SOLAR ENERGY

Overview:

In this lesson, students investigate energy transfer and photovoltaic (PV) cells through hands-on experiments. Students explore the impact of intensity and angle of light on the power produced by solar panels and extrapolate this to examine how/where solar panels might be used in their community.

Objectives:

The student will:

- differentiate between voltage, current, and watts;
- predict and observe the output of a solar panel under variable conditions;
- compute and graph the power produced by a solar panel under variable conditions;
- consider the feasibility of solar energy applications in Alaska; and
- apply knowledge of solar energy to their own community.

Targeted Alaska Performance Standards for the High School Graduation Qualifying Exam:

M2.2.3 Use a variety of measuring tools; describe the attribute(s) they measure.
M4.3.4 Translate among and use tables of ordered pairs, graphs on coordinate planes, and linear equations as tools to represent and analyze patterns.
M10.3.1 Apply mathematical skills and processes to science and humanities.
M10.3.2 Apply mathematical skills and processes to situations with peers and community.

Targeted Alaska Grade Level Expectations:

Science

[11] SA1.1 The student develops an understanding of the processes of science by asking questions, predicting, observing, describing, measuring, classifying, making generalizations, analyzing data, developing models, inferring, and communicating.

[11] SB2.1 The student demonstrates an understanding of how energy can be transformed, transferred, and conserved by demonstrating energy (e.g., nuclear, electromagnetic, chemical, mechanical, thermal) transfers and transformations by comparing useful energy to total energy (entropy) (L)

Vocabulary:

active solar design—a design strategy using mechanical systems such as batteries, pumps and fans to transport and store solar energy

ammeter—a device used to measure current

amperes (amps)—the unit of measure used to express current (rate of flow of electrons)

dependent variable—a variable whose value is determined by the value of another variable

independent variable—a variable whose value determines the value of other variables

multimeter—an instrument used to measure voltage, current and resistance in an electric system

n-layer—the visible layer of a solar cell that is composed of a semiconductor (usually silicon) mixed with another element (usually phosphorus) to create a negative character; this layer usually appears dark blue or black

nonrenewable energy source— a mineral energy source that is in limited supply, such as fossil (gas, oil, and coal) and nuclear fuels

p-layer—the layer of a solar cell that is composed of a semiconductor (usually silicon) mixed with another element (usually boron) to create a positive character

passive solar design—a design strategy where the structure itself functions as the solar collector; solar radiation (heat and light) is transferred by natural energy flow (conduction, convection, radiation)

photovoltaic (PV) cell—a device that converts solar radiation into electricity

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radiant energy—the energy of electromagnetic waves

renewable energy source—an energy source that can be replenished in a short period of time (solar, wind, geothermal, tidal)

semiconductor—a substance (such as silicon in a solar cell) that's electrical conductivity is intermediate between that of a metal and an insulator; its conductivity can be increased with the addition of impurities

solar panel—a number of solar cells connected in a frame

volts—the unit of measure used to express voltage (the potential for energy to flow)

watts—the unit of measure used to express electric power

Whole Picture:

From the time of breakup beginning in March through the long days of summer, Athhabascan people have long enjoyed the benefits and energy from the sun. (In Ahtna sun is Saa; Gwich'in, Srii'; and Koyukon, So.) The light and heat from the sun affords more freedom to travel and with access to unfrozen lakes and rivers, the summer fishing season can commence. In his book "Make Prayers to the Raven," Richard K. Nelson writes: "Most salmon are caught in the warmth of July and August" and the drying power of the sun helps in the preservation of protein-rich salmon for much-needed food supply during the long winter months in Alaska.

In this lesson, students learn how to harness the sun's energy through the technology of solar cells. Solar cells (also called photovoltaic or PV cells) convert solar energy (radiant energy carried through the sun's heat and light) into electricity. A solar panel is a group of connected solar cells packaged in a frame.

Solar energy is practical in most of Alaska for about nine months of the year. (There is not enough direct sunlight in most parts of the state from November to January to provide adequate electricity.) Solar panels require little maintenance and actually work more efficiently at colder temperatures. As long as you scrape the snow and ice off the surface, they produce more power per daylight hour as the days grow colder. Since radiant energy from the sun is not available all the time (i.e. at night), solar electric systems require a storage bank of batteries. Solar systems also usually require an inverter which converts DC (12-volt) current produced by solar cells to AC (120-volt) current used in most homes, schools and businesses.

Solar energy systems are classified as "active" or "passive." Passive design implies that the building itself functions as the solar collector and thermal energy is transferred by natural energy flow (conduction, convection, radiation). Examples of passive solar design include buildings with south facing windows to maximize sunlight and solar chimneys. The latter serve to ventilate buildings via convection. Active solar energy designs use mechanical systems such as batteries, pumps, and fans to transport and store solar energy for future use.

Materials:

- 2-volt (200 mA) solar panel with wires and alligator clips attached (one per group)
- Digital ammeter (needs to measure up to 500 mA, one per group)
- Small protractor (2 inches in height, one per group)
- Lamp with at least 100 watt bulb (one per group)
- Meter stick (one per group)
- Wax paper (one square, slightly larger than the solar panel, per group)
- Red, yellow, green, blue transparency sheets (one square, slightly larger than the solar panel, per group)
- Quart-sized resealable bag full of crushed ice or snow (one per group)
- Masking or duct tape
- Small, portable electronic device (if available)
- STUDENT LAB PACKET: "Solar Energy"
- TEACHER INFORMATION SHEET: "Solar Panels 101"

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Activity Preparation:

1. Review TEACHER INFORMATION SHEET: "Solar Panels 101" to build a deeper understanding of solar energy systems and their applications in Alaska.
2. Check to ensure ammeter(s) have batteries.
3. Make ice cubes, if needed.
4. Cut wax paper and transparency sheets to size of solar panel, if necessary.

Activity Procedure:

1. Open with a discussion about energy. Ask students leading questions such as: Where does the electricity that powers our homes and school come from? Students may answer oil or diesel fuel. Follow up with questions about where those resources come from. Bring the discussion around to the fact that almost all Earth's energy comes from the sun. Small amounts also come from within the Earth (geothermal) and the moon (tidal). Ensure students understand that solar energy is radiant energy carried through the sun's heat and light and we can transfer this energy into electricity for use in our homes and schools.
2. Use one solar panel as a demonstration during the introduction. Pass the panel to a student and ask him/her to share some observations. Pass it to another student or two to share additional observations. Allow time for the class to share what they know about how and where solar panels are used.
3. Distribute STUDENT LAB PACKET: "Solar Energy" to each student. Divide students into groups of 4-6 and distribute a solar panel, lamp, ammeter, meter stick, protractor, wax paper, colored transparency sheets and a small piece of tape to each group.
4. Read the first page of the student lab aloud as a class. Review how solar cells transform solar energy into electricity, and how electricity (including that produced by solar panels) is quantified and measured (volts, amps, watts). Use as much detail as is appropriate for your class. See TEACHER INFORMATION SHEET: "Solar Panels 101" for more information.
5. Review the procedure as a class then allow student groups time to complete STUDENT LAB PACKET: "Solar Energy." Remember that when students get to part IV, they will need the resealable bag and ice.
6. When all groups have finished, discuss the results and review the discussion questions as a class. End with a more detailed discussion about the possible advantages and limitations of using solar panels at your school and/or at other locations in your community. Compare and contrast current energy sources used in your community to solar energy. Discuss how each relates to climate change issues in your community.

Extension Ideas:

1. Design reflectors using aluminum foil, magnifying glasses or mirrors to intensify the light hitting the solar panel. (Be careful not to burn a hole in the panel!) Design and experiment to test the efficiency of the panel using these tools. Discuss practical applications for Alaska.
2. Instruct student groups to create a 5-minute skit for younger students describing how solar cells transform solar energy into electricity. The "actors" in the skit may include: a narrator, the sun, electrons, the p-n junction and an electronic device.

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Answers:

STUDENT LAB PACKET: Solar Energy

Data Analysis:

1. Power decreases as distance from the light source increases.
2. less than half the power.

   As you move away from a light source the same amount of light is spread over a larger area so the solar panel only intercepts part of the energy.
3. Power decreases as the angle of the solar panel decreases or increases from 90˚.
4. 90˚
5. about half the power produced at 90˚

   As the solar panel is tilted to a 45 degree angle, the light hits the solar panel at increasing angles spreading the same amount of light over a greater distance (making it more diffuse).
6. Answers may vary. Colors with higher frequency (blue/violet) may generate more current. However, this difference is slight. The difference in the intensity of light (that can infiltrate the different films) will also affect the current and may be more significant.
7. Answers may vary. See #5 above.
8. The wax paper diffuses the light, reducing intensity and, therefore, reducing the power produced.
9. Power increases as temperature decreases.
10. Answers will vary but may include: shading and debris (representing snow or leaves) on the panel. These variables can be studied in the same basic way as the ones used in the lab.

Conclusion:

1. The power produced by solar panels is affected by: angle of light (changes with season and time of day), direction the panels are facing, weather (clouds diffuse light), shade from nearby trees or buildings, reflection from snow and more. (Students may have additional ideas.)
2. Answers will vary but should indicate an understanding that panels should be placed to maximize exposure to direct sunlight (usually south facing and at a 90˚ angle to the sunlight). Other considerations might include: locations that use a lot of electricity, locations where a lot of people will see and learn about them and accessibility of panels (to clean off snow and ice and to keep them oriented at a 90˚ angle as the sun moves across the sky).
3. Answers may vary but should indicate an understanding that the panels should be adjusted throughout the day to follow the movement of the sun and that if snow or ice accumulates on the panels, it should be removed.
4. Answers will vary. Some benefits include:
   - is a clean, renewable and sustainable energy source
   - saves money by reducing our dependence on expensive fuel
   - does not produce greenhouse gas emissions (so they do not contribute to climate change or poor air quality)
   - once installed they do not cost anything to operate and require little maintenance

   Some challenges include:
   - initial cost of materials can be high
   - a large area is needed to put up enough panels to meet demand
   - efficiency is very low in the winter in Alaska when demand for electricity is highest
   - electricity is not produced at night, so a storage system is needed (batteries)
5. Answers will vary but may include the Internet, parents, Elders and community leaders.

Solar Photovoltaic Cells

Solar photovoltaic cells are made up of two or more very thin layers of semiconductor material. The most commonly used semiconductor is silicon. Silicon is the second most abundant element in Earth's crust and it has some special chemical qualities. The outermost orbital of electrons in a silicon atom is not full. It is always looking to "share" electrons with neighboring atoms. Sharing electrons with nearby molecules is what forms silicon's crystalline structure.

Solar cells have two layers. The "n-layer" appears dark blue or black. In silicon-based cells, this layer consists of silicon mixed with a small amount of phosphorus. Phosphorus has five electrons in its outer orbital, so even when it bonds with nearby silicon atoms there is still one electron that remains "free" giving this layer a negative "character." (It does not have a negative charge since there are still equal numbers of protons and electrons at this point.)

The "p-layer" is underneath the "n-layer" and is not usually visible. In silicon-based cells, it consists of silicon mixed with a small amount of boron. Boron has only three electrons in its outermost orbital, giving this layer a positive character. When the two layers are placed together at the time of production, electrons flow from the n-layer to the p-layer creating an imbalance in the charge, and an electrical field. (Now the n-layer has a slight positive charge and the p-layer has a slight negative charge.) The point of contact is called the "junction" and the two layers are joined by a connector (a wire) to form a circuit.

When radiant energy (sunlight composed of photons) strikes the solar cell, it can be absorbed, reflected or pass through. Photons that are absorbed provide energy to knock electrons loose, allowing them to move. This creates a current (flowing through the wire) as electrons move away from the negative charge in the p-layer, toward the positive charge in the n-layer. The junction acts like a one-way door and does not allow electrons to flow back into the p-layer.

A single silicon-phosphorus based solar cell produces about 0.5 volts, regardless of its size. The cell's voltage varies slightly depending on the type of material that is mixed with the silicon. Cells must be connected in series to get a higher voltage. Voltage can be thought of as water pressure in a hose. The "pressure" or voltage must be high enough to achieve the desired result (i.e. charge a battery or appliances.) Current is measured in amperes (amps). The larger the solar cell, the greater the current will be. If voltage is compared to water pressure in a hose, current is equivalent to the flow (volume) passing through. However, solar panels are usually described and rated in watts. Watts are a measure of total power and are calculated by multiplying volts by amps.

Research in solar technology is producing simpler, cheaper and more efficient solar cells all the time. The materials used differ in efficiency and cost. Thin-film solar cells are made from a variety of different materials, including amorphous (non-crystalline) silicon, gallium arsenide, copper indium diselenide and cadmium telluride. These are becoming widely available to charge laptop computers, cell phones, and other portable electrical devices. Another strategy, called multi-junction cells, uses layers of different materials. This increases efficiency by increasing the spectrum of light that can be absorbed. Another field of development includes strategies for boosting the output of photovoltaic systems by concentrating light (with lenses and mirrors) onto highly efficient solar cells.

More on Measuring Solar Output

The three basic units in electricity are voltage (V), current (I) and resistance (r). Voltage (V) is the potential for energy to move and is measured in volts. Current (I) is the rate of flow (or amount of electrons) and is measured in amperes, or amps for short. A solar panel that produces two amps sends twice as many electrons as a panel that produces one amp. Resistance (r) is a measure of how strongly a material opposes the flow of electrons and is measured in ohms. Current is equal to the voltage divided by resistance: $I = V/r$

Power (P) in an electric system is the amount of work that can be done with the energy and is equal to the voltage multiplied by the current: $P = V \times I$. Power is measured in watts.

Various devices are used to measure current, voltage and resistance. An ammeter measures electric current; a voltmeter measures voltage; and an ohmmeter measures resistance. A multimeter is a device capable of measuring all three.

Returning to the analogy of a garden hose used previously, voltage is equivalent to water pressure, resistance is equivalent to the size of the hose and current is equivalent to the amount of water passing through. If you want to increase the overall power capacity of a system, you should increase the "pressure" (voltage), increase the rate of flow (current) or increase the "hose size" (decrease resistance). A single solar cell produces 0.5 volts, regardless of size. Higher voltages can be achieved by connecting individual cells in series; think of this like steps in a staircase. The cells are connected along a single path so that voltage increases with each cell, but the same current flows through all of them. Solar panels are solar cells connected in series (usually to produce 12 volts.) Current can be increased by increasing the size of individual solar cells or by connecting solar cells in parallel. When cells are connected in parallel there is more than one path for electrons to flow, so current is increased while voltage remains the same.

Solar panels do not always operate at full capacity. The total power (watts) produced by a solar panel is significantly affected by the intensity of the sunlight. Solar panels do not need full sun exposure all day to work but they will be most efficient with maximum sun intensity. The intensity of the sun is impacted by atmospheric conditions (cloud cover, smog, shading from nearby structures and trees). Light passing through clouds or smog is scattered and becomes more diffuse.

The angle at which sunlight hits the solar panel is also a significant factor in determining the total power output. Maximum intensity is achieved when the sun's rays hit perpendicular to the panel. The amount by which the sun's rays differ from this optimum perpendicular arrangement is called the angle of incidence. It is affected by latitude and season, but also by the direction and angle at which the panels are arranged. Changing the angle has the effect of decreasing the cross section of light that is intercepted. In addition, low angle sun on Earth must pass through more atmosphere so some energy is absorbed. Some solar systems incorporate mechanisms to automatically rotate the panels, minimizing the angle of incidence (and maximizing solar output) throughout the day. When the sun is high in the sky (summer) it passes through less atmosphere, is less likely to encounter interference (from trees, chimneys, rooftops, etc.) and is therefore at maximum intensity. Solar panels in Alaska can actually reach peak efficiency in late spring when sunlight abounds, temperatures are cold, skies are often clear and snow on the ground increases reflectivity of light.

Energy Storage

Solar energy (photons) is not available 24 hours per day, but our homes and classrooms require energy during the dark hours. Consequently, solar photovoltaic systems are generally designed to incorporate some sort of energy storage such as a battery (or possibly heating water stored in a tank.) Battery storage is limited by the type of battery used. Historically, deep-cycle lead-acid batteries have been used for this purpose, but more modern technologies include lithium and vanadium batteries. Battery technology has not come as far as was expected mainly due to the limitations of the chemicals and the nature of the technology.

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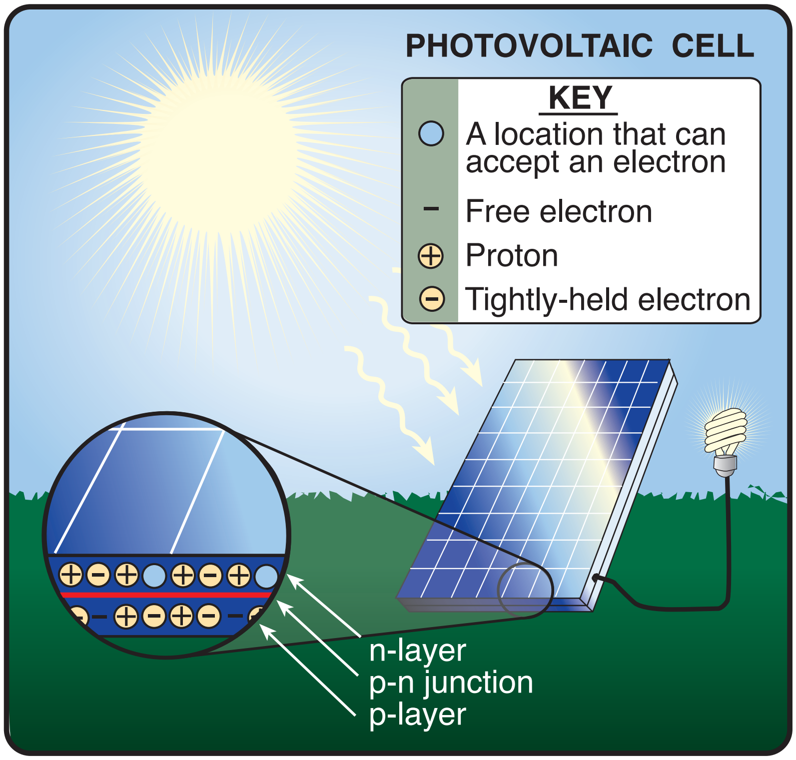

A **photovoltaic (PV) solar cell** is a device that converts the radiant energy (carried by the sun's heat and light) into electricity.

A **solar panel** is a number of solar cells connected in a frame.

Each solar cell consists of two layers. When sunlight hits the solar cell, it provides the energy needed for electrons to flow from the slight negative charge in the **p-layer** through the **p-n junction** and towards the **n-layer**. The p-n junction acts like a one-way door and does not allow electrons to flow back into the p-layer.

We can form a circuit by attaching a wire. The electrons flow through the circuit and power electric devices.

Power (P) in an electric system (such as a solar panel) is equal to the **voltage (V)** multipled by the **current (I)**. Voltage (V) is the potential for energy to move. The solar cell you are using creates 2 volts. Current (I) is the rate of flow (the volume of electrons flowing). It is measured in amps. Your ammeter measures milliamps.

$$P = V \times I$$

1 amp = 1000 milliamps

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Directions: Work in groups to complete the following lab.

In this lab four experiments will be conducted to investigate how distance from the light source, angle of the panel, color of light and temperature affect the power produced by a solar panel. The distance, angle, color and temperature are the ***independent variables*** in the experiments. The power produced by the solar panel is the ***dependent variable***. Make a hypothesis for each experiment. Each hypothesis should predict how changing the independent variable will affect the dependent variable.

Testable Question:
What factors affect the power produced by a solar panel?

Experiment:

Materials:

- 2-volt solar panel
- Ammeter
- Protractor
- Lamp
- Meter stick
- Tape
- Wax paper
- Red, yellow, green and blue transparency squares
- Resealable bag
- Ice cubes or snow

Procedure:

1. Set up the lamp as directed by your teacher.
2. Measure with the meter stick and use a small piece of tape to mark the following distances from the heat lamp: 15 cm, 30 cm, 45 cm, 60 cm, 75 cm and 90 cm.
3. Turn on the ammeter and ensure it is set to measure DC current in mA (milliamps).
4. Use the alligator clips to attach the solar cell to ammeter. Attach the black (negative) wires together and the red (positive) wires together.

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Part I: Distance from Light Source (measured at 90˚)

1. Write a hypothesis about the affect the distance from the light source will have on the power produced by the solar panel. Fill it in on the lines provided.
2. Hold the solar cell at 90˚ on the 15 cm mark.
3. Read and record the current (in milliamps) displayed on the ammeter.
4. Repeat at each distance, keeping the solar panel at 90˚. Record the data in the chart.
5. Convert the values in milliamps to amps and record.
6. Calculate the watts produced by the panel at each distance. Record.
7. Draw a line graph of your results. Be sure to give your graph a title and to label each axis

Hypothesis: IF ____

THEN the power produced by a solar panel will ______________________________________

Distance from Lamp	Current (milliamps)	Current (amps)	Voltage (volts)	Watts (amps x volts)
15 centimeters			2	
30 centimeters			2	
45 centimeters			2	
60 centimeters			2	
75 centimeters			2	
90 centimeters			2	

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Part II: Angle of Solar Panel (measured at 30 cm)

1. Write a hypothesis about the affect the angle of the solar panel will have on the power produced by the solar panel. Fill it in below.
2. Hold the solar cell upright facing the light on the 30 cm mark. Place the flat part of the protractor flat on the table. Align the solar cell with the 90o mark.
3. Read and record the current (in milliamps) displayed on the ammeter.
4. Repeat for the other angles. Record the data in the chart.
5. Convert the values in milliamps to amps and record.
6. Calculate the watts produced by the panel at each angle. Record.
7. Draw a line graph of your results. Be sure to give your graph a title and to label each axis.

Hypothesis: IF ____

THEN the power produced by a solar panel will ____

Angle of Solar Panel	Current (milliamps)	Current (amps)	Voltage (volts)	Watts (amps x volts)
90˚			2	
60˚			2	
30˚			2	
15˚			2	

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Part III: Color/Wavelength of Light (measured at 30 cm, 90˚)

1. Write a hypothesis about the affect the color/wavelength will have on the power produced by the solar panel. Fill it in on the lines provided.
2. Hold the solar cell upright facing the light on the 30 cm mark.
3. Read and record the current (in milliamps) displayed on the ammeter.
4. Place the red transparency square in front of the solar panel.
5. Read and record the current (in milliamps) displayed on the ammeter.
6. Repeat with each color and the wax paper.
7. Convert the values in milliamps to amps and record.
8. Calculate the watts produced by the panel with each color. Record.
9. Draw a bar graph of your results. Be sure to give your graph a title and to label each axis.

Hypothesis: IF ____

THEN the power produced by a solar panel will ____

Filter Color	Current (milliamps)	Current (amps)	Voltage (volts)	Watts (amps x volts)
no filter			2	
red 400-484 THz			2	
yellow 508-526 THz			2	
blue 631-668 THz			2	
wax paper			2	

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Part IV: Temperature (measured at 30 cm, 90˚)

1. Write a hypothesis about the affect temperature will have on the power produced by the solar panel. Fill it in on the lines provided.
2. Hold the solar cell at 90o on the 30 cm mark.
3. Read and record the current (in milliamps) displayed on the ammeter.
4. Place the solar panel outside (if below freezing) or in the freezer for 10 minutes.
5. Read and record the current (in milliamps) again.
6. Convert the values in milliamps to amps and record.
7. Calculate the watts produced by the panel at each time. Record.

Hypothesis: IF ____

THEN the power produced by a solar panel will ____

Time at freezing (minutes)	Current (milliamps)	Current (amps)	Voltage (volts)	Watts (amps x volts)
0 minutes room temperature			2	
10 minutes			2	

Data Analysis:

1. Describe what the graph shows about the relationship between power produced by the solar panel and distance from the light source. Why?

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2. If the solar panel is moved twice the distance away it produced:

_____ more than half the power. _____ less than half the power. _____ about half the power.

Explain why you think this happens.

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3. Describe what the graph shows about the relationship between power produced by the solar panel and the angle of the panel.

____

____

4. At what angle is the power (watts) produced by the panel the greatest? ______________________

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5. If the solar panel is oriented at a 45 degree angle, it produced: ______________________________

   Explain why you think this happens.

   ____

   ____

6. Describe what the graph shows about the relationship between power produced by the solar panel and the color/wavelength of light.

   ____

   ____

7. What color filter allows the solar panel to produce the most power (watts)? ____________________

8. Describe what happens when you filter the light with wax paper.

   ____

   ____

9. Describe what the lab shows about the relationship between power produced by the solar panel and temperature.

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   ____

10. In this investigation, distance, angle, color and temperature were in the independent variables studied. Describe one additional independent variable that might affect the power produced by a solar panel and briefly describe how you would conduct the investigation.

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Conclusion:

1. In this experiment, you changed the distance of the light source from the solar panel, however, Earth's distance from the sun does not change significantly as it orbits the sun. What factors might influence the strength of the light reaching a solar panel on your school or home?

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2. You have solar panels to place around your village. You want them to produce the most power possible where it is needed most. Where in your village would be a good place to put solar panels? Why? Explain where on the building they would be located and how they would be oriented.

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3. Describe how you could increase the output of a solar panel during the day when the angle of the sun's rays and the weather are constantly changing?

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4. List at least two benefits and two challenges of using solar power in your community.

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5. If you are interested in installing solar panels on your home or school, where could you look for more information? Who in your community might be able to help?

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