Solar Power

Subject Area(s)  number & operations, data analysis and probability, measurement, physical science, science and technology

Associated Unit  Clean Energy

Lesson Title  Introduction to Solar Power

Grade Level  11 (9-12)

Lesson #  4 of 5

Lesson Dependency  Introduction to Energy, Power, and Electricity, Introduction to Solar Power

Time Required  90 minutes including associated activities

Summary
Students learn the theory behind solar power, then build, test, and optimize solar cells for maximum power output.

Engineering Connection
Conversion of the sun's direct energy into electrical power is a subject of enormous interest to engineers today. Electrical, materials, and mechanical engineers work together to develop new photovoltaic materials that can better convert the electromagnetic spectrum's energy into useful electricity. In this lesson we will learn the fundamental theory behind solar power. We will then use our knowledge of solar power and optimization to produce the maximum power possible from solar cells.

Engineering Category
Engineering analysis or partial design

Keywords
power, electricity, electromagnetic spectrum, silicon, dope, boron, phosphorus, solar thermal, solar updraft tower, Sterling engine, Ohm’s Law
Educational Standards

**Colorado State Science:** *Colorado, 2011, science, physical science, grades 9-12, 5b:* Use appropriate measurements, equations and graphs to gather, analyze, and interpret data on the quantity of energy in a system or an object.
*Colorado, 2011, science, physical science, grades 9-12, 5d:* Identify different energy forms, and calculate their amounts by measuring their defining characteristics.
*Colorado, 2011, science, physical science, grades 4, 1c:* Describe the energy transformation that takes place in electrical circuits where light, heat, sound, and magnetic effects are produced

**Colorado State Math (from jesandco.net):**
- 3.16.1: Construct picture graphs and bar graphs from a data set
- 3.16.2: Read and explain information in picture graphs and bar graphs
- 4.1.3: Solve for unknown quantities in relationships involving perimeter, area, surface area, and volume

**ITEEA:** ITEEA, Standard 5, Grades 9-12, K. Humans devise technologies to reduce the negative consequences of other technologies.
ITEEA, Standard 2, Grades 9-12, Z. Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.

**Pre-Requisite Knowledge**
Knowledge of astronomy and physics including: understanding that solar energy comes from the sun, the sun's rays do not all reach earth, solar radiation contains energy. Students should be able to use scientific calculators and multimeters to compute power dissipation across a resistor using Ohm's Law and the power equations (Lesson 3: Energy, Power, and Electricity). Students should be able to use a protractor and have experience deciphering the angular relationships between straight lines (ie understanding of what parallel and perpendicular mean). Aptitude with relationships between area, height, and volume. Experience with plotting scatter data and making these data into line graphs. Knowledge of how to work safely in the sun.

**Learning Objectives**
After this lesson, students should be able to:
- Identify at least 3 unique methods for creating useful power from the sun's rays
- Measure the power produced by a solar photovoltaic cell vs. various angles of light incidence.
- Use a multimeter to measure resistance of a resistor
- Use a multimeter to measure voltage across a resistor
- Use Ohm's Law and the power law of electricity to determine the power dissipated in the resistor
- Analyze power vs. panel angle and determine optimal solar panel angle
- Choose an optimal solar panel angle given an angle of incident light
Introduction / Motivation

[Play National Geographic clip about solar]

Solar power can take many forms, but the broadest definition of the term might be "extraction of useful power directly from the electromagnetic spectrum." It is true that nearly all available energy on our planet is derived from one source: our sun. Wind for wind power and rain and thus rivers for hydropower rely on the power of the sun. Even fossil fuels, which are the decomposed remains of ancient plants and animals, needed the sun to exist. Our sun is an incredibly powerful source or energy, and it is up to our generation to harness it.

We find ourselves at a critical time in history. How we obtain energy has become one of the hottest topics in engineering, politics, and society. Not only have the greenhouse gases emitted by burning fossil fuels contributed to the warming of our planet, but we are, simply, running out of fossil fuel energy. The current system of harvesting and burning fossil fuels is in its twilight, and your generation will need to find a new way to harvest useful energy for a new tomorrow. That is why, in this lesson, we will learn how to extract energy from the sun, convert that every into something useful like electricity, and then optimize our system to produce as much energy as possible given our resources.

Lesson Background & Concepts for Teachers

Electricity Production: There are three primary methods of producing electricity:

- **Passing a magnetic field over a coil of wire or vice versa:** this is by far the most commonly utilized method for producing electricity. This technique exploits Faraday's Law of Induction to induce an electromotive force (EMF), and hence a current, in a closed loop system. In order to get this effect, we typically turn a magnetic shaft (rotor) inside a coiled wire "cage" (stator). However, in order to get mechanical rotation of the shaft, we must have some sort of energy source. Coal, nuclear, or solar thermal power can be used to boil water to turn a turbine, or, likewise, wind or water flow can be used to turn a turbine. See Lesson 3: Production of Electricity and Motor Theory
- **Solar photovoltaic:** we utilize the power of the sun to "knock loose" electrons from doped silicon in a transistor. We then harness those electrons to do useful work.
- **Fuel cells:** we harness the free electron released when hydrogen has combines with oxygen gas to do useful work

Solar Power: Power is a way of measuring how much energy is being produced/used in a given time and can be described by the equation $P = E/t$ where $P$ is power, $E$ is energy, and $t$ is time. Solar power is defined generally as the rate of electromagnetic energy that can be supplied by the light of the sun. Colloquially, we typically define solar power as electricity derived from the electromagnetic energy of the sun.

Solar energy is stored in the electromagnetic spectrum. As a result of extremely high-temperature fusion reactions on the sun's surface, the sun emits a broad spectrum of electromagnetic rays. Depending on the rays' frequency (spectrum), we call them different names. These rays have many names that we are familiar with: radio waves, microwaves, x rays, and gamma rays. However, the most well-known band of the electromagnetic spectrum is visible light.
We can harness the energy of the electromagnetic spectrum to do useful work in several ways:

1. We can use the energy of the sun to heat up a fluid to warm something
   a. Solar hot water heater
2. We can use the energy of the sun to heat up a fluid, then use that fluid to turn a turbine
   a. Solar updraft tower
   b. Solar parabolic mirror/turbine
3. We can use the energy of the sun to knock electrons loose from a special material and then use those moving electrons (electricity) to do useful work.
   a. Solar photovoltaic (most common)

Solar photovoltaic cells are the most common way of extracting useful energy from the sun. When most people think of "solar power," they are really thinking of "solar (photovoltaic) panels." Solar photovoltaic (PV) panels use a simple trick in order to make electricity. Two sheets of silicon are layered. One of these sheets of silicon is impregnated or "doped" with phosphorus. This is called the "n" side of the cell. The other side is doped with boron, and this is called the "p" side. When the sun hits the "p" side of the cell, it knocks an electron loose from the boron-doped silicon. This electron travels through the phosphorus-doped silicon and can be run through an electrical circuit to do useful work. If we stack many of these "p-n" systems together, we can produce a significant amount of electricity.

**Efficiency:** no energy conversion process is 100% efficient. Hence, we seek to quantify how efficient our particular system is. As an engineer, it is important not only to optimize your system, but to understand how your optimized system holds up against the "ideal." The comparison of your system’s performance to the "ideal" is called efficiency and is symbolized with the Greek letter eta: $\eta$

$$\eta = \frac{P_{\text{actual}}}{P_{\text{ideal}}}$$

**Ohm’s Law:** Ohm’s Law describes the relationship between voltage current and resistance as takes the form ($V=IR$). Given two of the three variables, the unknown can be solved for.

**The Power Equation:** the power of an electric current over some voltage gradient can be derived as $P=VI$

**Derivation of other forms of the power equation:** combining Ohm's Law and the power equation:

$$V = IR$$

$$P = VI$$

$$P = \frac{VV}{R} = \frac{V^2}{R}$$

$$P = IRI = I^2R$$

We will utilize the relationship $P=V^2/R$ to measure the power across a load resistor.
**Parabolic Mirrors:** Parabolic mirrors are typically used to gather solar thermal energy. The mirrors concentrate the sun's energy onto one focal point. Typically, a dark-colored tube filled with oil is placed at this focal point. The oil heat up to very high temperatures, and then runs through a heat exchanger where it exchanges its heat with water. The water boils, produces steam, and that steam turns a steam turbine and generator.

**Solar Towers:** Solar towers are another form of concentrated solar thermal power. The top of the tower is the focal point for hundreds or even thousands of mirrors that focus the sun's light. At the top of the tower is typically a reservoir filled with oil that heats up and then runs through a heat exchanger where it exchanges its heat with water. The water boils, produces steam, and that steam turns a steam turbine and generator.

**Stirling Engines:** A Stirling Engine is a special kind of engine that uses heat to turn a shaft. The Stirling Engine requires no combustion, but just relies on the expansion of air from heat to move its piston. Solar concentrators can be used to turn Stirling Engines instead of heat water to make steam.

**Solar Updraft Tower:** A solar updraft tower uses the greenhouse effect to heat air underneath a giant transparent sheet of plastic. This warm air rises towards a giant chimney (tower) at the center of the plastic sheet. As the air moves through the chimney, it turns turbines which power generators.

**Solar Photovoltaic:** (note: this explanation is simplified for brevity) The word "Photovoltaic" comes from the word "photo" meaning light and the word "voltaic" meaning electricity. Most photovoltaic materials available are made from silicon. Silicon is a special material because its outer-most electron shell is only half full. This shell only has 4 electrons even though it has room for 8. The silicon wants its outer electron shell to be full, so it shares its 4 electrons with 4 neighbors. Because silicon is so stable and "happy" in this structure, it does not like to give up electrons, and therefore, it does not like to conduct electricity. However, if the silicon is "doped" with an impurity such as phosphorus, it's electrical properties change. Phosphorus' outer electron shell has 5 electrons: one more than silicon. When phosphorus starts sharing electrons with silicon in the crystal, its 5th electron has nowhere "comfortable" to go. This phosphorus-doped silicon is called n-type silicon because it has one too many electrons and is negatively charged. A similar logic applies to p-type silicon which is doped with boron which has 3 electrons in its outer shell, has too few electrons, and is positively charged. When a PN junction (meeting of n and p-type silicon) is formed, the extra electrons in the n-type silicon will move into the p-type silicon to fill up the "need" for extra electrons. If light hits the solar cell and knocks one of the electrons on the p-side loose, that electron will move from the p-side to the n-side of the sandwich. If we connect an electrical circuit from the n back to the p-side, we can use the moving electron to do work before it re-unites with the "hole" it left on the p-side.
**Vocabulary / Definitions**

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
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<tbody>
<tr>
<td>solar</td>
<td>Of or relating to the sun</td>
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<tr>
<td>electromagnetic waves</td>
<td>A spectrum of waves emitted by the sun (and other sources) including radio waves, microwaves, infrared light, visible light, ultraviolet light, x-rays, and gamma rays</td>
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<tr>
<td>solar photovoltaic cell</td>
<td>A device consisting of silicon doped with phosphorus and boron used to create electricity directly from the energy of the sun</td>
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<tr>
<td>solar updraft tower</td>
<td>A system used to warm air with the heat of the sun, the use the kinetic energy of the rising air to turn a turbine</td>
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<tr>
<td>parabolic mirror</td>
<td>A mirror that focuses light onto a point or line</td>
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<tr>
<td>multimeter</td>
<td>An instrument that can measure useful electrical quantities such as voltage, current, resistance</td>
</tr>
<tr>
<td>breadboard</td>
<td>A device that allows one to connect wires without soldering</td>
</tr>
<tr>
<td>Ohm’s Law</td>
<td>Ohm’s Law is the equation V=IR and relates voltage, current, and resistance in simple circuits.</td>
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<td>n-type silicon</td>
<td>Silicon doped with phosphorus that has one too-many electrons</td>
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**Associated Activities**

**Solar Cell Activity**

**Lesson Closure**

Solar power is a very promising renewable energy source. The sun is, in fact, the original source of all fuels and energy sources on the planet (petroleum, coal, wind, biomass), so why not tap it directly? As you have learned, we can capture the sun's energy in many ways: photovoltaic, solar updraft towers, solar hot water, and solar/oil/turbines, and Sterling engines.

However, solar faces challenges: it is expensive, panels are heavy, fragile, and awkward, the sun does not always shine, and it has limited power density. It will be up to you, a new generation of engineers, to work around and with these challenges to develop robust, reliable, and clean solar energy for the 21st century.

**Assessment**

**Pres-Lesson Assessment:**

*Small Group Discussion:* Ask students to discuss the following questions in small groups and present their answer on one question to the class:

- What is solar energy?
- How do we get electricity from the sun?
- What important factors might you consider when building a solar power installation?

**Post-Introduction Assessment:**

*Group Interaction:* Interaction with students building, testing, and optimizing solar cells will confirm whether students have learned how to use multimeters, bread boards, and Ohm's law to determine the panel's power output.
Lesson Summary Assessment: See homework.
Self Assessment: Students will fill out the “Introduction to Solar Power” skeleton notes as well as construct, test, and optimize their own solar cell.

Homework: Students will be challenged to take their solar panel home, and to return it in one week. The returned solar cell should be equipped to do some useful task: power a motor, light, or anything else that is doing a useful task. This assignment will be accompanied by a one-page report on how the students chose their design need, defined constraints, brainstormed ideas, selected a final idea, prototyped and iterated on a solution.

Lesson Extension Activities
None

Additional Multimedia Support
http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

References
http://science.howstuffworks.com/environmental/energy/solar-cell.htm

Attachments
Solar Power Presentation(ppt)
Solar Power Presentation (pdf)
Solar Power Skeleton Notes and Worksheets (doc)
Solar Power Skeleton Notes and Worksheets (pdf)
Solar Photovoltaic Activity (doc)
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