EXPERIMENTS with PHOTOVOLTAIC CELLS

for high school science students

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For Emerald People's Utility District

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I. OBJECTIVES

OVERVIEW

This unit introduces students to the concept of converting sunlight to electricity with photovoltaic cells. Students will familiarize themselves with these concepts through the Reading Passage, answering Assessment Questions, and by conducting a Lab Activity to determine the effect of several variables on the output of a photovoltaic cell. The follow up activity explores energy from the sun in terms of radiant energy to expand on the concept of electricity generation.

SUGGESTED TIMEFRAME

Teacher will need to determine how many class periods to devote to each activity, based on the suggested timeframe and length of classes.

Time	Activity Description	Subject
60 minutes	1 – Introduction and Reading Passage	Science Vocabulary Reading
90 minutes	2 – Lab Activity – Testing PV Cells	Science Mathematics
45 minutes	3 – Assessment	Science Vocabulary
60 minutes	4 – Follow Up Lab Activity – Energy Output from the Sun	Science Mathematics Reading

REQUIRED MATERIALS

- Copy of **Reading Passage** and **Student Data Sheets** for each student
- An equipment kit for each group containing:
  - three 0.5 volt PV cells, at least 10 square centimeters (1.5 sq in) in size each, (found at most science supply companies and electronic stores)
  - several sheets of colored transparency film in various colors, including yellow and blue (office supply stores) Small pieces should be cut beforehand just to cover the PV cells.
  - 30 cm of thin electrical wire (use with alligator clips unless the meter leads have alligator clips on their ends)
  - DC ammeter (reads amps)
  - DC voltmeter
  - direct sunlight (desk lamp or flashlight could be substituted)
  - aluminum foil
  - protractor
  - goggles
  - hair dryer

BACKGROUND INFORMATION

Solar energy can be part of a mixture of renewable energy sources used to meet the need for electricity. Using photovoltaic cells (also called solar cells), solar energy can be converted into electricity. Solar cells produce direct current (DC) electricity and an inverter can be used to change this to alternating current (AC) electricity.

This electricity can be stored in batteries or other storage mechanisms for use at night. Batteries used for this purpose have a large storage capacity. Practical photovoltaic (PV) cells were discovered in 1954 when they were demonstrated by powering toys. In 1958 they found wide acceptance as part of the space program after initial success on the Vanguard I satellite. PVs are made from silicon and other semiconductor materials. Silicon crystals have all four valence electrons bound with other silicon valence electrons. When silicon is "doped" with atoms of with fewer valence electrons is brought in contact with silicon doped with atoms with extra valence electrons, an electric field is created the electrons from atoms with extra valence electrons fill "holes" created by atoms with fewer electron. When sunlight enters a PV cell, the light can separate an electron from an atom and the electric field helps move the electrons to charge collecting areas. The electrons are then gathered on the surface of the solar cell by a grid of metal connected to a circuit. The circuit allows the electrons to flow to the electron-poor back of the cell from the electron-rich front of the cell. Photovoltaic panels are oriented to maximize the use of the sun's light, and the system angles can be changed for winter and summer. When a panel is perpendicular to the sunlight, it intercepts the most energy. Students are familiar with the PV cells used in most calculators.

SUMMARY OF ACTIVITIES

Activity 1 – Introduction and Reading Passage

Teachers should read the entire sequence of activities first, before starting the lab. Explain to the class the topic that will be covered in this unit of study. Teachers can include statements from the teacher background information section.

Have students consider the following quote:
"I think there is a world market for maybe five computers."
– Thomas Watson, chairman of IBM, 1943

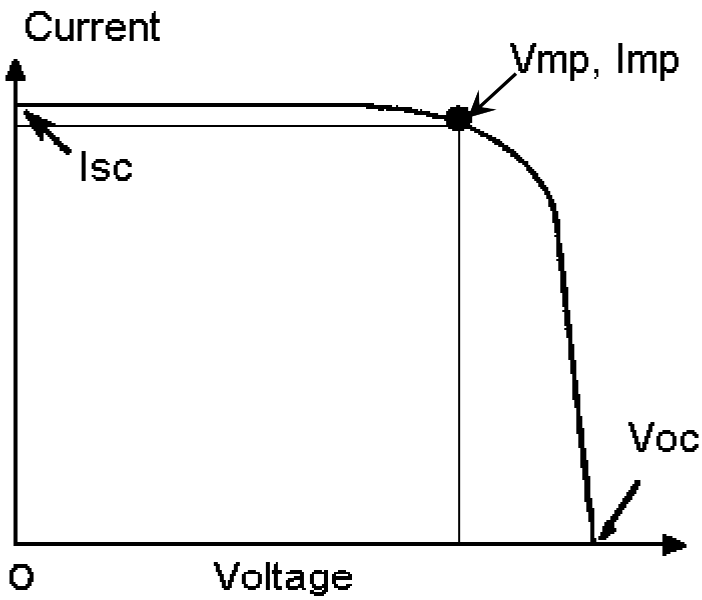
Computers were initially costly and cumbersome. However, now almost everyone has access to or owns a computer. Photovoltaic systems were initially costly and cumbersome, but now? They are being used as a clean source of energy. Discuss with the class what they know about PV systems and their possibilities for use in and around the home and community.

Each student will need a copy of the Reading Passage and the Student Data Sheets (includes reading comprehension questions, vocabulary words and Lab Activity). Instruct students to study the Reading Passage, "Introduction to Photovoltaic Systems," and complete the questions and vocabulary. This activity will help them learn about PV systems and some of their applications. Key vocabulary words in the Reading Passage will assist them in understanding the Lab Activity instructions. For students who wish to learn more of the detailed physics principles behind the operation of PV cells and other solid state devices, direct them to the appropriate resources. Suggested resources are included in the Teacher Resource Guide. Appropriate safety guidelines should also be reviewed.

Activity 2 – Lab Activity – Testing Photovoltaic Cells

1. Explain to the class that during this activity, students will test PV cell response to different wavelengths of light, shade, the angle and intensity of the sun, and temperature. Emphasize to the class safety precautions when taking current and voltage readings using volt- and ammeters. Use either meter leads that have alligator clips on the ends, or attach insulated alligator clips to the wire ends that come into contact with the meter leads. Students should never touch any bare or exposed metal in a circuit that is generating electricity (i.e. meter leads, bare wire, etc.). Give students clear instructions

on how to safely measure voltage and current using meters. Each PV cell (or PV cells wired in series) has a nominal voltage of 0.5v output. The solar cells should be large enough to produce milliamp reading that can be read by the amp meter. The colored transparency sheets can be cut into pieces large enough to completely shade the PV cell.



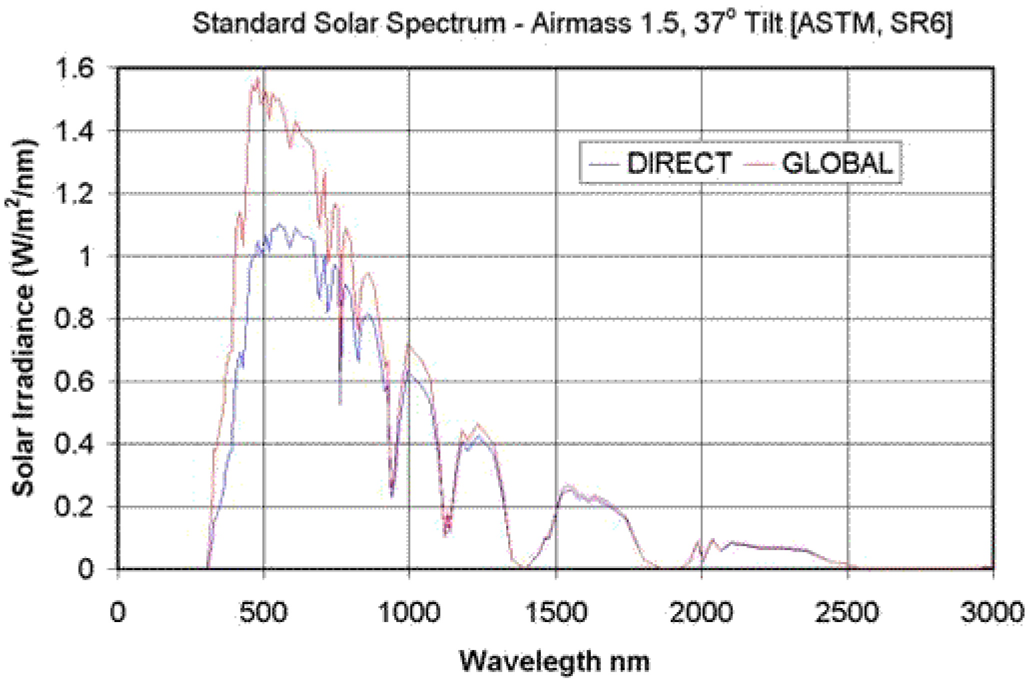
Plot of IV curve for a solar cell. Current times Voltage equals Power. Short circuit current (the current when the voltage is zero) increases in proportion to the incident energy (sunlight).

2. Distribute copies of the Lab Activity to each student but have students work in groups (as determined by the teacher). Instruct students to review the Lab Activity before beginning so they will understand the purpose and the goals. To enhance the class's scientific inquiry in this lab, instruct each student to develop statements for the following: hypothesis, predictions, conclusions and finally significance/implications. Note that the hypothesis and predictions should be made before beginning the Lab Activity. Refer to the Teacher Resource Guide for more information. Ask students to obtain a materials kit. Students should record their current and voltage readings in the tables provided in the Lab Activity. After students have completed their Data Tables, students should answer the data summary questions listed in the Lab Activity.

Expected Observations

Students should see the effects of more and less light and different wavelengths of light on the PV cell and of the cell's temperature.

- Current readings will be larger when more light is absorbed.
- Open circuit voltage readings should be smaller when the PV cell is cold, though this temperature effect may be too minor to observe on a small scale.
- The decreasing angles from the sun (light source) result in lower current readings.



Activity 3 – Assessment

Distribute a copy of the Assessment Questions to each student. Instruct each student to work alone and answer the short answer and multiple-choice questions. Collect the handouts, grade and return them to the students.

Activity 4 – Follow Up Lab

The Follow Up Lab can be conducted to expand the concept of energy from the sun as it relates to heat energy. Students should understand that photons from the sun create electricity (photovoltaic) as well as heat (solar thermal). Teachers should read and understand the Lab Activity and obtain the materials needed. Distribute a copy of the Follow Up Lab and instruct students to follow the steps.

ADDITIONAL ACTIVITY

Internet or Library Research

Students can learn about the uses of PV systems in countries of the Caribbean, in Mexico, and in South America and compare them with the United States. The advantages for PV are self-evident where no power grid exists. With increasing costs for electricity and potential blackouts, a solar alternative in U.S. homes for providing some of the power needed may be part of a viable answer to the energy problem.

REFERENCES:

Solar Electricity Generation – How it works, Catalyst vol. 4 no 2 fall 2005, picture illustration by Aaron Thomason/SRPnet.com

Useful Web Sites:

http://www.californiasolarcenter.org/history_pv.html

http://www.fatspaniel.com/live-sites/index.html

http://solardata.uoregon.edu/EducationalMaterial.html

http://www.eren.doe.gov/millionroofs/whatispv.html

http://www.sandia.gov/pv/training.htm

http://www.nrel.gov/ncpv/

http://www.fsec.ucf.edu/Ed/index.htm

http://www.nrel.gov/data/pix/searchpix.html

http://www.ascensiontech.com/RTD/ashlandrtd.html

http://www.ascensiontech.com/RTD/pge.html

http://www.ases.org/

http://www.seia.org/main.htm

For further reading:

The Solar Electric House by Steven J. Strong with William G. Scheller, Sustainability Press, Still River, Massachusetts 01467-0143, 1987.

From Space to Earth – The Story of Solar Electricity, John Perlin, aatec publications, Ann Arbor, MI 48107, 1999.

The Sun – Our Future Energy Source, David K. McDaniels, John Wiley & Sons, New York, NY 10016, 1979

II. LAB ACTIVITY - TESTING PHOTOVOLTAIC CELLS

The purpose of this activity is to construct a simple photovoltaic (PV) system, using a PV cell(s) and a DC ammeter, in order to learn:

- how the amount and wavelength of light affect the generation of electricity
- how PV systems are connected to produce different voltages and currents
- how temperature affects the efficiency of a PV cell

BEFORE YOU START

Review the vocabulary words from the Reading Passage. Ask your teacher if you are unsure of any of the meanings.

Example -
PV lab test setup
Courtesy of Igor Tyukhov

MATERIALS

Obtain a materials kit from your teacher. Check that it contains the following materials:

- small PV cells
- several sheets of colored transparency film in different colors
- two electrical leads with alligator clips
- DC ammeter
- DC volt meter
- source of bright light or access to direct sunlight (desk lamp or flashlight could be substituted)
- aluminum foil
- protractor
- hair dryer or heat gun
- goggles

Step I. Constructing the Photovoltaic Energy System for Light Source Changes (wear goggles)

1. If your PV cell does not have wires already attached to it, you should attach 15 cm of wire to each node of the PV cell. The cell should have either clips or hooks around which you can manually twist the wire.
2. Follow your teacher's safety instructions and attach the red wire from the PV cell to the red lead of the ammeter (either clip or wrap the wires together).
3. Similarly, attach the black wires from the PV cell to the black lead of the ammeter.
4. Use the sun or shine a light source on the PV cell to see if you are getting a current reading. If the ammeter shows no current, check the wire connections.

Step II. Performing the Activity for Light

1. Keeping the sunlight constant (or the light source at constant distance), cover the PV cell(s) with a piece of colored transparency film. Repeat with the other colors of transparency film, and then use just direct sunlight alone (or light substitute). Record the current generated for all colors tested and for direct light in Data Table 1.

Table 1. Effect of Color (Wavelength) on Cell Current

Color of Filter	**Current**
No filter	

2. With just 1 PV cell in the circuit, shade 1/4 of the PV cell with a piece of cardboard or paper and take a reading. Shade 1/2, 3/4 and then all of the photovoltaic cell. Record the readings in Data Table 2.

Table 2. Effect of Shading on Cell Current

Amount of Shade	**Current**
No shade	
1/4 covered	
1/2 covered	
3/4 covered	
All covered	

3. Connect PV cells in series and take a reading. Shade one cell completely and take a reading. Cover all PV cells and take a reading.
   Record the readings in Data Table 3.

Table 3. Effect of Shading on Cell Current – PV Cells in Series

Amount of Shade	**Current**
No shade	
1 cell covered	
All covered	

4. Connect PV cells in parallel and take a reading. Shade one cell completely and take a reading. Cover all PV cells and take a reading.
   Record the readings in Data Table 4.

Table 4. Effect of Shading on Cell Current – PV Cells in Series

Amount of Shade	**Current**
No shade	
1 cell covered	
All covered	

5. Place the PV cell(s) directly pointed at the sun (or light source). Using a protractor to determine the angle, slant the PV cell(s) at 15-degree intervals away from the direct perpendicular position. Record the amps generated at every 15-degree change in Data Table 5.

Table 5. Effect of Tilt Angle on Cell Current

Angle	**Current**
0° (Pointed at sun or light source)	
15°	
30°	
45°	
60°	
75°	
90°	

6. Take a piece of aluminum foil and design a light reflector for your PV cell to concentrate the light shining on it. Measure the new current with the reflector attached and record.
   Current with and without aluminum foil reflector ________, ________

Step III. Constructing the Photovoltaic Energy System for Temperature Changes

Take your PV cell(s) with its attached wires and attach the red wire from the PV cell to the red lead of the voltmeter. Attach the black wire from the PV cell to the black lead of the voltmeter. Check that you are getting a reading. If you do not get a reading check the wire connections.

Step IV. Performing the Activity for Temperature

1. Take your PV cell(s) that is connected to the voltmeter and, shading the PV cell, read the voltmeter at regular room or outside temperature and record your readings in Data Table 6.
2. Place the PV cell directly in the sun (or under a lamp) so that the cell becomes warm. Record this new reading.
3. Heat the solar cell with a hair dryer for 15 seconds, take a reading. Heat the solar cell for 30 seconds, take a reading. Heat the solar cell for 1 minute, take a reading. Record the readings in Data Table 6.

Table 6. Effect of Temperature on Cell Voltage

Temperature	**Voltage**
Room temperature, shaded	
Full sunlight, warm	
After heating 15 seconds	
After heating 30 seconds	
After heating 1 minute	

Step V. Performing the Activity for Effects of Distance from Light Source

1. Put your PV cell on the table below the light source. Measure the distance between the light source and the solar cell. Record distance in Data Table 7. Measure current and record current in Data Table 7. Move cell to ½ the original distance to the light source. Record distance in Data Table 7. Measure current and record current in Data Table 7. Move the cell to ¼ the original distance to the light source. Record distance in Data Table 7. Measure current and record current in Data Table 7.

Table 7. Effect of Distance on Cell Current

Distance – inches	**Current**

Questions

1. Which colors allowed the most electricity to be generated?
2. What happens when the PV cell is shaded?
3. What happens to the current when the PV cells are connected in series and shaded?
4. What happens to the current when the PV cells are connected in parallel and shaded?
5. What happens when the PV cell is heated?
6. How does temperature affect the efficiency of a PV cell?
7. What is the relationship between the color of filter used and the current produced by the photovoltaic cell?
8. Does more light produce more current? Explain.
9. What happens when the solar cell is moved closer to the light source?

Assessment Questions

1. What are three benefits of using solar power?

   ____

   ____

   ____

2. Does the future for both industrial and less developed countries hold a place for the use of photovoltaic systems? Discuss.

   ____

   ____

3. How could you increase the output of a PV cell during the day, when the angle of the sun's rays is constantly changing?

   ____

   ____

4. In what direction would you face a photovoltaic system being installed on your home? Explain

   ____

   ____

   ____

Multiple Choice Questions

1 The word photovoltaic comes from words meaning:
   a) wind energy
   b) brightness
   c) light and electricity
   d) picture which moves

2 A PV module is:
   a) dozens of photovoltaic cells connected together
   b) wired in series
   c) wired in parallel
   d) all answers a, b, c

3 Solar PV systems can be:
   a) connected to the power grid
   b) used to sell power to the grid
   c) a stand alone source of electricity
   d) all answers a, b, c

4 In the shade:
  a) less light strikes the PV cells
  b) less current is generated in PV cells
  c) the PV cell is cooler
  d) all answers a, b, c

5 Improving the efficiency of a PV cell can be done by:
  a) adjusting the light facing angle all day
  b) placing colored acetates on the cell
  c) heating the cell
  d) changing its direction to north

6 Solar photovoltaic cells were originally deployed for:
  a) desert cooling
  b) winter use
  c) the space program
  d) brick houses

7 Developing solar energy is important because it:
  a) does not produce pollution
  b) can be utilized in most regions of the U.S.
  c) reduces our dependency on imported energy
  d) all of the above

8 When planning your future home you will:
  a) never consider photovoltaic systems
  b) research the cost of a PV system as a supplement to the grid
  c) work with local builders to find out if PV will be practical
  d) b and c

9 The ammeter reads:
  a) volts
  b) amps
  c) ohms
  d) none of the answers

10 In a series connection:
  a) the positive terminal is connected to the positive terminal
  a) the negative terminal is connected to the negative terminal
  b) the positive terminal is connected to the negative terminal
  c) all of the above

III. SOLAR ENERGY TECHNOLOGY QUESTIONS

Name____________________

Reading Guide http://www.rnp.org/RenewTech/tech_solar.html

1. Solar technologies convert the sun's light into ____________________ and ________________________
2. What are the two major categories of solar energy technology?
____
____
3. Photovoltaic cells produce ____
4. There are two types of thermal solar systems. Describe them.
____
____
____
5. What are the fuel costs of solar systems? __________________________
6. Most of the costs of solar systems come from ___________________________
____
7. According to the article, what is the cost difference between photovoltaic systems and hot water systems? ______________________________________
8. Briefly describe the solar potential of the northwest. _____________________
____
9. How does the region compare to Germany regarding solar potential?
____
Why is this significant?____
10. Typical photovoltaic cells (PVs) are made from __________________________
11. The cost per kWh of PV generated power ranges between ________________
12. Small PVs are often used in ______________________ areas because these areas are "off-grid" or too far from established transmission systems.
13. List three cost effective applications of PV generated power.
____
____
14. How much has the demand for Solar PV increased over the last 20 years?
____

15. Since 1982, solar cell prices have dropped from ______________________ to ______________________

16. Direct-use thermal systems are designed to heat water or air for individual buildings. List some specific uses. ______________________

17. What is the estimated cost of a direct thermal type of system? ____________

18. Briefly describe the environmental impacts of using either type of solar technology. ______________________

19. What is meant by "net metering"? ______________________

20. Net metering systems allow customers to install solar equipment without the need for ______________________ and ______________________

21. Net metering is available in the following states: ______________________

22. List four types of incentives available for the development of solar energy in the Northwest. ______________________

23. What is the increase in number of U.S. solar installations from 1998 to 2005? ______________________

24. Where can you get more information about solar energy? ______________________