National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-022-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Can a Spacecraft Use Solar Panels at Saturn?

Objective

To demonstrate the effect of the inverse square law of illumination with distance.

Time Required: 1 hour

Saturn System Analogy: The reduction in solar illumination at Saturn's distance compared to Earth's distance from the Sun.

Keywords: Current, Illumination, Inverse Square Law, Photovoltaic, Power, Spacecraft Power, Solar Cell, Solar Energy, Voltage

MATERIALS

- One silicon solar cell (available at an electronics parts store for a few dollars)
- Standard metal window screen material. *A strip somewhat wider than the solar cell and long enough for 10 layers to be placed in front of the cell is necessary. (A hardware store might have free scrap available. If not, a strip of this size costs less than $5.)*
- Digital multimeter (available at an electronics parts store for $10 to $30)
- Optional: desk lamp (available at any variety store for a few dollars)

Background

Students of all ages ask why spacecraft at Mars can use solar panels when Cassini cannot make use of solar power at Saturn. Working with a simulated Saturnian illumination environment, students will use commercially available solar cells to determine the approximate power output of a solar cell at Saturn.

One of the laws of physics states that as energy radiates equally in all directions from a source, the intensity (brightness) decreases at a rate that is proportional to the square of the distance that the energy has traveled. In other words, if a light bulb is turned on and you measure the illumination 1 meter (about 1 yard) from the light bulb (the source) and then you measure the brightness of the light 2 meters (approximately 2 yards) away from the light bulb, the illumination 2 meters away is 4 times weaker than the illumination at 1 meter from the bulb. Doubling the distance reduces the illumination by a factor of two squared, or four. Tripling the distance reduces the illumination by a factor of three squared, or nine times. This is called the "inverse square law" and is applicable to all forms of electromagnetic radiation as well as to the force of gravity, sound intensity, and other forms of energy transfer.

Solar panels convert solar energy directly to electricity using photovoltaic cells. When sunlight strikes the photovoltaic cell, a small voltage is generated. Wires connected to the cell permit an electric current to flow through circuits to power various electrical and electronic components. Electricity generated this way is used on Earth and on spacecraft to power electronics, motors, and science instruments.

Missions to Mars and Venus, as well as satellites in Earth orbit, have solar panels. However, at increasing distance from the Sun, the amount of available sunlight drops below the level at which the use of solar panels is practical. Either the spacecraft must be very small or the solar panels must be very large. Beyond Jupiter's distance, solar panels cannot produce enough power to operate a spacecraft, no matter what size the panels and spacecraft are.

Facts You Need

- Earth is 149,600,000 kilometers (92,970,000 miles) from the Sun.
- Saturn is 1,429,400,000 kilometers (888,200,000 miles) from the Sun (9.555 times more distant than Earth).
- Cassini needs 628 watts of power to operate all its systems at Saturn.

Procedure

1. Measure the dimensions of the power-generating area of the solar cell with a millimeter ruler (sometimes the protective case is much larger than the actual working area).
2. Attach the leads of the solar cell to the same color leads of the digital multimeter (red is positive, black is negative; no damage will be done if the leads are mismatched). Alligator or wire clips on the multimeter leads will be easier to use than standard probes, or use alligator clip jumpers (also available from electronics parts stores) to make the connections.
3. Set the multimeter to current (or voltage) and turn it on.
4. Record the current and then switch to voltage and record that value, both as generated by the solar cell under: (1) ambient room light, (2) direct, mid-day sunlight, and (3) at measured, recorded distances from a bare 100-watt light bulb. If the meter settings are adjustable, the multimeter range can be set under 5 volts and less than a few tens of milliamperes for most single solar cells.
5. Now place 10 layers of metal window screen mesh between the light source(s) and the solar cell. It may be easiest to simply wrap the mesh around the cell 10 times. This will simulate the amount of sunlight falling on Saturn.

If the solar cell is not covered with a protective case, be careful not to damage the active surface of the solar cell. Also, be careful to avoid shorting the solar cell with the metal mesh. Plastic food wrap will provide minimal but effective scratch and short circuit protection. Small clear pieces of glass or plastic or a clear transparent plastic box with holes for the leads can be used to provide more protection.

For proper comparisons, the current and voltage measurements should be made with the same transparent protective layers in place for both direct lighting and mesh-reduced lighting experiments. Record current and voltage generated by the mesh-covered solar cell at the same places as the measurements made when it was uncovered.

Calculations

- Determine the active, electricity-generating area of the solar cell by multiplying the measured length times the width.
- Compute the power generated by the cell under the varied lighting conditions: multiply the voltage times the current.
- If measurements were made at different distances from a light bulb, plot the power output as a function of distance from the bulb. Also, compute some ratios between various distances from the bulb and compare the power ratios from those distance pairs — does the power go down as the square of the distance?
- Using the ratio of direct-Sun power output to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Earth's surface.
- Using the ratio of direct-Sun output from the window screen wrapped solar cell to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Saturn's distance from the Sun and compare to the first array size.
- Compare the ratio of array sizes computed above with the square of Saturn's distance from the Sun, relative to Earth (i.e., 9.555^2). This is an indication of how well the transmission of 10 layers of window screen actually mimics the decrease in illumination at Saturn's distance from the Sun. How many layers of your window screen reduce the illumination by 9.555^2?

Extension

Several vendors offer light-measuring photometry systems that acquire data and plot it under computer control. Such systems can be adapted for quantitative measurements of the illumination or voltage/current/power generated. Computerized data acquisition is common in many laboratories.

Determine whether a cloudy day on Earth equals the amount of sunlight falling on Saturn's cloud tops. How many minutes after sunset does skylight illuminating your solar cell equal the direct sunlight falling on Saturn?

Distance from the Sun is not the only limitation in using solar cells to power Cassini at Saturn. The environment at Saturn is much colder than the environment around Earth. The extreme cold affects the efficiency of energy generation by silicon solar cells. What are some possible ways of boosting the efficiency of a solar cell at Saturn? Are there other types of solar cells (other than silicon) that are more efficient and/or more resistant to temperature extremes?

Education Standards

A visit to the URL http://www.mcrel.org yielded the following standards and included benchmarks that may be applicable to this activity:

Mathematics Standards

3. Uses basic and advanced procedures while performing the processes of computation.

LEVEL 2 (GRADES 3–5)

Solves real-world problems involving number operations (e.g., computations with dollars and cents).

LEVEL 3 (GRADES 6–8)

Adds, subtracts, multiplies, and divides whole numbers, fractions, decimals, integers, and rational numbers.

Understands exponentiation of rational numbers and root-extraction (e.g., squares and square roots, cubes and cube roots).

4. Understands and applies basic and advanced properties of the concepts of measurement.

LEVEL 3 (GRADES 6–8)

Understands the relationships among linear dimensions, area, and volume and the corresponding uses of units, square units, and cubic units of measure.

6. Understands and applies basic and advanced concepts of statistics and data analysis.

LEVEL 2 (GRADES 3–5)

Understands that data represent specific pieces of information about real-world objects or activities.

Science Standards

9. Understands the sources and properties of energy.

LEVEL 1 (GRADES K–2)

Knows that the Sun supplies heat and light to Earth.

Knows that electricity in circuits can produce light, heat, sound, and magnetic effects.

LEVEL 3 (GRADES 6–8)

Knows that energy is a property of many substances (e.g., heat energy is in the disorderly motion of molecules and in radiation; chemical energy is in the arrangement of atoms; mechanical energy is in moving bodies or in elastically distorted shapes; electrical energy is in the attraction or repulsion between charges).

Knows that electrical circuits provide a means of transferring electrical energy to produce heat, light, sound, and chemical changes.

12. Understands the nature of scientific inquiry.

LEVEL 2 (GRADES 3–5)

Plans and conducts simple investigations (e.g., formulates a testable question, makes systematic observations, develops logical conclusions).

LEVEL 4 (GRADES 9–12)

Uses technology (e.g., hand tools, measuring instruments, calculators, computers) and mathematics (e.g., measurement, formulas, charts, graphs) to perform accurate scientific investigations and communications.

Teachers — Please take a moment to evaluate this product at http://ehb2.gsfc.nasa.gov/edcats/educational_brief.
Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.

Student Worksheet — Can a Spacecraft Use Solar Panels at Saturn?

Procedure

1. Measure the dimensions of the active, power-generating area of the solar cell with a millimeter ruler (sometimes the protective case is much larger than the actual working area).

2. Attach the leads of the solar cell to the same color leads of the digital multimeter (red is positive, black is negative; no damage will be done if the leads are mismatched).

3. Set the multimeter to current (or voltage) and turn it on.

4. Record the current and then switch to voltage and record that value, both as generated by the solar cell under: (1) ambient room light; (2) direct, mid-day sunlight; and (3) at measured, recorded distances from a bare 100-watt light bulb. If the meter settings are adjustable, the multimeter range can be set under 5 volts and less than a few tens of milliamperes for most single solar cells.

5. Now place 10 layers of metal window screen mesh between the light source(s) and the solar cell. It may be easiest to simply wrap the mesh around the cell 10 times. This will simulate the amount of sunlight falling on Saturn.

Calculations

- Determine the active, electricity-generating area of the solar cell by multiplying the measured length times the width.

- Compute the power generated by the cell under the varied lighting conditions: multiply the voltage times the current.

- Plot the power output as a function of distance from the bulb. Also, do some ratios between various distances from the bulb and compare the power ratios from those pairs — does the power go down as the square of the distance?

- Using the ratio of direct-Sun power output to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Earth's surface.

- Using the ratio of direct-Sun output from the screen-wrapped solar cell to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Saturn's distance from the Sun and compare to the first array size.

- Compare the ratio of array sizes computed above with the square of Saturn's distance from the Sun, relative to Earth (i.e., 9.555^2). This is an indication of how well the transmission of 10 layers of window screen actually mimics the decrease in illumination at Saturn's distance from the Sun. How many layers of your window screen reduce the illumination by 9.555^2?