Sun Tracker Teacher's Notes

Focus questions

- Why does the output of a solar cell vary as the sun goes across the sky?
- What is the best angle to tilt a solar cell for the best performance?
- How does an automatic sun tracker work?

Essential materials

- Solar cell backpack with two attached solar cells connected to junction box and *Power Out* cable
- Additional solar cell
- Voltmeter (Make sure it is turned off.)
- Two electric motors
- Two wheels to fit the electric motors
- One pair of alligator clip leads
- Coaxial adapter
- Coaxial DC power jack
- Stopwatch
- Protractor
- Transparent tape
- Three sheets of basswood or other lightweight wood each 30 cm by 10 cm by 5 mm (12 inches by 4 inches by one-fourth inch) with 1.25 cm (one-half inch) diameter hole
- Wooden block with 1.25 cm (one-half inch) hole and wooden dowel 1.25 cm (one-half inch) diameter 30 cm (12 inches) long for constructing sundial
- Tape measure
- Magnetic compass

Optional equipment for automated solar tracker (not included):

- GoGo board
  http://padthai.media.mit.edu:8080/cocoon/gogosite/home.xsp?lang=en
- Serial cable
- Two light sensors
- Connecting posts
- Alligator clips
- GoGo Monitor software available as a free download from
  http://padthai.media.mit.edu:8080/cocoon/gogosite/home.xsp?lang=en

Main ideas and background information

- A solar cell, or *photovoltaic cell*, converts sunlight directly into electricity at the atomic level by absorbing light and releasing electrons. This behavior is a demonstration of the *photoelectric effect*, a property of certain materials that produce small amounts of electric current when exposed to light.
- A typical solar cell has two slightly different layers of silicon in contact with each other. When the sun shines on these layers, it causes electrons to move across the junction between the layers, creating an electric current.
- The top silicon layer in a solar cell is very thin. It includes as a deliberate impurity some atoms of an element that has more electrons than silicon, such as phosphorus. These impurity atoms are called *donors*, because they can donate or release their extra electrons into the silicon layer as free electrons.
- The bottom silicon layer in a solar cell is much thicker than the top layer. It has as an impurity some atoms of an element such as boron that has fewer electrons than silicon atoms. These impurity atoms are called *acceptors*, because relative to the silicon atoms they have "holes" where electrons can be accepted.
- At the junction where these two layers come together, the donors next to the junction give up their electrons, which migrate across the junction to the adjacent acceptors. This gives the top layer with the donors a net positive charge (because they gave up their excess electrons), and the bottom layer a net negative charge (because the acceptors have their "holes" filled with the excess electrons).
- When light shines on the layers, atoms in the bottom layer absorb the light and release electrons in accordance with the photoelectric effect. These electrons then migrate to the positively charged top layer. This movement of electrons creates the electrical current from a solar cell that can flow through a circuit with contacts at the two layers.
- Typical specifications for optimal solar cell operation include a location with unshaded sunlight from about 9:00 a.m. to about 3:00 p.m., and a solar cell tilt toward the south at an angle equal approximately equal to the latitude of the location. (For locations south of the equator, the tilt would be to the north.) As a practical matter, a little deviation in one direction or another will not significantly decrease the results.
- During the central part of the day, the output of the solar cell will be at or near its maximum because the sunlight is arriving at a more direct angle. At the beginning and at the end of the day, the output will fall off regardless of the orientation of the solar cell, mainly because the sunlight has to travel obliquely through the atmosphere at these times, arriving at a low angle. This decreases the intensity of the sunlight.
- Because of its design, a solar cell will develop a *voltage* that is fairly constant. However, the higher the intensity of the sunlight falling on the cell, the more electrical *current* is produced. This is why a voltmeter connected to a solar cell will have just about the same reading from midmorning to midafternoon, while a motor connected to the solar cell will run faster during the middle of the day, when the output current is a maximum.

- The latitude of your location is also the value, on average, for the angle of your solar cell tilt to provide the maximum output. For example, if you are located at a latitude of 30 degrees north, your solar cell should be tilted up at an angle of 30 degrees from the horizontal and faced toward the south.
- A photocell works like a solar cell, except it is small enough to be used as a light sensor.

Procedural tips

- Make sure that the center of the magnetic compass is mounted immediately over the central point of the protractor. When reading the direction of the sundial shadow, turn the protractor so that the compass needle is aligned with the edge of the protractor. Place the compass so that the center of the compass is on one edge of the shadow. Read the protractor where this same shadow edge crosses the protractor scale. (By the way, this simple sundial design is what Bill Nye, the Science Guy, persuaded NASA to include on the Mars Rover.)
- It is important to count the turns of the motor wheel carefully. The temptation is to count "One," as you start the stopwatch, when in fact the first complete turn will not be finished until the wheel goes around once more. We suggest saying, "Go, one, two, three,… nine, ten," as the turns are timed. Start the stopwatch when you say, "Go," and stop it when you say, "Ten." This will give you the time for ten full turns.
- Starting and stopping the stopwatch when the wheel is in the same angular position is also important. Select a starting position for the mark on the wheel that you can observe easily and consistently.
- When connecting alligator clips to the motor, be careful not to bend the metal motor contacts.
- When measuring the tilt of the solar cell, be sure that the central point of the protractor lies along the same line that you are using for the protractor reading.

Safety considerations

- Do not allow your students to look directly at the sun at any time. This can result in permanent eye damage.
- Do not allow horseplay of any kind.

Discussion

1. Why does the voltmeter reading stay about the same during the day? (The output voltage of a solar cell is produced when light falls on it. This voltage is determined by the design of the cell.)
2. Why does the electric motor connected to the solar cell run faster during the middle of the day? (This is when the maximum electrical current is produced. The motor runs faster with more current and slower with less current.)

3. How does the angle of tilt affect the output of a solar cell? (Light falling on the solar cell at an angle has less intensity per unit of area than light falling directly (or perpendicularly) on the cell. It is possible to see a small variation in the output voltage as the angle is changed. However, there will be a noticeable difference in the output current as the angle is changed. At locations above and below the equator, the solar cell should be tilted up from the horizontal to an angle equal to the local latitude for optimal performance.)
4. How might this activity be useful in everyday life? (For example, students might describe solar cell use they have already seen, such as charging battery packs for nighttime lighting for walking paths, solar powered traffic lights, or other similar applications. They might also describe inventions of their own with novel applications of solar cells.)

Assessment

Are students able to describe why the output of a solar cell varies as the sun goes across the sky? (In the early morning and the late afternoon hours, the sun is low in the sky. The sunlight has to travel obliquely through the atmosphere, arriving at a low angle. This decreases the intensity of the sunlight. Between these times, the sun goes higher in the sky and its light arrives at a higher more direct angle. As the sun goes across the sky during a day, the output of a solar cell would be low at first, then higher in the middle part of the day, and then lower once more.)

What is the best angle to tilt a solar cell for the best performance? (The best angle of tilt is the one that will keep the solar cell facing directly toward the sun for the maximum number of hours each day. Typically, this angle is the same as your latitude. To set this angle, start with your solar cell flat (angle of 0 degrees tilt) and tilt it upwards until its slanting angle has the same value as your latitude.)

How does an automatic sun tracker work? (One way is by use of a photocell. A photocell can sense whether it is in shadow or in sunlight. As the sun moves across the sky, it also moves its shadow. When the shadow falls on a photocell, it could turn on a motor to turn the solar cell until the photocell is in sunlight and the solar cell faces the sun directly.)

Extensions and further investigations

- Have students repeat the experiment with
  - more than one solar cell connected together.
  - other solar cells of different sizes and designs.
  - different weather conditions.
  - different types of indoor lighting.
- Before the students carry out each additional experiment, challenge them to predict what they think will happen and why. Then have them compare the results with their predictions and develop possible explanations for any discrepancies.

Career connections

Electrical engineering
Environmental engineering
Architecture

Correlations with Standards

United States: This activity correlates with portions of NSES Content Standard A, Science as Inquiry, and Content Standard G, History and Nature of Science, Grades 5-8 and 9-12, and with the following additional standards.

Grades 5-8
Standard B - Physical Science: B3, E1-E4

Grades 9-12
Standard B - Physical Science: B2, B5, B6, E1-E4

Glossary/vocabulary

Acceptor
Donor
Photoelectric effect
Photovoltaic cell

Resource links

Solar Electricity from Florida Solar Energy Center
http://www.fsec.ucf.edu/pvt/pvbasics/
A good general treatment of solar cells (photovoltaic cells) and how they work.

Solar cell from Wikipedia, the free encyclopedia
http://en.wikipedia.org/wiki/Solar_cell
In-depth discussion of solar cells, their history, and the science and technology behind their function.

Photovoltaics from National Renewable Energy Laboratory
http://www.nrel.gov/learning/re_photovoltaics.html
Overview of uses of solar cells.

How do Photovoltaics Work? from Science@NASA
http://science.nasa.gov/headlines/y2002/solarcells.htm
Excellent discussion of solar cell design and function.