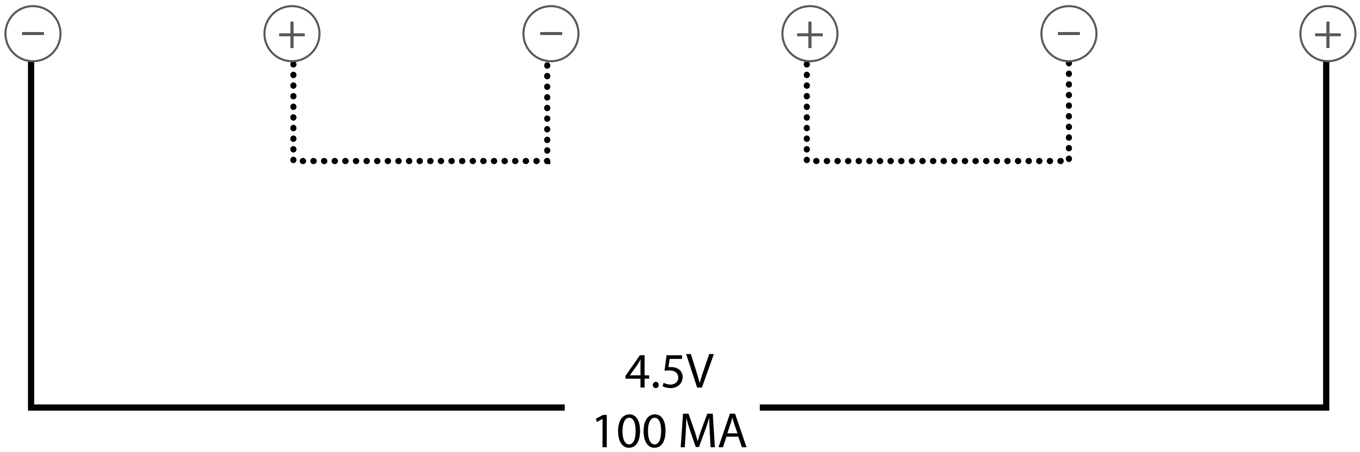
1. Connect RED lead to VΩmA jack and BLACK to COM.
2. Set ROTARY SWITCH to highest setting on DC VOLTAGE scale (1000).
3. Connect leads to the device to be tested using the alligator clips provided.
4. Adjust ROTARY SWITCH to lower settings until a satisfactory reading is obtained.
5. With the solar modules or array, the 20 DCV setting usually provides the best reading.

DC Current (A⎓)

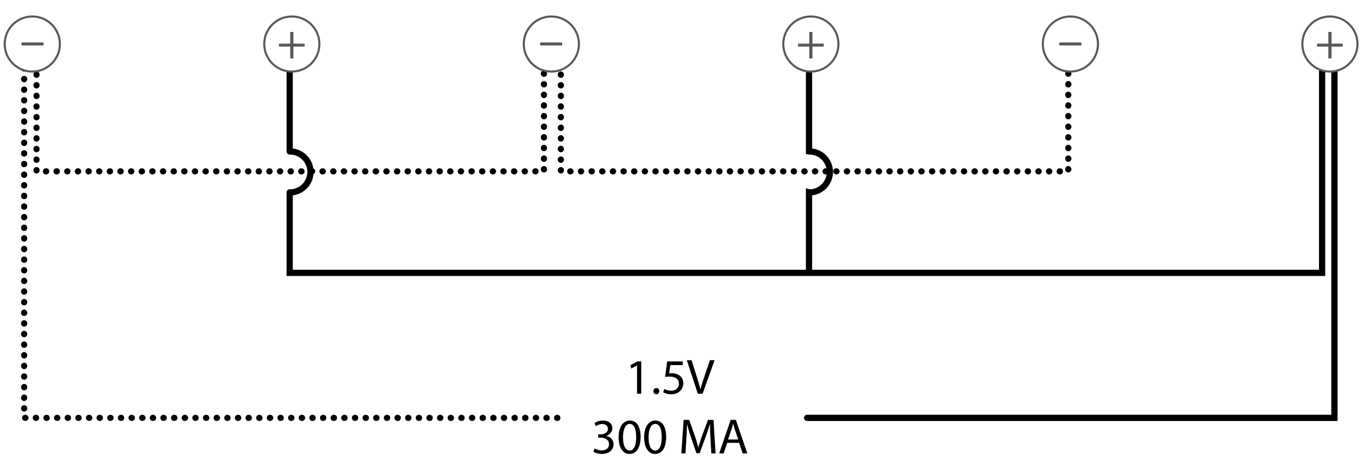
1. Connect RED lead to VΩmA jack and BLACK to COM.
2. Set ROTARY SWITCH to 10 ADC setting.
3. Connect leads to the device to be tested using the alligator clips provided.
   Note: The reading indicates DC AMPS; a reading of 0.25 amps equals 250 mA (milliamps).
4. With the solar modules or array, the 200mA DC setting usually provides the best reading.

YOUR MULTIMETER MIGHT BE SLIGHTLY DIFFERENT FROM THE ONE SHOWN. BEFORE USING THE MULTIMETER READ THE OPERATOR'S INSTRUCTION MANUAL INCLUDED IN THE BOX FOR SAFETY INFORMATION AND COMPLETE OPERATING INSTRUCTIONS.

Series Circuit



Parallel Circuit



Calculation of Power

Power (P) is a measure of the rate of doing work or the rate at which energy is converted. **Electric power** is defined as the amount of electric current flowing due to an applied voltage. Electric power is measured in **watts (W)**. The formula is:

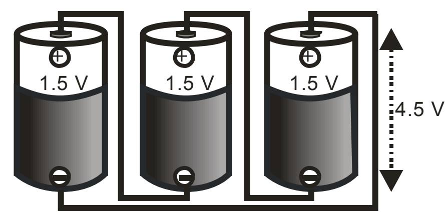
power = voltage x current

$$P = V \times I \quad \text{or} \quad W = V \times A$$

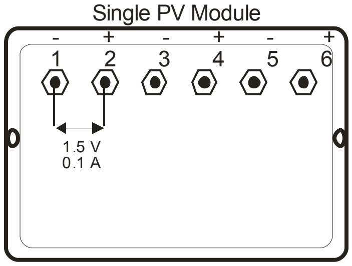
Series Circuits

In series circuits, the current remains constant while the voltage changes. To calculate total voltage, add the individual voltages together:

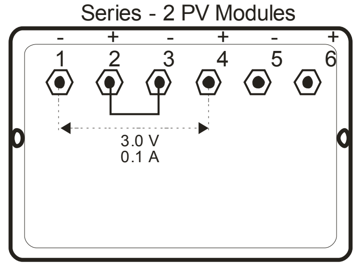
$$I_{total} = I_1 = I_2 = I_3$$
$$V_{total} = V_1 + V_2 + V_3$$



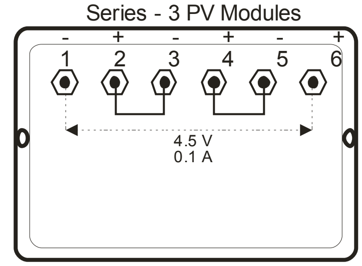
Single PV Module



Series - 2 PV Modules



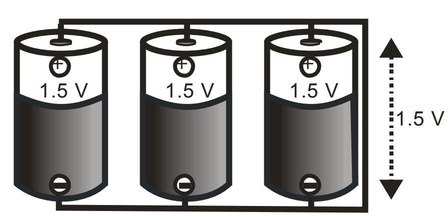
Series - 3 PV Modules



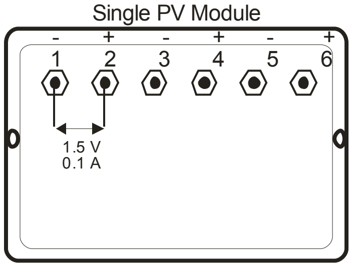
Parallel Circuits

In parallel circuits, the voltage remains constant while the current changes. To calculate total current, add the individual currents together:

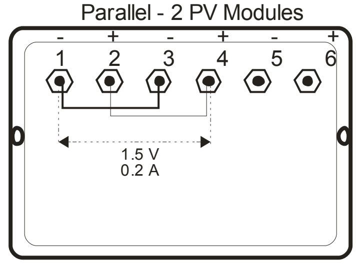
$$I_{total} = I_1 + I_2 + I_3$$
$$V_{total} = V_1 = V_2 = V_3$$



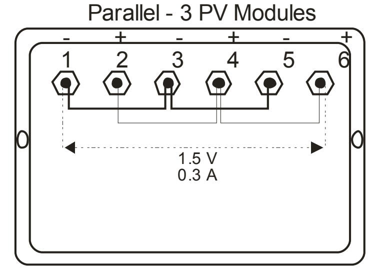
Single PV Module



Parallel - 2 PV Modules



Parallel - 3 PV Modules



Basic Measurement Values in Electronics

SYMBOL	VALUE	METER	UNIT
V	Voltage (the force)	Voltmeter	Volts (V)
I	Current (the flow)	Ammeter	Amps/Amperes (A)
R	Resistance (the anti-flow)	Ohmmeter	Ohms (Ω)

1 Ampere = 1 coulomb/second

1 Coulomb = 6.24 x 10^{18} electrons (about a triple axle dump truck full of sand where one grain of sand is one electron)

Prefixes for Units

- **Smaller**

  (m)illi x 1/1000 or .001

  (µ) micro x 1/1000000 or .000001

  (n)ano x1/100000000 or .000000001

  (p)ico x 1/1000000000000 or .000000000001

- **Bigger**

  (K)ilo x 1,000

  (M)ega x 1,000,000

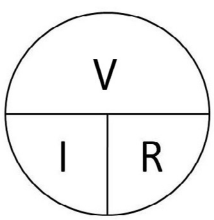
  (G)iga x 1,000,000,000

Formulas for Measuring Electricity

V = I x R

I = V/R

R = V/I



The formula pie works for any three variable equation. Put your finger on the variable you want to solve for and the operation you need is revealed.

- **Series Resistance (Resistance is additive)**

  $R_T = R_1 + R_2 + R_3 \ldots + R_n$

- **Parallel Resistance (Resistance is reciprocal)**

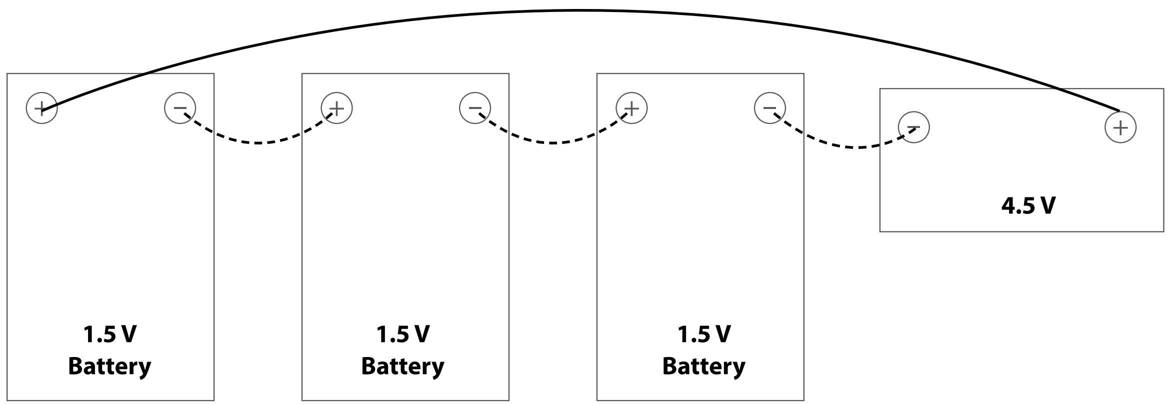
  $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 \ldots + 1/R_n$

Note: ALWAYS convert the values you are working with to the "BASE unit." For example—don't plug kilo-ohms (KΩ) into the equation—convert the value to Ω first.

Solar Array Wiring

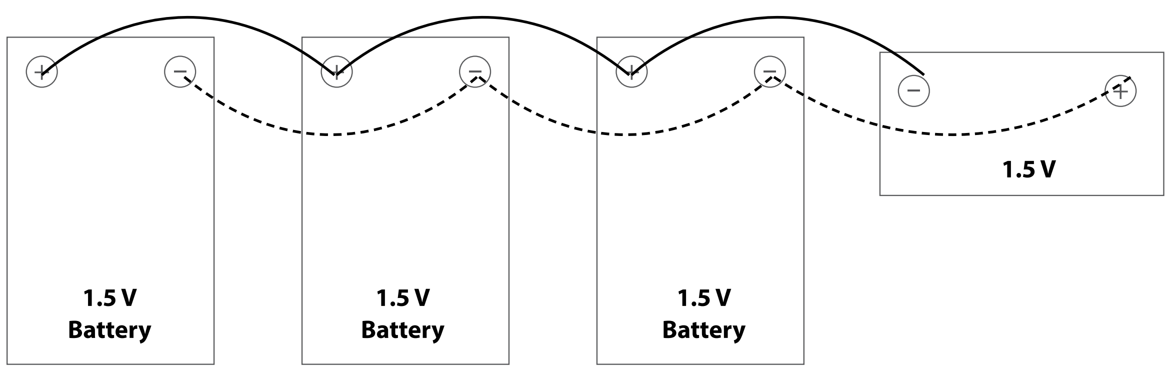
The effects of parallel and series circuitry on voltage output with multiple power sources:

With series circuits, the negative terminal of one component is connected to the positive terminal of the next component, like batteries in a typical flashlight (positive end contacting negative end of the next battery). With series circuits, the total voltage output is cumulative; the sum of the voltage of each component. With three 1.5 V components wired in a series circuit, the total output is 4.5 volts.

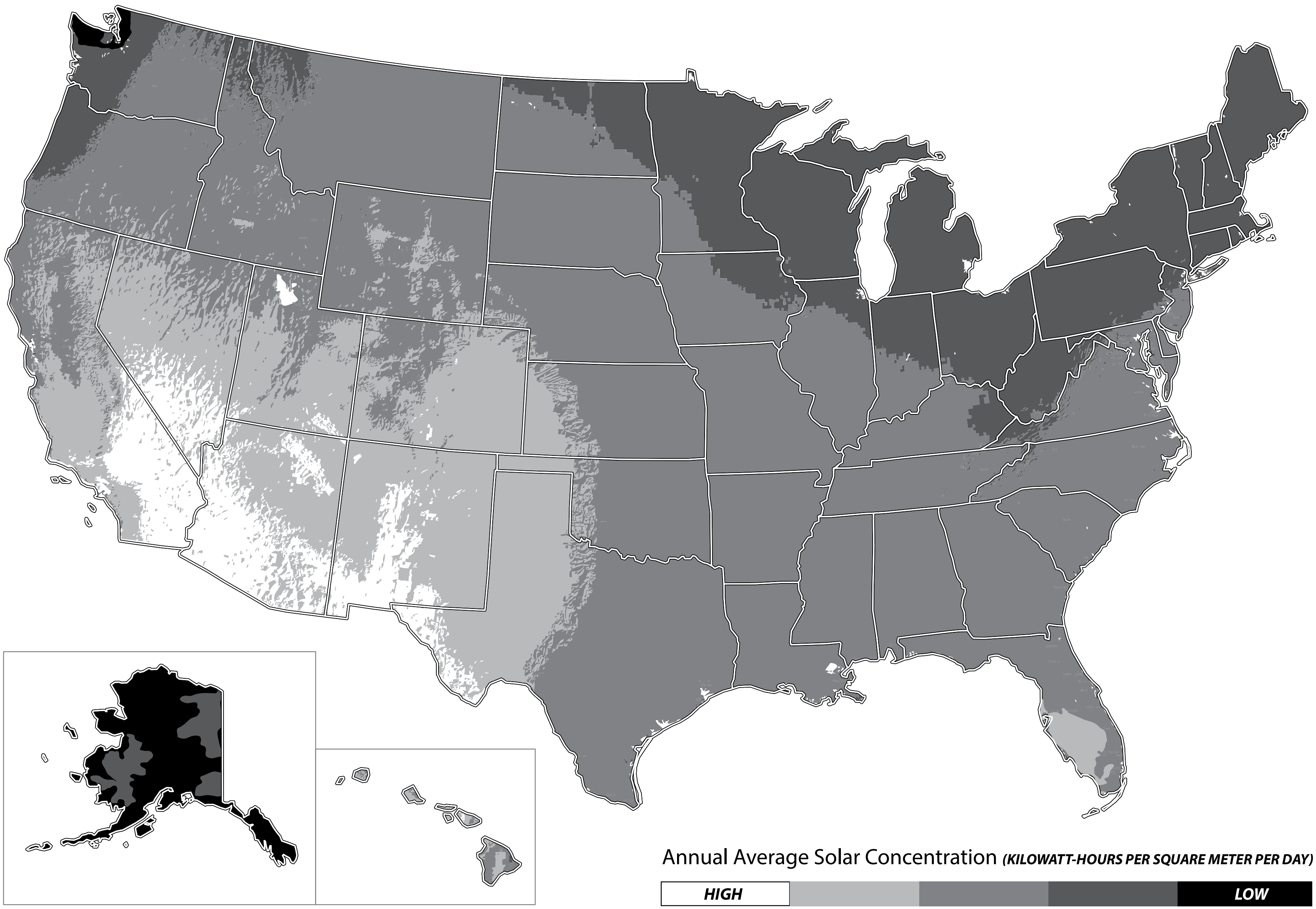


With parallel circuits, all positive terminals are connected and all negative terminals are connected in two strings. The total output voltage of several components wired in parallel is the same as a single component. Using jumper cables to start a car is an example of a parallel circuit with two batteries.

If three 1.5 V components are wired in parallel, the total output of the circuits is 1.5 volts.



U.S. Solar Resource Map



Annual Average Solar Concentration ***(KILOWATT-HOURS PER SQUARE METER PER DAY)***

HIGH				LOW
More than 6	**5 to 6**	**4 to 5**	**3 to 4**	**Less than 3**

Note: Alaska and Hawaii not shown to scale
Data: NREL

Solar Space Heating

Space heating means heating the space inside a building. Today, many homes use solar energy for space heating. There are two general types of solar space heating systems: passive and active.

Passive Solar Homes

In a passive solar home, the house itself operates as a solar collector. A passive home does not use any special mechanical equipment such as pipes, ducts, fans, or pumps to transfer the heat the house collects on sunny days. Instead, a passive solar home relies on properly oriented windows and is designed with added thermal mass to store and release heat. Since the sun shines from the south in North America, passive solar homes are built so that most of the windows face south. They often have few or no windows on the north side.

A passive solar home converts solar energy into heat just as a closed car does. Sunlight passes through a home's windows and is absorbed in the walls and floors. Materials such as tile, stone, and concrete are often used, because they can store more heat than wood or sheetrock. To control the amount of heat in a passive solar home, the designer must determine the appropriate balance of mass in the floors and walls with the admission of sunlight.

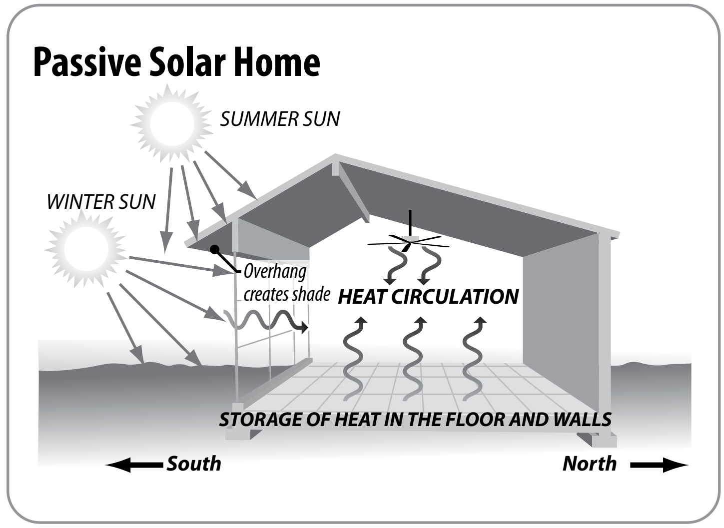
Windows let in the sunlight, which is converted into heat when it is absorbed by the walls and floors. The mass stores the heat from the sun and releases it when the air temperature inside drops below the temperature of the mass. Heating a home by warming the walls or floors is more comfortable than heating the air inside a home.

Additionally, the doors and windows can be closed to keep heated air in or opened to let it out, to keep the temperature in a comfortable range. At night, special heavy curtains or shades can be pulled over the windows to keep the daytime heat inside the home. In the summer, awnings or roof overhangs help to shade the windows from the high summer sun to prevent the home from overheating. Passive homes are quiet, peaceful places to live. A well-designed passive solar home can harness 30 to 80 percent of the heat it needs from the sun.

Many passive homeowners install equipment such as fans to help circulate air to further increase the comfort and energy efficiency of their homes. When special equipment is added to a passive solar home, it is called a hybrid system.

Active Solar Homes

Unlike a passive solar home, an active solar home uses mechanical equipment such as pumps, blowers, and PV cells to convert radiant energy to thermal energy or electricity. Pumps and blowers allow for greater control of when, where, and how much of the collected heat from the sun gets used. This equipment delivers the heat from where it is collected to where it is needed.



PUEBLO DWELLING

Native Americans in the Southwest used passive solar designs when building their homes.

ACTIVE SOLAR HOME

Active solar homes use mechanical equipment such as PV cells, pumps, and blowers to harness the sun's energy.

Storing Solar Heat

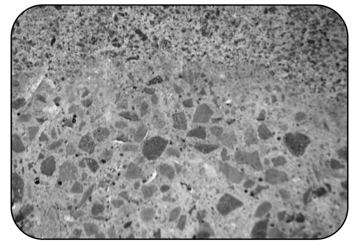
The challenge confronting any solar heating system—whether passive, active, or hybrid—is heat storage. Solar heating systems must have some way to store the heat that is collected on sunny days to keep people warm at night or on cloudy days.

In passive solar homes, heat is stored by using dense interior materials that retain heat well—masonry, adobe, concrete, stone, tile, or water. These materials absorb surplus heat and radiate it back into the room when the air temperature is lower than the surface temperature of the material. Some passive homes have walls up to one foot thick.

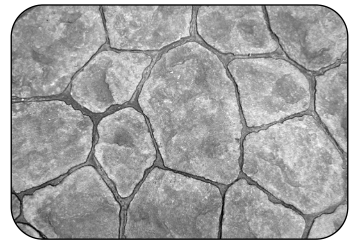
In active solar homes, heat may be stored in one of two ways—a large tank may store a heated liquid, or rock bins beneath the house may store warm mass. Houses with active or passive solar heating systems may also have furnaces, wood-burning stoves, or other heat sources to provide heat during long periods of cold or cloudy weather. These are called back-up systems.

MATERIALS THAT RETAIN HEAT WELL


Masonry


Concrete


Adobe


Stone

Solar Water Heating

Solar energy is also used to heat water. Water heating is the second largest home energy expense, costing the average family nearly $300 a year. Installing a solar water heater can save 50 to 80 percent of your water heating bill, depending on which type of back-up system you have, where you live, and how much hot water your family uses. A well-maintained solar water heating system can last around 20 years, longer than a conventional water heater.

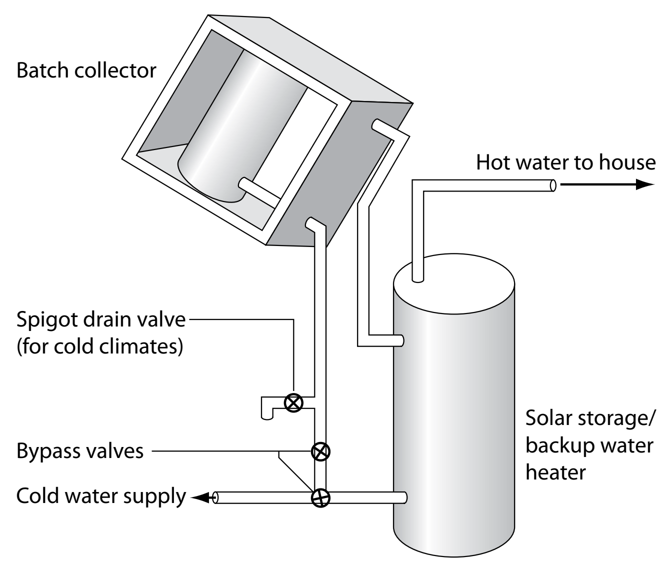
A solar water heater works in the same way as solar space heating. A solar collector is mounted on the roof, or in an area of direct sunlight. It collects sunlight and converts it to heat. When the fluid in the system becomes hot enough, a thermostat starts a pump. The pump circulates the fluid through the collector until it reaches the required temperature, called the set point. Then the heated fluid is pumped to a storage tank where it is used in a heat exchanger to heat water.

The hot water may then be piped to a faucet or showerhead. Most solar water heaters that operate in cold climates use a heat transfer fluid similar to antifreeze that will not freeze and damage the system.

Today, more than 2 million homes in the U.S. use solar heaters to heat water for use in household activities or swimming pools.

SOLAR WATER HEATER

Passive Solar Water Heater



Passive solar water heaters work best in areas where temperatures rarely fall below freezing. They also work well in households with significant daytime and evening hot water needs.

SOLAR ENERGY BINGO

A. Has used a solar clothes dryer

B. Knows the average conversion efficiency of PV cells

C. Knows the nuclear process in the sun's core

D. Knows how radiant energy travels through space

E. Can explain how solar energy drives the water cycle

F. Has used a photovoltaic cell

G. Rides in a solar collector

H. Can explain how solar energy produces wind

I. Knows how plants convert solar energy into chemical energy

J. Uses passive solar energy at home

K. Has seen a solar water heater

L. Has cooked food in a solar oven

M. Can name two advantages of solar energy

N. Knows the energy conversion that a PV cell performs

O. Can explain why dark clothes make you hotter in the sun

P. Owns solar protection equipment

A NAME	**B** NAME	**C** NAME	**D** NAME
E NAME	**F** NAME	**G** NAME	**H** NAME
I NAME	**J** NAME	**K** NAME	**L** NAME
M NAME	**N** NAME	**O** NAME	**P** NAME

I have energy. Who has the two major gases that make up the sun?	**I have the speed of light.** Who has the form of energy that sunlight is converted to when it is absorbed by the Earth?
I have hydrogen and helium. Who has the process in which very small nuclei are combined into larger nuclei?	**I have thermal energy.** Who has the color that absorbs more sunlight than other colors?
I have nuclear fusion. Who has the form of energy emitted into space by stars and the sun during fusion?	**I have the color black.** Who has a system that captures solar energy and uses it to heat spaces or substances?
I have radiant energy. Who has the amount of time it takes the sun's energy to reach the Earth?	**I have a solar collector.** Who has the process of using the sun's energy to heat buildings?
I have eight minutes. Who has 186,000 miles per second?	**I have solar space heating.** Who has a home that relies on orientation and construction materials to capture the sun's energy for heating interior spaces?

I have a passive solar home. Who has a home with solar collectors and other solar equipment to heat it?	**I have chemical energy.** Who has the process that traps the sun's energy in the atmosphere and makes life on Earth possible?
I have an active solar home. Who has the energy source produced by uneven heating of the Earth's surface?	**I have the greenhouse effect.** Who has the process plants use to convert radiant energy into chemical energy?
I have wind. Who has organic matter that has absorbed energy from the sun?	**I have photosynthesis.** Who has evaporation, condensation, and precipitation driven by energy from the sun?
I have biomass. Who has the energy sources that can be replenished in a short time?	**I have the water cycle.** Who has an object that can be used to cook food on a sunny day?
I have renewables. Who has the form of energy that is stored in fossil fuels?	**I have a solar oven.** Who has the system that uses mirrors to capture the sun's energy?

I have concentraed solar power. Who has the Greek word that means light?	**I have silicon.** Who has the device that nearly 2 million U.S. homes use to increase the thermal energy in their water?
I have photo. Who has tiny bundles of energy from the sun?	**I have solar water heater.** Who has the direction solar collectors should face in the U.S.?
I have photons. Who has the form of energy directly produced by solar cells?	**I have south.** Who has a major reason that capturing sunlight is difficult?
I have electrical energy. Who has the technical word that is abbreviated as PV ?	**I have solar is spread out.** Who has the only renewable energy source that is NOT produced by the sun's energy?
I have photovoltaic. Who has the element that is a semi-conductor used to make PV cells?	**I have geothermal.** Who has the ability to do work or cause a change?

Exploring Photovoltaics 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?	❑ Yes	❑ No

Please explain any 'no' statement below

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:

Please fax or mail to: **The NEED Project**
8408 Kao Circle
Manassas, VA 20110
FAX: 1-800-847-1820

National Sponsors and Partners

2019 Exelon Women's Leadership Summit
Association of Desk and Derrick Clubs Foundation
Alaska Electric Light & Power Company
American Electric Power Foundation
American Fuel & Petrochemical Manufacturers
Apex Clean Energy
Armstrong Energy Corporation
Association for Learning Environments
Robert L. Bayless, Producer, LLC
Baltimore Gas & Electric
BG Group/Shell
BP America Inc.
Blue Grass Energy
Bob Moran Charitable Giving Fund
Boys and Girls Club of Carson (CA)
Buckeye Supplies
Cape Light Compact–Massachusetts
Central Alabama Electric Cooperative
Citgo
CLEAResult
Clover Park School District
Clovis Unified School District
Colonial Pipeline
Columbia Gas of Massachusetts
ComEd
ConocoPhillips
Constellation
Cuesta College
Cumberland Valley Electric
David Petroleum Corporation
David Sorenson
Desk and Derrick of Roswell, NM
Desert Research Institute
Direct Energy
Dominion Energy, Inc.
Dominion Energy Foundation
DonorsChoose
Duke Energy
Duke Energy Foundation
East Kentucky Power
EduCon Educational Consulting
Edward David
E.M.G. Oil Properties
Energy Trust of Oregon
Ergodic Resources, LLC
Escambia County Public School Foundation
Eversource
Exelon
Exelon Foundation
Exelon Generation
First Roswell Company
Foundation for Environmental Education
FPL
The Franklin Institute
George Mason University – Environmental Science and Policy
Gerald Harrington, Geologist
Government of Thailand–Energy Ministry
Grayson RECC
Green Power EMC
Greenwired, Inc.
Guilford County Schools–North Carolina
Gulf Power
Harvard Petroleum
Hawaii Energy
Houston LULAC National Education Service Centers
Illinois Clean Energy Community Foundation
Illinois International Brotherhood of Electrical Workers Renewable Energy Fund
Illinois Institute of Technology
Independent Petroleum Association of New Mexico
Jackson Energy
James Madison University
Kansas Corporation Commission
Kentucky Office of Energy Policy
Kentucky Environmental Education Council
Kentucky Power–An AEP Company
Kentucky Utilities Company
League of United Latin American Citizens – National Educational Service Centers
Leidos
Linn County Rural Electric Cooperative
Llano Land and Exploration
Louisiana State University – Agricultural Center
Louisville Gas and Electric Company
Midwest Wind and Solar
Minneapolis Public Schools
Mississippi Development Authority–Energy Division
Mississippi Gulf Coast Community Foundation
National Fuel
National Grid
National Hydropower Association
National Ocean Industries Association
National Renewable Energy Laboratory
NC Green Power
Nebraskans for Solar
New Mexico Oil Corporation
New Mexico Landman's Association
NextEra Energy Resources
NEXTracker
Nicor Gas
Nisource Charitable Foundation
Noble Energy
North Carolina Department of Environmental Quality
North Shore Gas
Offshore Technology Conference
Ohio Energy Project
Oklahoma Gas and Electric Energy Corporation
Oxnard Union High School District
Pacific Gas and Electric Company
PECO
Pecos Valley Energy Committee
People's Electric Cooperative
Peoples Gas
Pepco
Performance Services, Inc.
Petroleum Equipment and Services Association
Permian Basin Petroleum Museum
Phillips 66
Pioneer Electric Cooperative
PNM
PowerSouth Energy Cooperative
Providence Public Schools
Quarto Publishing Group
Prince George's County (MD)
R.R. Hinkle Co
Read & Stevens, Inc.
Renewable Energy Alaska Project
Resource Central
Rhoades Energy
Rhode Island Office of Energy Resources
Rhode Island Energy Efficiency and Resource Management Council
Robert Armstrong
Roswell Geological Society
Salal Foundation/Salal Credit Union
Salt River Project
Salt River Rural Electric Cooperative
Sam Houston State University
Schlumberger
C.T. Seaver Trust
Secure Futures, LLC
Seneca Resources
Shell
Shell Carson
Shell Chemical
Shell Deer Park
Shell Eco-Marathon
Sigora Solar
Singapore Ministry of Education
Society of Petroleum Engineers
Sports Dimensions
South Kentucky RECC
South Orange County Community College District
SunTribe Solar
Sustainable Business Ventures Corp
Tesla
Tri-State Generation and Transmission
TXU Energy
United Way of Greater Philadelphia and Southern New Jersey
University of Kentucky
University of Maine
University of North Carolina
University of Rhode Island
University of Tennessee
University of Texas Permian Basin
University of Wisconsin – Platteville
U.S. Department of Energy
U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy–Wind for Schools
U.S. Energy Information Administration
United States Virgin Islands Energy Office
Volusia County Schools
Western Massachusetts Electric Company - Eversource