Introduction to Photovoltaic Systems

RENEWABLE ENERGY
THE INFINITE POWER
OF TEXAS

For High School

OBJECTIVES

See High School Teacher Resource Guide for TEKS objectives and additional information regarding this and other high school units.

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 heat 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:
  - small PV cell, at least 0.5v output, or several PV cells in series (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 volt meter
  - direct sunlight (desk lamp or flashlight could be substituted)
  - magnifying glass
  - aluminum foil
  - protractor
  - ice in sealed plastic bag
  - goggles

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 used as direct current (DC) electricity or alternating current (AC) electricity or both. This electricity can be used at night by employing a storage mechanism, such as a battery. Batteries used for this purpose have a large storage capacity.

Photovoltaic (PV) cells were developed in the 1950s as part of the space program. They are made from silicon, a semiconductor. When light hits a PV cell, electrons move and travel along wires inside the PV cell, just as electrons travel through the wiring in our homes. A PV cell changes sunlight into electricity by causing electrons to move toward the treated front surface of the cell. This creates an electron imbalance. When a connector, like a wire, joins the electron-poor back and electron-rich front, a current of electricity flows between the negative front and positive backsides. Photovoltaic systems are set up to maximize the sun's light, and the system angles can be changed for winter and summer, always facing the PV system south.

Students are familiar with the PV cells used in most calculators. In fact some students may wish to try some of the activities on a calculator PV cell for comparison. More possible future photovoltaic applications can be discussed with students.

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. The PV cell (or PV cells wired in series) needs at least 0.5v output. The colored transparency sheets can be cut into pieces large enough to completely shade the PV cell.
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. Voltage readings will be larger when more light is absorbed. 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 PV cell should remain dry. The decreasing angles from the sun (light source) result in lower 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 (photovoltaics) 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.

Learning About Photovoltaic Systems

RENEWABLE ENERGY
THE INFINITE POWER OF TEXAS

HIGHLIGHTS

- **The energy needs of a typical home in Texas could be met by covering only half of its roof with solar electric panels**
- **Photovoltaic (PV) cells convert sunlight directly into electricity without creating any air or water pollution**

INTRODUCTION

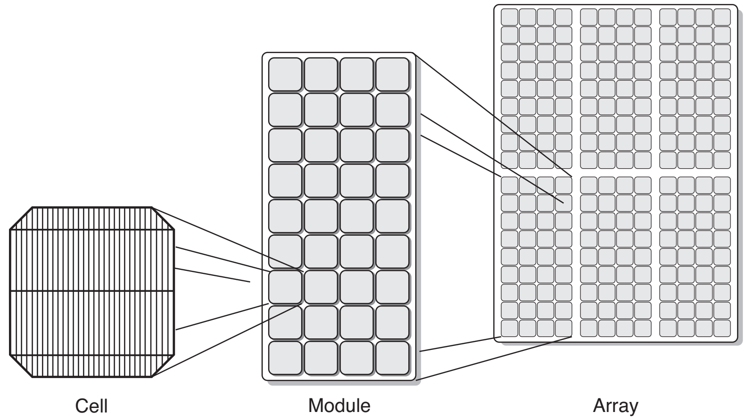
Solar energy can be part of a mixture of clean, renewable energy sources used to meet Texans' need for electricity. An area the size of the United States receives more solar energy in less than 40 minutes than can be generated from all of the fossil fuels (oil, gas, etc.) used in the United States in one year. Texas has thousands of square miles that could be safely and efficiently used for solar power plants.

Photovoltaics offer consumers the ability to generate electricity in a clean, quiet, and reliable way. Home photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity, and inverters that convert the direct current from the photovoltaic into alternating current used in homes. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from "photo," meaning light, and "voltaic," which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight." Photovoltaics are often referred to as PV.

Texans who already have electrical grid-supplied electricity but want to begin to live more independently or who are concerned about the environment are installing PV systems. For some applications where small amounts of electricity are

RESIDENTIAL PV SYSTEM *The solar panels on the roof produce electricity that travels through wires to the distribution panel on the side of the home.*

required, such as emergency call boxes or school crosswalk signals, PV systems are often cost justified even when grid electricity is not very far away. When applications require larger amounts of electricity and are located away from existing power lines, photovoltaic systems can in many cases offer the least expensive, most viable option. In use today on streetlights, automatic gate openers and other low power tasks, photovoltaics are gaining popularity in Texas and around the world as their price declines and efficiency increases.

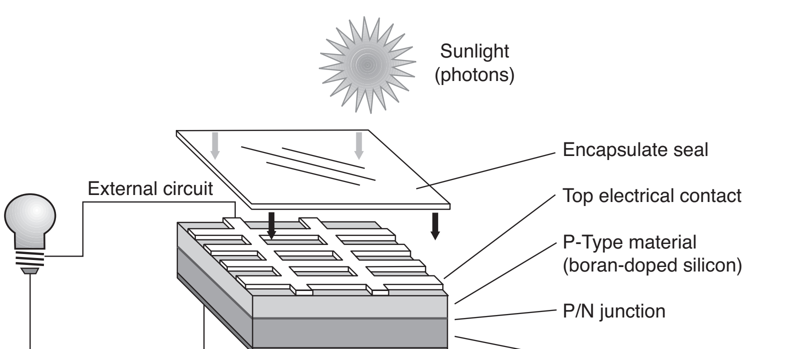


PHOTOVOLTAIC CELLS, MODULES AND ARRAYS *The building blocks of solar electricity are modular in nature, allowing great flexibility in applications.*

HOW IT WORKS

PV cells were developed in the 1950s as part of the space program. PV cells convert sunlight directly into electricity without creating any air or water pollution. PV cells are made of at least two layers of semiconductor material. One layer has a positive charge, the other negative. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current.

To increase their utility, many individual PV cells are connected together in a sealed, weatherproof package called a module. When two modules are wired together in series, their voltage is doubled while the current stays constant. When two modules are wired in parallel, their current is doubled while the voltage stays constant. To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array. Through a mixture of different series and parallel combinations, any desired voltage and current can be achieved. The flexibility of the modular PV system allows designers to create solar power systems that can meet a wide variety of electrical needs, no matter how large or small.



BASIC SOLAR CELL CONSTRUCTION
The sandwich of semiconductor materials produce electricity directly from the sunlight without any moving parts.

THE GRID: ON OR OFF?

Some homeowners in Texas are turning to PV as a clean, reliable, and infinitely renewable energy source even though it is often more expensive than power available from their electric utility. These homeowners can supplement their energy needs with electricity from their local utility when their PV system is not supplying enough energy (at nighttime and on cloudy days) and can export excess electricity back to their local utility when their PV system is generating more energy than is needed.

For locations that are "off the grid" — meaning they are far from, or do not use, existing power lines — PV systems can be used to power water pumps, electric fences or even an entire household.

While PV systems may require a substantial investment, they can be cheaper than paying the costs associated with extending the electric utility grid. A consumer in Texas may be asked to pay anywhere from $5,000 to $30,000 per mile to extend power lines.

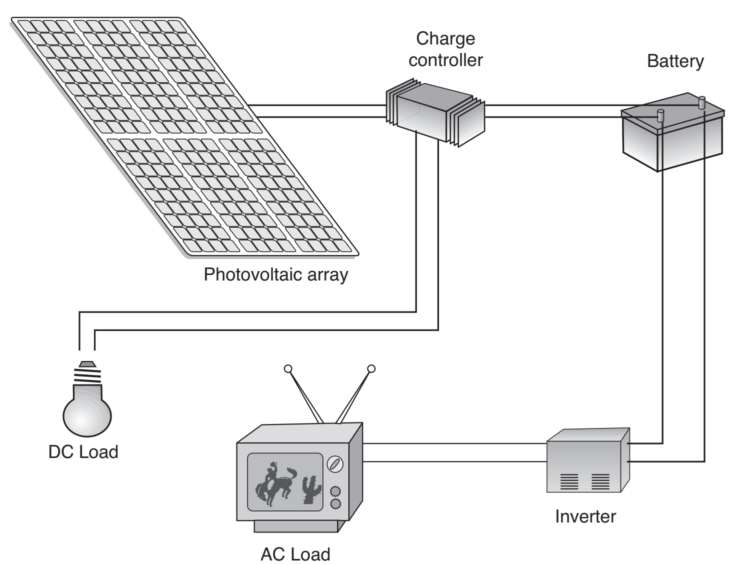
THE RIGHT EQUIPMENT FOR THE JOB

A grid-connected PV system will require a utility interactive DC to AC inverter. This device will convert the direct current (DC) electricity produced by the PV array into alternating current (AC) electricity typically required for household appliances such as radios, televisions and refrigerators. Utility interactive inverters also have built-in safety features required by electric utilities nationwide.

For an off-grid PV system, consumers must decide whether they want to use the direct current (DC) from the PVs or convert the power into alternating current (AC). Appliances and lights for AC are much more common and are generally cheaper, but the conversion of DC power into AC can consume up to 20 percent of all the power produced by the PV system.

To store electricity from PVs, batteries will be needed. The batteries used for PV systems are different from car batteries. The batteries best suited for use with PV systems are called secondary or deep cycle batteries. There are two types of deep cycle batteries: lead acid, which require the periodic addition of water, and captive electrolyte (or gelcell) batteries, which are maintenance free.

In addition, PV systems require proper wiring, switches and fuses for safety, controllers to prevent the batteries from being overcharged or overly discharged, diodes to allow current to flow in the right direction, and grounding mechanisms to protect against lightning strikes.



COMPONENTS OF A TYPICAL OFF-GRID PV SYSTEM *Solar electricity can be used for many purposes, either directly, or by storing in batteries for use when the sun is not shining.*

LIGHT ENERGY

The color of light is related to its frequency. The frequency of light is related to its energy by this formula:

$$E = hf = \frac{hc}{\lambda}$$

In this formula, h is a constant, c is the speed of light, f is the frequency of the light, and λ is the wavelength of the light. The frequency of a color is directly proportional to its energy whereas the wavelength of a color is inversely proportional to its energy. Red has the least energy, and based on the formula above, a low frequency but relatively long wavelength; UV has a higher frequency and a relatively shorter wavelength.

The different colors of light can be arranged according to wavelength, frequency, or energy. From lowest energy to highest, the colors are red, orange, yellow, green, blue, violet, ultraviolet. That is, red has the least energy and ultraviolet has the highest energy. (A well known acronym to remember this order is ROY G BIV: red, orange, yellow, green, blue, indigo, violet.)

Sunlight contains a lot of infrared and ultraviolet as well as all other colors. Some people think heat is a different form of energy from light. Both are forms of electromagnetic radiation and both can provide energy for homes. Since most infrared and ultraviolet are blocked by Earth's atmosphere, solar energy, whether it is used to heat water or is converted to electricity in a PV cell, comes from the visible part of sunlight.

Understanding the Reading Passage

1. What are some advantages of using off-grid PV systems for emergency call boxes and emergency warning signals?

____

____

2. PVs require light to operate. What is one big disadvantage of PV systems?

____

____

3. Remove the batteries from a "solar powered" calculator or other device. Now turn on the device. Does it still work? Cover the PV cell with a piece of thick paper like an index card. Does the device still work? Explain.

____

____

4. How do you think systems that are off-grid work at night or during extended periods of cloudy weather?

____

____

5. Describe four different situations where off-grid PV systems are the best solution for providing electrical power.

1 ______________________________

2 ______________________________

3 ______________________________

4 ______________________________

6. How does the energy of light change if the frequency is increased (higher frequency, bluer light)?

____

____

7. How does the energy of light change if the wavelength is increased (longer wavelength, redder light)?

____

____

Vocabulary

Based on the Reading Passage, write down your understanding of these words or word pairs and verify your definitions in a dictionary, on the Internet if available or with your teacher:

alternating current (AC) ____________________

ammeter ____________________

array ____________________

direct current (DC) ____________________

electrical grid ____________________

electricity ____________________

infrared ____________________

inverter ____________________

joule ____________________

module ____________________

parallel ____________________

photon ____________________

photovoltaics ____________________

PV cell ____________________

series ____________________

ultraviolet ____________________

volt meter ____________________

LAB ACTIVITY - TESTING PV CELLS

INTRODUCTION

The purpose of this activity is to construct a simple photovoltaic (PV) system, using a PV cell and a DC ammeter, in order to learn how the amount and wavelength of light affect the generation of electricity. You will also learn how PV systems are connected to produce different voltages and currents. Finally, you will study 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.

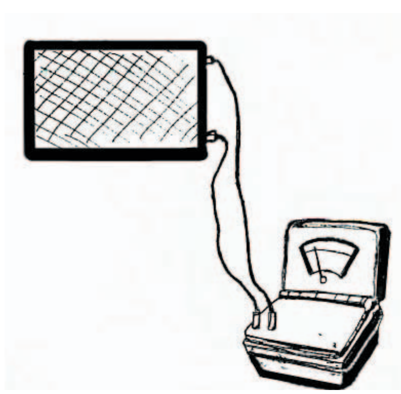
MATERIALS

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

- small PV cell
- 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)
- magnifying glass
- aluminum foil
- protractor
- ice in sealed plastic bag
- 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
(wear goggles)

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.
2. Shade ¼ of the PV cell(s) with a piece of cardboard or paper and take a reading. Shade ½, ¾ and then all of the photovoltaic cell(s). Record the readings in Data Table 2.
3. 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 3.
4. Take a magnifying glass and concentrate the sunlight (or light source) on the PV cell. Measure the new current and record.
5. 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.

Step III. Constructing the Photovoltaic Energy System for Temperature Changes
(wear goggles)

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 (wear goggles)

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 4. Place the PV cell directly in the sun (or under a lamp) so that the cell becomes warm. Record this new reading.
2. Place some crushed ice in a Ziploc bag, then set the PV cell(s) on top so the cell(s) becomes cold. Take 3 readings over a 5-minute interval. Record the readings in Data Table 4.

Step V. Data Summary

Complete the data summary by answering the questions and record your answers.

DATA TABLES

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

Color of Filter	Current
No filter	

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	

Table 3. Effect of Tilt Angle on Cell Current

Amount of tilt	Current
0° (No tilt)	
15°	
30°	
45°	
60°	
75°	
90°	

Current with magnifying glass ______________________ Current with aluminum foil reflector ______________________

Table 4. Effect of Temperature on Cell Voltage

Temperature	Voltage
Room temperature, shaded	
Full sunlight, warm	
On ice, after 5 minutes	
On ice, after 10 minutes	
On ice, after 15 minutes	

DATA SUMMARY

1. Which colors allowed the most electricity to be generated? ______________________
2. What happens when the PV cell is shaded? ______________________

   ____
3. What happens when the PV cell is cooled? ______________________

   How does temperature effect the efficiency of a PV cell? ______________________
4. What is the relationship between the color of filter used and the current produced by the photovoltaic cell? Does higher energy light produce more current? Explain. ______________________

   ____

Assessment Questions

1. What are three benefits of using solar power?

   1 ______________________________

   2 ______________________________

   3 ______________________________

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 producing 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) PV cells absorb much less light
   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) cooling the cell
   d) changing its direction to north

6. Solar photovoltaic cells were originally developed 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) keeps energy costs down
   c) reduces our dependency on imported energy
   d) all of the above

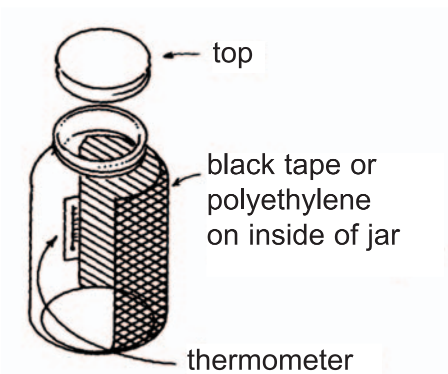
8. When planning your future home you will:
   a) never consider photovoltaic systems
   b) research the cost of a PV system as a supplement to the grid
   c) work with local builders to find out if PV will be possible
   d) b and c

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
    b) the negative terminal is connected to the negative terminal
    c) the positive terminal is connected to the negative terminal
    d) all of the above

FOLLOW UP LAB

The idea of this experiment is to set a jar of water in the sun and measure the temperature rise as the water absorbs energy from the sun. From the temperature rise, the amount of solar energy absorbed in a certain amount of time can be determined. The final result will be in units of power per unit area, or watts per square meter. The apparatus you will use is shown here.



EQUIPMENT

- wide mouth jar with leak proof lid and vertical sides (a mayonnaise jar works well)
- small Celsius thermometer
- black plastic tape
- watch
- metric ruler
- measuring cup or beaker or graduated cylinder

Step I. Constructing the Energy Collector

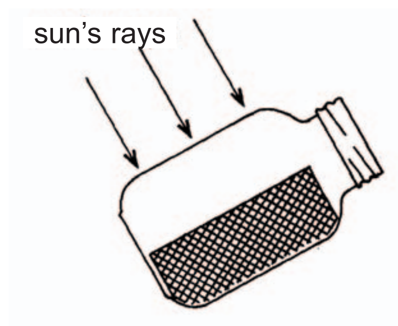
Cover the inside of one side of the jar with black tape as shown. Tape or glue a small thermometer inside the jar next to the tape as shown. Use the measuring cup to fill the jar with water to the top of the black area and determine the amount of water the jar will hold in milliliters. Use the same amount of water for each experimental run.

Step II. Performing the Activity for Solar Energy Output

Do this experiment on a clear day with no wind.

1. Using the apparatus, make a measurement in the sun.
   a) Fill the jar with the predetermined amount of water. Measure and record the temperature, estimated to the nearest 0.1 degree if possible.

   b) Place the jar in the sun and tilt the jar so that sunlight falls perpendicular to the sides of the jar and prop it in place as shown.



   c) After exactly 15 minutes, read the temperature again and record in the Data Table.

2. As a control, repeat the procedure in the shade.
   a) Empty the jar and refill the jar with the predetermined amount of water from the same source. Measure and record the temperature, estimated to the nearest 0.1 degree if possible.

   b) Place the jar in deep shade in the same environment as in the previous step, such as under a tree or an umbrella.

   c) After exactly 15 minutes, read the temperature again and record in the Data Table.

3. Repeat steps 1 and 2 again, for a total of four measurements: two in the sun and two in the shade.

Lab Report Form

Date______________

Water volume in mL _________________________

	Start		End		Total	
	Time	Temperature	Time	Temperature	Difference in temperature	Change per minute
sun						
shade						
sun						
shade						

1. For the sixth column in the table, calculate the change in temperature for the fifteen-minute interval. The two readings in the sun should be about the same and the two readings in the shade should also be about the same. If they are not, you may have done something wrong and you should start over. The temperature in the shade may go down on a cool day. Record decreases in temperature as negative. Also, calculate the change per minute and record this in the last column of the table.

2. Add the sun readings from the last column and divide by two to get the average. Repeat for the shade readings.

   Average change per minute in the sun ______________________

   Average change per minute in the shade ______________________

3. Subtract the average change per minute in the shade from the average change per minute in the sun to get the net change. Be sure to account for negative numbers (if the change in the shade is negative, change the sign to a positive number and add).

   Net change _________________________

4. Now calculate the amount of energy absorbed per second. (Hint: determine how many seconds are in fifteen minutes.) Multiply the volume of water by the net change in temperature.

   Calories absorbed per second: ____________________

   Convert calories to joules by multiplying the calories absorbed per second by 4.19.

   Joules absorbed per second (watts): ____________________

5. Compute the collecting area. Measure the height of the tape section and the diameter of the jar in centimeters. Multiple the height of the black tape section by the diameter of the jar.

   Collecting area in square centimeters _____________cm^2

   To convert to m^2, divide the area in cm^2 by 10,000: ___________m^2

6. Finally, calculate the **provisional solar constant** in watts per square meter. Divide the number of watts from step 4, by the collecting area from step 5.

   Provisional solar constant: ___________________W/m^2

7. Determine the number of watts your PV cell could generate if it was 100% efficient. Measure the length and width of your PV cell in cm. Multiply to get the area. Divide by 10,000 to convert the area to m^2. Multiply by the provisional solar constant.

   Power output if PV cell were 100% efficient ____________________

8. Determine the total energy output of the sun.

   a) Imagine a sphere surrounding the sun with a radius equal to the Earth's distance from the sun in meters (1.5×10^{11} m). Calculate the surface area of this sphere, since all light the sun produces must pass through it, using the following formula:

      Surface Area of a sphere = $4\pi r^2$ = ______________________ m^2.

   b) Multiply this large number by the watts per square meter you measured above to get the total power the sun produces:

      ____ W.

   c) The generally accepted value for the energy output of the sun is 3.9 × 1026W. How close is your answer?

      ____

Understanding the Reading Passage

1. In the event of a power failure, the call boxes and emergency alerts will still function.
2. They quit working at night or on cloudy days. Batteries are required to store power.
3. Some calculators may not work when the batteries are removed. Some do not have batteries. They will quit working with no batteries and no light source.
4. They use banks of batteries to store electrical power.
5. remote flood alerts, livestock feeders, automatic gates, highway warning signs, remote houses far off the grid, emergency call boxes, water pumps
6. Energy increases as frequency increases.
7. Energy decreases as wavelength increases.

Lab Activity Data Summary

1. Colors with higher frequency (closer to blue) have more energy per photon and may generate more current. However, the different films may allow more or less light to pass (intensity) and this will also affect the current.
2. Shade prevents the PV cell from absorbing light.
3. Lowering the temperature increases the voltage and the efficiency.
4. Colors closer to blue may produce more current, but this effect may be masked by the different amounts of light transmitted by the different filters.

Assessment Questions

1. Using solar power can reduce the cost of electricity, diminish our dependence on imported energy, provide cleaner air to breathe and provide a convenient source of power independent of the power grid in remote areas.
2. For industrial countries with a well-developed electricity grid system, photovoltaic electrical generation can provide energy and reduce the occurrence of blackouts. Industrial countries produce significant amounts of pollution, and PV electricity can help clean the air by using less oil and coal. Less developed countries can have more options than just grid power and have independent electricity generation anywhere it is desired. The costs of running power lines across hundreds of miles will not be needed.
3. If the PV cell changes angles during the day for optimum light, the output will increase.
4. South, in order to maximum it's exposure to the sun which is in the southern part of the sky in the northern hemisphere.

Multiple Choice Questions:

1 c; 2 d; 3 d; 4 d; 5 c; 6 c; 7 d; 8 d (best answer); 9 b; 10 c

Vocabulary Definitions

alternating current (AC) – an electrical current that reverses its direction at regular intervals

ammeter – instrument for measuring electrical current

array – modules wired into series and parallel arrangements

direct current (DC) – electric current that flows in one direction only

electrical grid – the transmission lines and generating facilities that supply homes and businesses with electricity

electricity – a flow of energy; electrons and some other sub atomic particles

infrared – light that lies outside of the visible spectrum, with wavelengths longer than those of red light

inverter – a device that converts direct current to alternating current

joule – a unit of energy equal to a watt/second or a newton/meter

module – dozens of PV cells interconnected and sealed to be weatherproof

parallel – a connection of 2 or more power sources where the positive terminal of one power source is connected to the positive terminal of another power source, and similarly, negative to negative

photon – a packet of electromagnetic energy, a particle of light

photovoltaics – comes from "photo" meaning light and "voltaic" referring to producing electricity; refers to PV cells

PV cell – (also called photovoltaic cell or photo cell) converts sunlight into electricity; made from at least 2 layers of semiconductor material (silicon)

series – a connection of 2 or more power sources (i.e. battery, solar cell, solar module) where the positive terminal of one power source is connected to the negative terminal of another power source

ultraviolet – a region of the electromagnetic spectrum that is of higher energy and shorter wavelength than visible light; typical wavelengths of ultraviolet radiation range from 375 nm to 12.5 nm (12.5 x 10-9 m)

voltmeter – instrument for measuring electric potential in volts (volts = ohms x amperes)

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