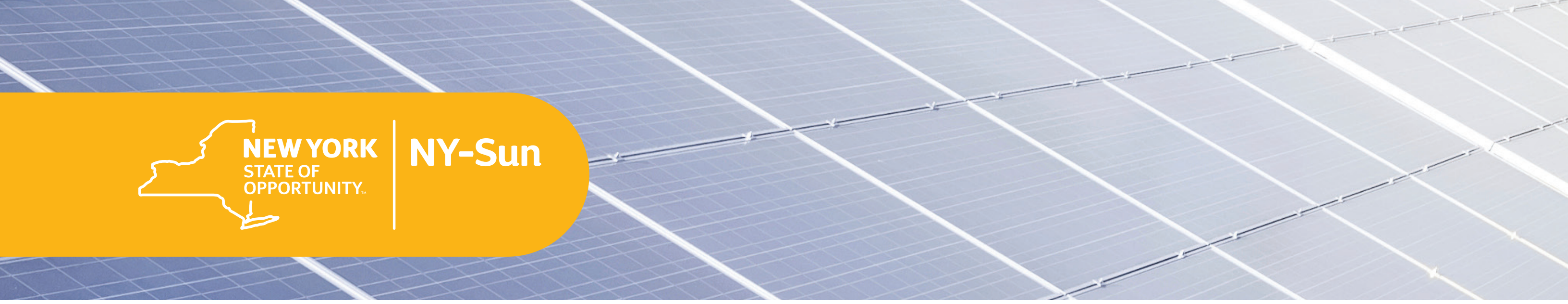


Orienting a Photovoltaic Cell

Suggested Level: High School Physics or Physical Science

LEARNING OUTCOME

After investigating the relationship between incident rays and collecting surface, students are able to state that as the angle between the two increases, the output power increases.

LESSON OVERVIEW

The purpose of this lesson is for students to learn the optimum angle for orienting a solar collector relative to the rays of incoming sunlight. Equinoxes, solstices, and various locational ideas might need to be reviewed before students undertake their investigations using meters, light sources, and photovoltaic cells.

MATERIALS

- Student handout
- 100 W incandescent light bulb and fixture
- One 1V, 400 mA mini-solar panel
- Stands for mounting the light fixture and photovoltaic cell
- Connecting wires
- DC ammeter
- Protractor

SAFETY

The only sources of electricity used in this experiment are photovoltaic cells, which produce very low currents, but as a matter of habit, students should exercise the usual care in experimenting with simple electric circuits. The light bulb and fixture should also be handled with the same safety as any lamp, including not touching a hot light bulb.

TEACHING THE LESSON

Discuss with students where the sun appears in the sky at noon on special days of the year—the vernal and autumnal equinoxes, and the summer and winter solstices. Because New York State lies entirely within the Northern Hemisphere, the sun is always found in the south at noon. If the northerly latitude of the location is x, the angle between the sun and the zenith (directly overhead) at noon at both equinoxes is x; it is ($x - 23.5°$) at the summer solstice and ($x + 23.5°$) at the winter solstice. Ask students how they think a photovoltaic cell should be oriented relative to the sun's rays in order to get maximum output power. Then, hand out the equipment and ask students to carry out the directions on the handout.

ACCEPTABLE STUDENT RESPONSES

The following data were measured results using a 100 W bulb 20 cm away from a small photovoltaic cell. If a 1 Volt, 400mA solar panel were used at 20 cm, the maximum current would be 30 mAmps. If this solar panel were used in midday sun the maximum current would be 400 mAmps as per specifications:

Angle between incident rays and PV cell (degrees)	Sine	Current (mA)	Max. current x sine (angle)
90	1.000	1.4	1.40
75	0.9659	1.3	1.35
60	0.8660	1.1	1.21
45	0.7070	0.9	0.99
30	0.500	0.6	0.70
15	0.25800	0.3	0.36
0	0	0.1	0.00

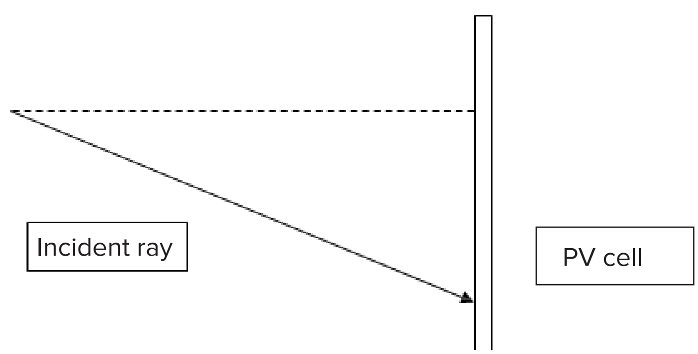
1. What happens to the output power from the photovoltaic cell (as measured by the reading on the milliammeter connected to the photovoltaic cell) as the angle between the incident rays and the surface of the photovoltaic cell increases?

Answer: As the angle between the incident rays and the surface of the photovoltaic cell increases, the output power increases.

2. How closely does the milliammeter reading correlate with the maximum milliammeter reading times the sine of the angle between the incident rays and the surface of the photovoltaic cell?

Answer: In the sample data provided above, the two correlate rather well.

3. Consider the following representation of an incident ray and a photovoltaic cell. The incident ray is represented by an arrow that forms the hypotenuse of a right triangle whose legs are a portion of the photovoltaic cell and a line segment perpendicular to the photovoltaic cell.



What feature of this diagram represents the incident ray multiplied by the sine of the angle between the incident ray and the photovoltaic cell?

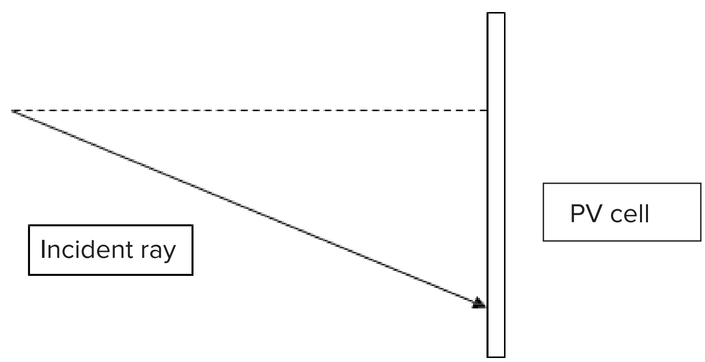
Answer: The incident ray multiplied by the sine of the angle between the incident ray and the photovoltaic cell is the horizontal line perpendicular to the photovoltaic cell. It represents the vector component of the incident ray that is perpendicular to, or directly incident upon, the photovoltaic cell.

4. How could your interpretation of the diagram in Question #3 explain a correlation between the output power, as measured by the milliammeter reading, and the maximum power times the sine of the angle between the incident ray and the surface of the photovoltaic cell?

Answer: The strong correlation between the milliammeter reading and the milliammeter reading at 90 degrees multiplied by the sine of the angle between the incident rays and the surface of the photovoltaic cell suggests a vector model for the oncoming light, and also suggests that only the component of the light directed perpendicular to the photovoltaic cells is being absorbed by the cell. This is well illustrated in the diagram. The horizontal line equals the length of the incident ray times the sine of the angle between the incident ray and the photovoltaic cell. It is the component of the incident ray that is perpendicular to the photovoltaic cell.

BACKGROUND INFORMATION

The output power from a photovoltaic cell is greatest when the incident light rays are perpendicular to the surface of the photovoltaic cell. This suggests a vector model for the oncoming light, and also suggests that only the component of the light directed perpendicular to the photovoltaic cells is being absorbed by the cell. This can be illustrated in the following diagram:



The horizontal line equals the length of the incident ray times the sine of the angle between the incident ray and the photovoltaic cell. It is the component of the incident ray that is perpendicular to the photovoltaic cell.

In this lesson the output power of the photovoltaic cell is measured by the reading of an ammeter connected to the terminals of the photovoltaic cell. This is valid because, in a first approximation, the maximum output of a photovoltaic cell occurs at constant voltage. What varies with the incoming intensity of light is the output current. Because the output power equals the output voltage times the output current, and the former is essentially constant, the output current (ammeter reading) varies proportionally to power.

(STUDENT HANDOUT FOLLOWS)

Name ____ Date ______________

Orienting a Photovoltaic Cell

If you have a photovoltaic power system on the roof of your school, observe where the photovoltaic cells are placed. Toward what direction in the sky are they facing? How does this relate to where the sun is most often found in the sky? In this experiment you will use a light bulb to model the sun, orient a small photovoltaic cell in various directions to the incoming light rays from the light bulb, and measure the output power of the photovoltaic cell.

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DEVELOP YOUR UNDERSTANDING

Mount a 100 W incandescent light bulb in a light fixture on a stand and a photovoltaic cell on another stand at the same height 20 cm from the surface of the light bulb. Connect the output terminals of the photovoltaic cell to a milliammeter to measure the cell's output power, as explained above. Initially orient the photovoltaic cell so that the incident rays from the bulb are perpendicular to its surface (90^o angle between surface of photovoltaic cell and incident rays), and record the milliammeter reading in a table like the following:

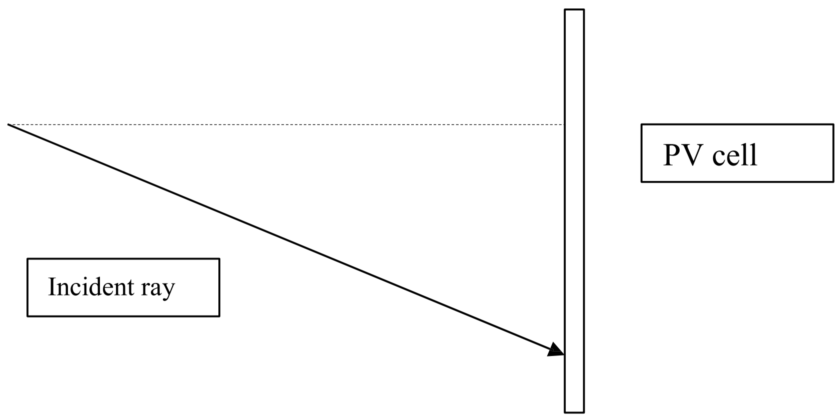
Angle between incident rays	SINE	Current (mA)	Max. current x sin(angle)
90			
75			
60			
45			
30			
15			
0			

Reorient the photovoltaic cell so that the angle between the incident rays and the surface of the photovoltaic cell assumes the other values listed in the table and record the respective milliammeter readings. In the third column, calculate the maximum milliammeter reading times the sine of the angle.

1. What happens to the output power from the photovoltaic cell (as measured by the reading on the milliammeter connected to the photovoltaic cell) as the angle between the incident rays and the surface of the photovoltaic cell increases?

2. How closely does the milliammeter reading correlate with the maximum milliammeter reading times the sine of the angle between the incident rays and the surface of the photovoltaic cell?

3. Consider the following representation of an incident ray and a photovoltaic cell. The incident ray is represented by an arrow that forms the hypotenuse of a right triangle whose legs are a portion of the photovoltaic cell and a line segment perpendicular to the photovoltaic cell.



What feature of this diagram represents the incident ray multiplied by the sine of the angle between the incident ray and the photovoltaic cell?

4. How could your interpretation of the diagram in Item #3 explain a correlation between the output power, as measured by the milliammeter reading, and the maximum power times the sine of the angle between the incident ray and the surface of the photovoltaic cell?