Series or Parallel?

SPN LESSON #28

TEACHER INFORMATION

LEARNING OUTCOME: After investigating circuits, students are able to describe how photovoltaic cells are optimally connected in arrays.

LESSON OVERVIEW: This lesson extends student mental models having to do with connecting light bulbs or resistors in series and/or in parallel in simple electric circuits to include the way photovoltaic cells are optimally connected in arrays. Students investigate open circuits, using a DC voltmeter, a light source, and photovoltaic cells. Comparisons are made to the 2 kW arrays used by School Power Naturally participants.

GRADE-LEVEL APPROPRIATENESS:
This Level III Physical Setting lesson is intended for use in high school physics, physical science, or technology education classrooms.

MATERIALS: Student handout, light bulb and fixture, two small photovoltaic cells and ways to mount them, connecting wires, DC voltmeter, plus DC ammeter and 10 ohm resistor if the activity is extended to include closed circuit voltages.

SAFETY: The only sources of electricity used in this investigation are photovoltaic cells, which produce very low voltages, but as a matter of habit students should exercise the usual care in working with simple electric circuits. The light bulb and fixture should also be handled with the same safety as any lamp; students should not touch a hot lamp.

TEACHING THE LESSON: Begin by asking students to describe their previous experiences with the concepts of "series" and "parallel." The difference between these two concepts is reviewed at the beginning of the student handout for those who need refreshing. Then distribute the student handout and the equipment and ask students to carry out the directions on the handout.

Note that the main part of this lesson focuses only on open circuit voltages. For an extension activity, students might connect the voltmeter with a light load, say, a 10 ohm resistance. An ammeter can be connected in series with the resistor to measure the current flowing through it.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION:

In trial data, the open circuit voltage for a single photovoltaic cell was measured to be 0.25 volts, the open circuit voltage for two photovoltaic cells in series was measured to be 0.50 volts, and the open circuit voltage for two photovoltaic cells in parallel was measured to be 0.25 volts. Ideally, students will make predictions along this line once they realize that electrons passing through two photovoltaic cells in series will pass through two photovoltaic cells and gain energy in passing through each cell. However, electrons passing through photovoltaic cells in parallel will pass through only one cell and thus gain energy only once. (On the other hand, two photovoltaic cells in parallel allow passage of twice as many electrons in a given time. So with cells connected in series each electron gets more energy, but fewer electrons do pass through. With the cells connected in parallel, the electrons get less energy, but more of them pass through. In either case, the same amount of energy is absorbed within a given time from the Sun, which after all is shining on the same amount of surface of photovoltaic cells.)

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ACTIVITY: This is not an adapted lesson.

BACKGROUND INFORMATION: When two light bulbs are in series, the same electric current flows through both of them. When they are connected in parallel, the electric current splits into two branches: some of the current flows through the first bulb in the first branch, while the rest flows through the second bulb in the other branch.

When two photovoltaic cells are connected in series, all of the electrically charged particles in the electric current pass through each of the photovoltaic cells and gain energy from each one of them. If they are connected in parallel, the electrically charged particles in the electric current pass through only one photovoltaic cell and thus gain energy from only one of them.

Although adding photovoltaic cells in series increases voltage, it does not increase current, because the same electrically charged particles pass through each of the photovoltaic cells in series. When photovoltaic cells are connected in parallel, though, more electrically charged particles are energized in a given time, and a larger electric current can be generated. Keep in mind that it is the product of both voltage (energy per charged particle) and current (rate of charged particles) that determines the power, or rate, at which the photovoltaic cell provides energy. If the electric load on a battery or photovoltaic cell demands more power than can be provided, the result will be a reduction in both voltage *and* current.

This reduction in voltage and current shows up in the difference between open and closed circuit voltage. The open circuit voltage represents a kind of “ideal state” in which the potential energy of a unit charge (in volts) is measured in a situation that does not require it to pass through a circuit and deliver that energy through conversion to other energy forms in parts of an electric circuit. The closed circuit voltage, measured when a resistive load is connected to the voltmeter, measures the actual potential energy of a unit charge that is converted to other energy forms in parts of the circuit. Because of possible limitations of power that a photovoltaic cell can provide, the closed circuit voltage is typically less than the open circuit voltage.

REFERENCES FOR BACKGROUND INFORMATION: Any high school physics textbook that deals with electrical circuits will be helpful.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA: 1: M1.1, 2.1, S1, 2.1, 2.3, 3.3; 6: 2.2, 2.3, 2.4, 3.1; 4: 4.1b

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

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

M1.1: Use algebraic and geometric representations to describe and compare data.

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

M2.1: Use deductive reasoning to construct and evaluate conjectures and arguments, recognizing that patterns and relationships in mathematics assist them in arriving at these conjectures and arguments.

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

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

S2.1: Devise ways of making observations to test proposed explanations.

S2.3: Develop and present proposals including formal hypotheses to test explanations; i.e., predict what should be observed under specific conditions if the explanation is true.

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

S3.3: Assess correspondence between the predicted result contained in the hypothesis and the actual result, and reach a conclusion as to whether or not the explanation on which the prediction was based is supported.

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

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

2.2: Collect information about the behavior of a system and use modeling tools to represent the operation of the system.

2.3: Find and use mathematical models that behave in the same manner as the processes under investigation.

2.4: Compare predictions to actual observations, using test models.

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

3.1: Describe the effects of changes in scale on the functioning of physical, biological, or designed systems.

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

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

4.1: Students can observe and describe transmission of various forms of energy.

4.1b: Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms.

Produced by the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
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Should you have questions about this activity or suggestions for improvement, please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date ____________________________________

Series or Parallel?

If you have already studied basic electric circuits—with bulbs and batteries or with power supplies and resistors—you have probably learned that there are two ways to connect light bulbs or resistors to a source of electric energy: in **series** and in **parallel**. When two light bulbs are in series, the same electric current flows through both of them. When they are connected in parallel, the electric current splits into two branches: Some of the current flows through the first bulb in the first branch, while the rest flows through the second bulb in the other branch.

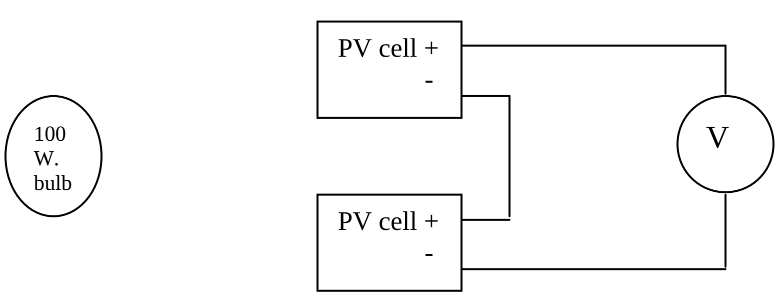
When an array of photovoltaic cells is mounted on a frame to produce photovoltaic electricity, the cells can be connected in series or in parallel. If the cells are connected in series, all the electrically charged particles in the electric current pass through each of the photovoltaic cells and gain energy from each one of them. If the cells are connected in parallel, the electrically charged particles in the electric current pass through one photovoltaic cell and thus gain energy from one of them. You are to investigate the question, Which is the better way?

DEVELOP YOUR UNDERSTANDING

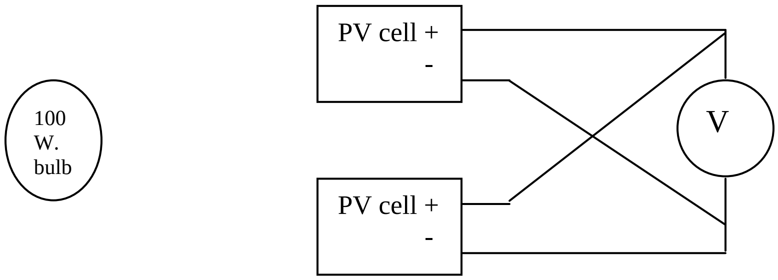
1. Mount two photovoltaic cells so that they are equally exposed to a source of light. A 100 W incandescent bulb about 30 cm away will do. Connect one of the photovoltaic cells to a DC voltmeter and record the voltage when the light is shining on the photovoltaic cell. This is the open circuit voltage for a single photovoltaic cell. All other voltages measured in this activity will be compared to it.

2. Given your observed open circuit voltage for a single photovoltaic cell, predict what the open circuit voltage will be when two photovoltaic cells are connected (a) in series and (b) in parallel.

3. Connect the two photovoltaic cells in series, with the voltmeter connected to the series combination, as shown in the following diagram. What is the voltmeter reading? How does this relate to the open circuit voltage for a single photovoltaic cell?



4. Connect the two photovoltaic cells in parallel, with the voltmeter connected to the parallel combination, as shown in the following diagram. What is the voltmeter reading? How does this relate to the open circuit voltage for a single photovoltaic cell?



5. How do the open circuit voltages observed for two photovoltaic cells in series and in parallel compare with your predictions in question 2?

6. Which is the better connection for PV systems?

   Support your claim: