How Solar Cells Work

Converting sunlight to electricity

What will happen

Students are introduced to the concept of converting sunlight to electricity with photovoltaic cells.

Students will

- Know that solar energy is the radiation from the sun that reaches the Earth's surface
- Explain how solar cells are used to generate electricity
- Understand that solar energy doesn't release carbon dioxide therefore helping to reduce green house gas emissions
- Use a voltmeter to measure energy produced by a solar panel

Total Time 1/2 - 1 1/2 hours	Establish what students know	The Activity		Debrief what students learned
		Part A	Part B	
	30 - 40 minutes	30-45 minutes	20-40 minutes	10 minutes

In Advance

What you need to know

Solar or photovoltaic (PV) cells are made up of materials that turn sunlight into electricity. Photovoltaic (PV) technologies including Solar thermal hot water are renewable energy technologies and are clean energy alternatives compared to non renewable energy technologies that burn fossil fuels.

PV cells are composed of layers of semiconductors such as silicon. Energy is created when photons of light from the sun strike a solar cell and are absorbed within the semiconductor material. This excites the semiconductor's electrons, causing the electrons to flow, and creating a usable electric current. The current flows in one direction and thus the electricity generated is termed direct current (DC).

One PV cell produces only one or two watts which isn't much power for most uses. In order to increase power, photovoltaic or solar cells are bundled together into what is termed a module and packaged into a frame which is more commonly known as a solar panel. Solar panels can then be grouped into larger solar arrays.

Vocabulary

- Power- Watts (W) - The rate at which work is performed or energy is converted; for example, the rate at which electrical energy is being produced by the solar electric system. A watt is the product of the current, in amperes (A), and the voltage, in volts (V). **Watt (W) = amps x volts.**
- Voltage- Volts (V) - The electrical force that makes electricity move through a wire and is measured in volts. The bigger the voltage, the more current will tend to flow.
- Current- Amps (I) - Current is the steady flow of electrons and is measured in amperes or Amps.

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Structure of a Solar Cell

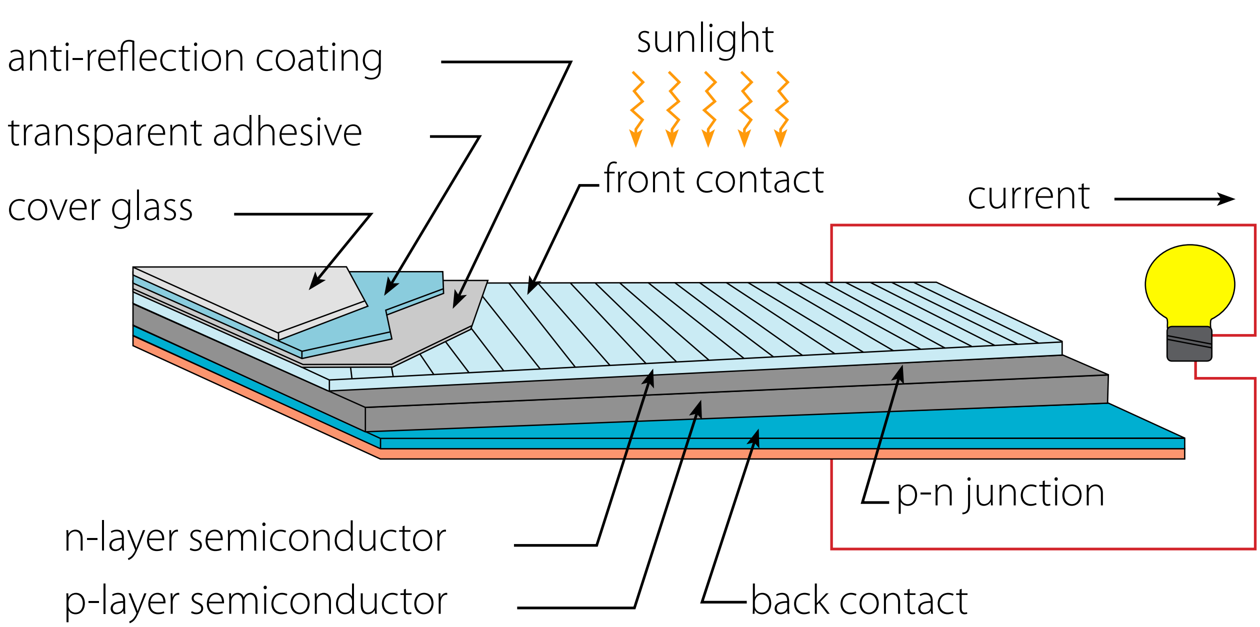
A typical solar cell is a multi-layered unit consisting of a:

- Cover - a clear glass or plastic layer that provides outer protection from the elements. Transparent Adhesive - holds the glass to the rest of the solar cell.
- Anti-reflective Coating - this substance is designed to prevent the light that strikes the cell from bouncing off so that the maximum energy is absorbed into the cell.
- Front Contact - transmits the electric current.
- N-Type Semiconductor Layer - This is a thin layer of silicon which has been mixed (process if called doping) with phosphorous to make it a better conductor.
- P-Type Semiconductor Layer - This is a thin layer of silicon which has been mixed or doped with boron to make it a better conductor.
- Back Contact - transmits the electric current.

N-Layer- is often formed from silicon and a small amount of Phosphorus. Phosphorus gives the layer an excess of electrons and therefore has a negative character. The n-layer is not a charged layer- it has an equal number of protons and electrons-but some of the electrons are not held tightly to the atoms and are free to move.

P-Layer- is formed from silicon and Boron and gives the layer a positive character because it has a tendency to attract electrons. The p-layer is not a charged layer and it has an equal number of protons and electrons.

P-N Junction - when the two layers are placed together, the free electrons from the n-layer are attracted to the p-layer. At the moment of contact between the two wafers, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving from one layer to the other. This contact point and barrier is called the p-n junction.



Once the layers have been joined, there is a negative charge in the p-layer and a positive charge in the n-layer section of the junction. This imbalance in the charge of the two layers at the p-n junction produces an electric field between the p-layer and the n-layer.

If the PV cell is placed in the sun, radiant energy strikes the electrons in the p-n junction and energizes them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-layer and are repelled by the negative charge in the p-layer.

A wire can be attached from the p-layer to the n-layer to form a circuit. As the free electrons are pushed into the n-layer by the radiant energy, they repel each other. The wire provides a path for the electrons to flow away from each other. This flow of electrons is an electric current that we can observe.

The electron flow provides the current, and the cell's electric field causes a voltage. With both current and voltage, we have power, which is the product of the two.

What might surprise you

- 45% of the cost of a solar cell is for the silicon wafers and about 35% is for the other components. With increasing numbers of photovoltaic cells being sold around the world and with ongoing research to make them more efficient, the price of PV cells has gone down about 4% per year for the last 15 years.
  Source: Green Learning, http://www.greenlearning.ca/
- The amount of solar energy that strikes the Earth's surface per year is about 29,000 times greater than all the energy used in the United States in 1995.
  Source: Solar in Schools Program by Madison Gas and Electric

What you need

- Materials for Demo 1 and 2
- Measuring Solar Cell Out worksheet

Establish what students know

1. Review the electron-proton-neutron model of the atom, the basic ideas of bond formation involving shared pairs of electrons, valence electrons and the notion that like charges repel and opposites attract.
2. Review basic electrical concepts such as direct current, series, parallel and voltage.

photons
electrons
current
voltage

Main Activity

Part A- Converting Photons to Electrons

Overview

The following two demonstrations will introduce students to a number of concepts key to understanding how solar cells work. Set the stage by using a prop to introduce the PV cell and component parts to the students. Display three calculators (or other common object that the students can relate to) at the front of the room: one that plugs into an outlet, one that runs on batteries, and one that is solar powered.

During the demonstrations highlight the following:

- Light energy (photons) strikes the PV cell.
- The silicon cells absorb some of the light energy.
- The absorbed energy knocks some of silicon's electrons loose.
- Electrons flow creating an electrical current.
- Current flows through metal contacts on the top and bottom of the PV cell. The metal contacts or leads can direct the current through wires that are attached to a battery or motor.

Demo 1- How Silicon in a PV Cell Creates Electrical Energy

What you need:

- Ice
- 2 plastic containers
- Clear Plastic tubing-long enough to connect the two containers, ~ 30cm
- Hair dryer
- Plasticine

What you do:

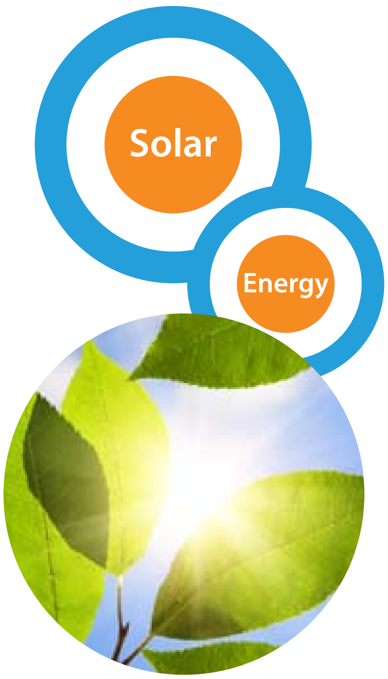
1. One plastic container represents a PV cell, the other represents a battery. Connect the two containers with the plastic tubing as follows.
2. The PV cell container should have the plastic tubing exiting from the bottom and the battery container should have the plastic tubing entering near the top.
3. Seal tubing with plasticine so there are no leaks.
4. Fill the PV cell container with ice cubes. The ice cubes represent Silicon found within the PV cell. The electrons in the Silicon do not have enough energy to move and create an electric current on their own so they exist in a "frozen" state.
5. The sun is represented by a hair dryer. The hair dryer melting the ice represents the release of the electrons by the sun and the flow of electric current.

Demo 2- Atomic Bumper Cars*

What you need:

- Chalk or cones to mark playing area
- Bell
- 1 Skipping rope (represents the p-n junction) or 5-10 students acting as turnstiles
- 2 ropes ~ 5m long (represents the wires)

What you do:



1. Explain that the class is going to conduct a demonstration that shows how a solar cell converts light energy into electrical energy.
2. Mark off a square area that will represent a photovoltaic (PV) cell approximately 10m x 10m. Mark off a circular area that represents the sun, approximately 3m in diameter and positioned about 5 m from one end of the PV cell. On the opposite end and about 5m from the PV cell, mark of an area approximately 1m x 1m to represent the battery.
3. Divide the PV cell in half with a skipping rope with 1 student on each end of the rope. This represents the P-N junction of the PV cell. They will hold the rope and turn it for the electrons as the electrons try to move from the p-layer to the n-layer once the simulation is started. Another option instead of a skipping rope is to use 5-10 students that line up along the p-n junction and act as turnstile, rotating as electrons tries to get through. Those electrons that can't get through go back to p-layer.
4. Place 8-10 students acting as electrons on the side of the PV cell closest to the battery to represent the n-layer.
5. Place 3-5 students, representing electrons, on the other half of the PV cell representing the p-layer.
6. Place 2 ropes leading from the PV cell to the battery. One connects the n-layer to battery and the other from the battery to p-layer. These represent the wires that carry the current to and from the battery.
7. One student stands in the battery area with the bell.
8. The remaining students stand in the sun area and represent the sun's photons.
9. Explain to the class that the sun's photons are energy and creates motion. To begin, one of the students who represent the Sun's photons runs over to the p-layer and tags an electron.
10. This electron must then move through (skip) the p-n junction and go tag an electron in the n-layer. The tagged electron then moves out of the PV cell along the rope (=wire) to the battery. Once the electron tags the student in the battery, that student rings the bell.
11. After the bell rings, the student in the battery moves along rope (wire) to the p-layer in the PV cell. Continue until all the photon's in the sun are released.
12. Debrief with student what happens when photon's hit the PV cell.

*adapted from Florida Solar Energy Centre. Lesson: Solar Matters

Main Activity
Part B- Measuring the Output of a Solar Cell

Students explore the concept that solar panel energy output is affected by shading, light intensity and angle.

What you need:

- Solar Cells (purchase from education supply companies e.g. Sunwind or Nasco Spectrum)
- Connecting wires
- Protractors
- Rulers
- 100W light source
- Voltmeter
- Cardboard

What you do:

1. Students will conduct a series of experiment with a solar cell to determine the affect shading, angle of the solar panel and distance from the light source has on the output of the solar cell.
2. Review with the students the following points. Note:The Power of PV lesson has background information on the following:
   - Current is measured in amps and is the rate of flow of the electrons
   - Voltage is measured in volts and is the force or push through the circuit
   - Power (watts) = Voltage (volts) x Current (amps)
3. Demonstrate with the students of how to attach the wires to the solar cell and voltmeter and how to read the voltmeter.
4. In groups students conduct the 3 different experiments from the Measuring the Output of A Solar Cell Worksheet.
5. Students graph their results for each of the 3 experiments.
6. After the class has completed their experiments discuss the variables the can affect the output of the solar cells.

Debrief what students learned

- Review students understanding of how a solar cell works by forming small groups and giving them 10 minutes to sketch and label how a solar cell produces electricity. Share results.
- Students work in groups to complete questions and share with the class:
  a. How does light cause electrons to flow?
  b. Which direction do electrons flow?
  c. What forms the electric field within the PV cell?
  d. What happens to the electrons when the light source disappears?

Extensions

Model it. Create a working model to illustrate producing electricity from the sun through a solar cell, include the electrons, n-layer, p-layer, and barrier.

Experiment further. Determine how much electricity can be produced under different lighting conditions, such as light intensity, angle of the light source, and concentration of light.

Assessment

- Draw a diagram that shows how a solar cell works. Label the parts.
- Describe factors that would affect solar cell output.

Check out

- How Photovoltaic Cells Work http://www.youtube.com/

Links

- Anatomy of a solar cell http://science.howstuffworks.com/solar-cell3.htm
- How silicon makes a solar cell http://science.howstuffworks.com/solar-cell2.htm

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Measuring Solar Cell Output

A. Light Intensity

Investigate how the light intensity, measured by the distance of solar cell from the light source, affects the solar cell output.

What you need

- Light source with 100 watt bulb
- Voltmeter
- Solar cell
- Ruler
- Connecting wires

What you do

1. Place the solar cell directly at the same angle for each distance measured.

2. Record the current and voltage for each distance.

Distance from Light Source	5 cm	10 cm	15 cm	30 cm
Current (Amps)				
Voltage (Volts)				

Questions

1. What is the relationship between he voltage produced and the distance from the light source?

2. What time of day would the solar cell produce the most electricity?

Measuring Solar Cell Output

B. Tilt Angle

Investigate how the angle between the sun and the solar cell affects the output.

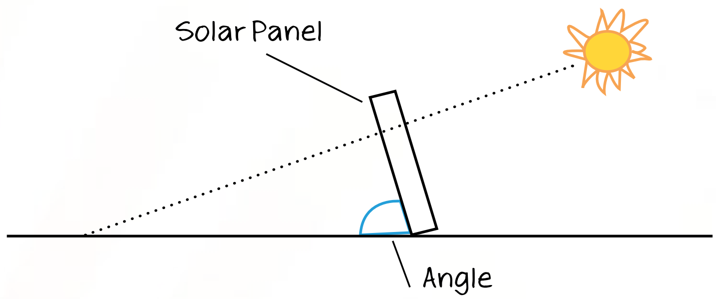
What you need

- Light source with 100 watt bulb
- Voltmeter
- Solar cell
- Protractor
- Connecting wires

What you do

1. Hold the panel at different angles using the protractor to measure the angles of the light source hitting the PV Cell.

2. Record the current and voltage change.



Angles of Solar Cell to Light Source	90°	45°	30°	15°
Current (Amps)				
Voltage (Volts)				
Power (Watts)				

Questions

1. What is the maximum amount of current (Amps) that can be produced? ____________
2. What is the angle of the solar panel for the maximum current? ____________
3. What is the maximum amount of voltage (Volts) that can be produced? ____________
4. What is the angle of the solar panel for the maximum voltage? ____________

Measuring Solar Cell Output

C. Shading

Investigate the how shading of the solar cell affects the solar cell output.

What you need

- Light source with 100 watt bulb
- Voltmeter
- Solar cell
- Motor
- cardboard
- Connecting wires

What you do

1. Measure the surface area of the solar cell
2. Cut different pieces of cardboard to cover 25%, 50%, 75% and 100% of the surface area of the solar cell.
3. Tilt the solar cell at an angle that generated the highest current Part B. Record current and voltage.

Shading of Solar Cell	0% coverage	25% coverage	50% coverage	75% coverage	100% coverage
Current (Amps)					
Voltage (Volts)					
Power (Watts)					

Questions

1. How does the shading affect solar cell output?

2. What percentage was the optimum output? Lowest output?

Structure of a Solar Cell

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