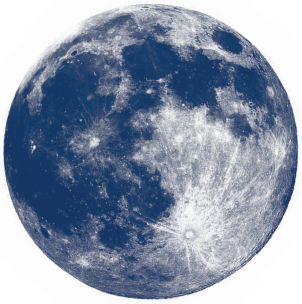

EDUCATOR'S RESOURCES

LAUNCHPAD

Apollo 11
Promises Kept

Fifty years ago, Apollo astronauts set foot upon the Moon—where will we be fifty years from now? Through artifacts and experiences, **Launchpad: Apollo 11 Promises Kept** commemorates the milestone anniversary of the Apollo 11 moon landing.

CLASSROOM CONNECTIONS TO EXTEND STUDENTS LEARNING

KEY QUESTION:
What is the importance of space exploration?
Use claim, evidence and reasoning to explain your position.

TEKS correlations (including but not limited to):

PROCESS SKILLS:
- Plan and implement comparative and descriptive investigations
- Analyze data to formulate reasonable explanations and communicate valid conclusions supported by data and trends
- Analyze, evaluate and critique scientific explanations by using empirical evidence logic and reasoning
- Create models
- Understand limitation of models
- Understand the impact of scientific research

CONTENT:
- Physical properties, location and movement of Sun, planets, moons, meteors, asteroids, comets
- Gravity is the force that governs the motion of our Solar System
- History and future of space exploration and transportation
- Identify accommodations that enabled Space Exploration

ELEMENTARY ACTIVITIES

- Create a timeline of the Space Race. Use pictorial representations for different events on the timeline.
- Compare and contrast space transportation, past and present. Create a new transportation system for space travel.
- The International Space Station been very valuable in forwarding research in space. Create a new International Space Station based on what we have learned from the current one.
- Research the different types of space vehicles, both manned and un-manned. Create a presentation focusing on the pros and cons of two or three vehicles.
- Scientists are investigating a way to send humans to Mars. Investigate how scientists landed the rover on Mars. Identify some of the challenges they were faced with.

https://www.jpl.nasa.gov/video/details.php?id=1090
https://www.jpl.nasa.gov/infographics/infographic.view.php?id=10776

MIDDLE AND HIGH SCHOOL

The Perimeter Institute and Vernier have provided classroom activities that will enhance your curriculum. The Fort Worth Museum of Science and History thanks these two organizations for their contributions to this educator resource.

Activities in this section include:

Signature of Stars

This activity is from Perimeter Institute's The Expanding Universe module. To download the full, free digital resource including a Teacher Guide, supporting video, and modifiable Word files, visit: www.resources.perimeterinstitute.ca/collections/lesson-compilations. For more information on Perimeter Institute resources and programs, please contact outreach@perimeterinstitute.ca

Find an Exoplanet

This activity is from Perimeter Institute's The Expanding Universe module. To download the full, free digital resource including a Teacher Guide, supporting video, and modifiable Word files, visit: www.resources.perimeterinstitute.ca/collections/lesson-compilations. For more information on Perimeter Institute resources and programs, please contact outreach@perimeterinstitute.ca

Doppler Effect: Sound Waves

Experiment Number: 23

Book: *Physics with Video Analysis*

Software: Logger *Pro*

This experiment is an excerpt from the *Physics with Video Analysis* lab book available from Vernier Software & Technology. It requires Logger *Pro* software for video analysis. For more information, visit **www.vernier.com/pva**

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info@vernier.com • **www.vernier.com**

Name:________________________________

Date:_________________________________

Doppler Effect: Sound Waves

Have you ever noticed that if a car with a horn blowing is moving past you rapidly that the sound waves emitted by the horn seems to change frequency? In 1842 an Austrian physicist, Hans Christian Doppler, observed and analyzed the same phenomenon for sound emitted by a passing train. Hence the phenomenon is known as the *Doppler Effect*.

A similar effect is found for the propagation of light and other electromagnetic waves from moving sources. In fact highway patrol officers use radar to measure Doppler shifts in radio waves so they can determine how fast vehicles are moving.

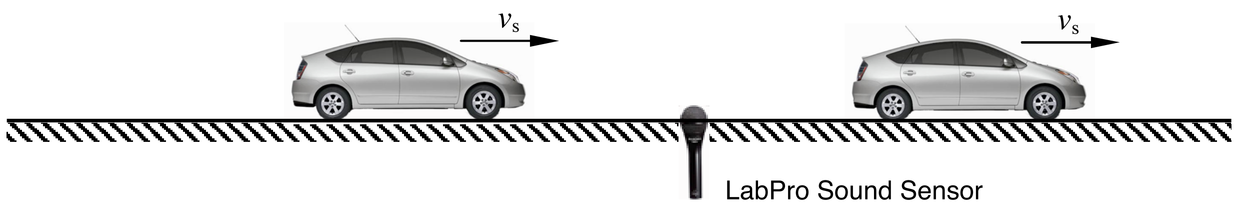

Fig. 1: A car is shown moving at a speed v_s past a sound sensor located at the side of a long straight road.

Suppose a driver is blowing her car horn and hears a predominant frequency denoted by f_0. What frequency, f_F will be detected by a microphone placed in front of the source of sound (consisting of the moving car horn)? Doppler proposed that the frequency, f_F detected in front of the source is given by

$$f_F = f_0 \frac{v_w}{v_w - v_s} \qquad \text{(Eq. 1: frequency detected in front of a moving source)}$$

where v_w is the speed of the sound wave propagation in air and v_s is the speed of the moving source from which the sound wave emanates.

Similarly, Doppler predicted that the frequency of waves propagating behind a source of sound that moves away from an observer at speed v_s can be determined using the equation

$$f_B = f_0 \frac{v_w}{v_w + v_s} \qquad \text{(Eq. 2: frequency detected behind a moving source)}$$

We have created movies of a honking car moving fairly rapidly on a straight level road past a stationary microphone. We have recorded the sound waves emanating from the car's horn separately using a sound sensor attached to the Logger *Pro* interface, operated by the roadside observer. You will be working with these files in this exercise.

Your goal in this assignment is to verify that the Doppler Equations, shown above, can be used to predict the ratio (f_F / f_B) of the apparent car horn frequencies before and after the car passes the microphone. To complete this assignment you will need to (1) use Equations 1 and 2 to derive an equation for this ratio as a function of the speed of sound waves in air (v_w) and the speed of the moving car horn (v_s), and then (2) use the Logger *Pro* video analysis tools to determine the value of v_s–the passing car's velocity.

1. Preliminary Questions

Note: You will receive **full credit for each prediction** made in this preliminary section whether or not it matches conclusions you reach in the next section. As part of the learning process it is important to compare your predictions with your results. **Do not change your predictions!**

(a) **What happens to the sound of the car's horn as is passes the sound sensor?** Open the movie entitled <CarHornDoppler.mov> and play it. This video clip was recorded by a digital video camera that was placed perpendicular to the road and 10.0 meters away from the center of the car just as it passes the sound sensor in the center of the frame as shown in Figure 2. The sound dubbed into the *Car Horn Doppler* movie was recorded at the roadside by this sound sensor. What happens to the sound of the car's horn as the car moves from an initial position to the left of the camera to a final position to the right of the camera? Replay the movie and listen several times, does the frequency of sound change? Is the loudness changing? Describe what you hear.

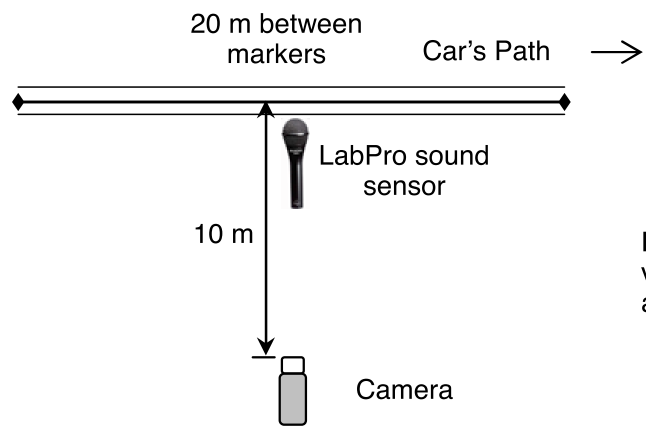

Figure 2: Overhead view of the recording apparatus

2. Activity-Based Questions

Verification of the Doppler Equations: In the section you are going to use the Logger *Pro* software along with the movie of the car's motion and the sound sensor data to verify the Doppler Equations.

(a) Use the Doppler Equations 1 and 2 to derive an equation for the ratio f_F/f_B as a function of the speed of sound waves in air (v_w) and the speed of the moving car horn (v_s). Show your work.

(b) Open the Logger *Pro* file entitled <CarSpeed.cmbl>, which has a shortened version of the movie inserted in it. Use the video analysis tools to find the speed of the car with its blowing horn "sound source," (v_s). Explain what you did to find (v_s). Record your value for (v_s) in the box below to three significant figures. **Hints**: Don't forget to scale the movie and figure out how to find the car's velocity using *x* vs. *t* data.

v_s = _____________m/s

(c) **Calculate the speed on sound on the day the movie was made:** It turns out that the speed of sound in air (v_w) depends on the air temperature (T_c) and can be calculated using the equation[1]

$$v_w = 331.45\sqrt{1+\frac{T_c}{273.16°\text{C}}}\ \text{m/s}$$

When the movie was made, the air temperature (T_c) was recorded as 27.2°C. Calculate the speed of sound in air (v_w) on that day. Show your calculations!

(d) Find the expected value of the ratio f_F/f_B in terms in terms of your calculated value of the speed of sound in air (v_w) and your measured value of the speed of the sound source (v_s). **Hint**: Use the equation you derived in Part 2(a). Show your calculations and round your answer to three significant figures.

[1] Dennis A. Bohn, "Environmental Effects on the Speed of Sound", Presented at the 83rd Convention of the Audio Engineering Society, New York, October 16-19, 1987. Http://www.rane.com/pdf/eespeed.pdf

(d) **Compare your calculated Ratio with Logger *Pro* frequency measurements**: This comparison serves as a direct test of the validity of the Doppler Equations. We have recorded the sound pressure using a LabPro Sound Sensor placed at the side of the road for about one second before the car passes the sound sensor and for about one second after it passes the sensor. In each case the Logger *Pro* a *Fast Fourier Transform* analysis (FFT) of the sound pressure waves can be used to find the predominant frequency just before (f_F) and just after (f_B) the car passes the roadside sound sensor.

Start by opening the Logger *Pro* file entitled <FrequencyShift.cmbl>. Look for the largest peak on the FFT graph describing the frequencies between 0 s and 1 s to find the predominant frequency just **before** (f_F) the car passes the sensor. Change the scale on the horizontal axis so that you see this region in more detail. You can accomplish this by selecting the ***Additonal Graph Options*** → ***FFT Graph Options*** from the ***Options*** menu or by double clicking on the FFT graph to reset the frequencies displayed so that you focus only on the highest amplitude frequencies. Next, use the ***Examine*** tool to find the predominant frequency just **before** (f_F) the car passes the sensor. Repeat the procedure between 2 s and 3 s to find the predominant frequency just **after** (f_B) the car passes the sensor. Summarize your results in the appropriate spaces below and calculate the ratio f_F/f_B.

FFT Max 0s to 1s: f_F = _________ Hz

FFT Max 2s to 3s: f_B = _________ Hz f_F/f_B = ____________________

3. Reflections on Your Findings

(a) How did the ratio f_F/f_B that was determined from the Doppler Equations (in Part 2 (d)) compare to the ratio determined from direct measurements (in Part 2(e))? Find the percent difference between the two results.

(b) Suppose you are assisting a policeman, who is sitting in stationary cruiser and is pointing his radar "gun" at the approaching car. His detector shows the car's speed. Describe how you could use your sound data for the car's resting frequency f_0 and measured frequency f_F while moving toward the policeman to calculate the speed of an approching car (v_s) in order to check the reliability of the radar gun.

Doppler Effect: Sound Waves

This activity requires students to use Logger *Pro* to analyze video and sound sensor data acquired for a car moving at a steady velocity along a straight road with its horn blaring. The purpose of this assignment is to have students verify that the Doppler Equations can be used to predict the ratio (f_F / f_B) of car horn frequencies in front of and behind the car as it passes the microphone.

To complete this assignment students will need to use Doppler equations for an advancing sound source and for a receding sound source to derive an equation for the frequency ratio. The calculation of predicted ratio of the frequencies, f_F / f_B, requires students to know the speed of sound waves in air (v_w) as well as the speed of the moving car horn (v_s).

We provide students with an equation for the speed of sound in air as a function of temperature and the temperature measurement on the day the video and sound recording was made. However, in order to validate the equation they have derived, students need to analyze the video using the Logger *Pro* video analysis tools to determine the value of v_s. They also need to use the Logger *Pro* FFT feature to determine the car horn frequencies (f_F and f_B) in front of and behind the microphone.

Time to complete as a homework assignment: This is a fairly rigorous assignment—especially for students who are weak with mathematics. It will take an hour on longer to complete. We suggest that this activity be started as a collaborative in-class activity and then completed as a homework assignment.

Light, Brightness, and Distance

Experiment Number: 29

Book: *Physics with Vernier*

Software: Graphical Analysis 4 app

Sensor: Go Direct Light and Color

This experiment is an excerpt from the *Physics with Vernier* lab book available from Vernier Software & Technology. For more information, visit **www.vernier.com/pwv**

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Light, Brightness, and Distance

You may have noticed that a light source appears to be brighter when you are close to it and dimmer when you are farther away. This is because the amount of the light that enters your eye increases as you move closer to the light source.

There are several ways to measure the brightness of light. In this experiment, you will use a light sensor to measure the *illuminance* detected by the sensor in *lux*. You will observe how illuminance varies with distance and compare the results to a mathematical model.

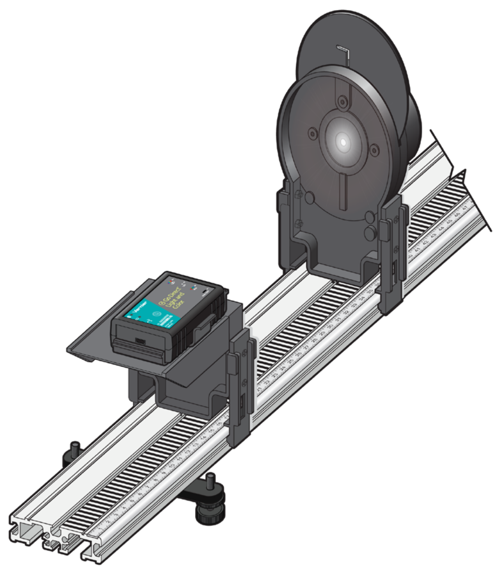


Figure 1

OBJECTIVE

Determine the mathematical relationship between illuminance and distance from a light source.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Light and Color
Vernier Dynamics Track
Optics Expansion Kit (OEK): Light Source Assembly, Screen, and Light Sensor Holder
pencil
flashlight

INITIAL SETUP

1. Launch Graphical Analysis. Connect Go Direct Light and Color to your Chromebook, computer, or mobile device.
2. Set up the data-collection mode.
   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   b. Enter **Distance** as the Event Name and **cm** as the Units. Click or tap Done.
3. Position the light source assembly so that the LED is exposed and is facing along the length of the Dynamics Track. Align the back edge of the foot of the light source assembly with the 10 cm mark on the track.
4. Turn on the light source. The brightness of the LED light source varies when it is first turned on. Make a note of the current time so that you can ensure 15 minutes have passed before you begin making the measurements during the Procedure.
5. Position the cradle that holds the light sensor on the base of the OEK Light Sensor Holder using the pins on the right side as you look towards the light source. The arrows on the cradle should point towards the light source. Place the light sensor in the cradle and snap it in place. This will align the light sensor with the light source in the center of the track.
6. Position the light sensor near the 100 cm mark, so it is out of the way. The position of the sensor can be read using the notch near the base of the holder. Later, you will move the sensor closer to the light source for data collection.
7. Turn down the lights to darken the room. A very dark room is critical to obtaining good results. There should be no reflective surfaces behind, beside, or below the bulb.

PROCEDURE

1. In this experiment, you will vary the distance between the light source and the light sensor and measure the illuminance. Predict the relationship between illuminance and the distance from a light source. Sketch a graph of how you think illuminance will vary with distance.
2. To explore the relationship between illuminance and distance, stand the screen along the track between the light source and the light sensor, far from the light source. Hold up a pencil between the screen and the light source so that a shadow is produced on the screen. Slowly change the position of the pencil and observe how the shadow changes. Where does the pencil produce the largest shadow? Where does it produce the smallest shadow?
3. If you were to think of the pencil as "catching" light, where does the pencil catch the most light? The least? Where would a measurement of the illuminance on the pencil be greatest? Do your observations change how you would sketch the graph of illuminance *vs.* distance?
4. Check that the light source has been on continuously for at least 15 minutes. Move the light sensor so the notched arrow is at the 20 cm mark.
5. Rotate the disk of the light source assembly until no light from the LED is visible. Click or tap the Illuminance meter and choose Zero to define the light level as zero. The illuminance reading should now be near zero.
6. Click or tap Collect to start data collection.

7. Click or tap Keep. Enter the distance between the light sensor and the light source and click or tap Keep Point.
8. Move the light sensor 1 cm farther away from the light source and repeat Step 7. Briefly turn on the flashlight if it is too dark to see the markings on the track.
9. Repeat Step 8, moving the sensor in 1 cm increments, until the light sensor is 20 cm from the light source.
10. Repeat Step 8, this time moving the sensor in 10 cm increments, until the light sensor is 60 cm from the light source.
11. Click or tap Stop to stop data collection. In your data table, record the illuminance for each distance.

DATA TABLE

Distance (cm)	Illuminance (lux)
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
30	
40	
50	
60	

ANALYSIS

1. Examine the graph of illuminance *vs*. distance.

2. Compare your data to your model. To model an inverse square, first calculate the inverse square of the distance data, and then compare it to the illuminance data.
   a. Click or tap View, , and choose Table.
   b. Click or tap More Options, , in the Distance column header in the table. Then, choose Add Calculated Column.
   c. Enter **1/d^2** as the Name.
   d. Click or tap Insert Expression and select the equation A/X^B. Choose **Distance** for the Column for X. For the A value, enter **1**. For the B value, enter **2**.
   e. Click or tap Apply.
   f. Click or tap View, , and choose Graph and Table. If necessary, change the x-axis to 1/d^2 and the y-axis to Illuminance.
   g. Click or tap Graph Tools, , and choose Apply Curve Fit. Select Proportional as the Fit Equation. Click or tap Apply.

3. How well does the model fit your experimental data? Do your data approximately follow an inverse square function?

EXTENSIONS

1. If you have a window facing the sun, it can be interesting to try an experiment to measure the illuminance from the sun. Place the light sensor 10 cm from a 150 W clear light bulb and measure the illuminance. Point the Light Sensor at the sun and measure the illuminance from the sun relative to the light bulb. How many light bulbs would you have to place 10 cm from the light sensor to be equal to the illuminance from the sun? Use the mathematical relationship found in this experiment to calculate the illuminance from the sun if it was placed 10 cm from the light sensor. Determine how many of these light bulbs would be equivalent to this value.

2. Use the light sensor to measure the illuminance from the sun over the period of a school day.

3. Use the light sensor to examine sunglasses. By what percentage is the sun's illuminance reduced when sunlight passes through the lens of sunglasses?

4. Use the light sensor to compare other light sources to the light source that you used in the lab. For instance, how does illuminance vary as you move away from a long fluorescent bulb or a circular fluorescent bulb?

5. Suppose a small light source is placed at the center of two transparent spheres, as shown in Figure 2. One sphere has a radius R, and the other a radius 2R. Energy in the form of light leaves the source at a rate P. That same power P passes through the surface of the inner sphere and reaches the outer sphere. Intensity is the power per unit area. What is the intensity at each sphere? Solve this problem by considering the following:
   - How does the power passing through the inner sphere compare to the power reaching the outer sphere?

- How do the surface areas of the two spheres compare?
- In general, then, how will the intensity vary with distance from the source?

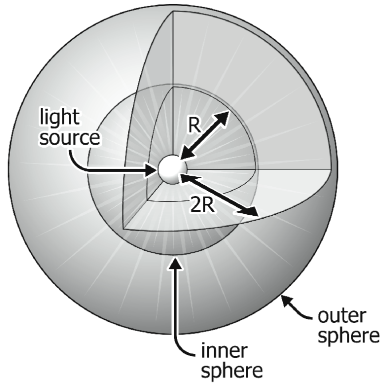


Figure 2

6. Compare the concentric spheres model described in Extension 5 to your experimental data.
   - Is your illumination *vs.* distance data consistent with the concentric spheres model? How can you tell?
   - Is the best-fit curve that you fit to your experimental data consistent with the concentric spheres model?
7. Since most light bulbs that you use are not true point sources of light, how do you think your answers to Extension 5 would change if an incandescent light bulb were used?

Light Brightness and Distance

See *Appendix A* for information about the word-processing files of the student experiments, as well as any other electronic resources available for this book.

RELATED SKILLS

- Changed what is graphed on the axes (LabQuest and calculator users)
- Create calculated columns

ESTIMATED TIME

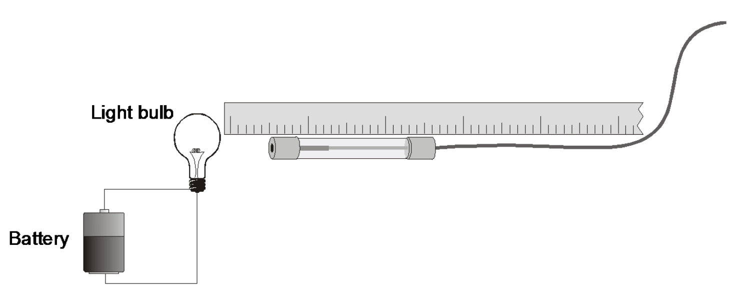
We estimate that data collection and analysis for this experiment can be completed in one 45-minute class period.

EQUIPMENT TIPS

1. The Materials list includes a Vernier Dynamics Track and the Optics Expansion Kit, which are available from Vernier Software & Technology (order codes: TRACK and OEK, respectively).

   If you do not have the Vernier Software & Technology products mentioned above, you can use a ruler and a light bulb powered by a battery. The following tips relate to use of alternate equipment.

   - Avoid reflective surfaces under, beside, or behind the light source; for example, do not perform the experiment next to a wall. If you can mount the light bulb and sensor above the work surface, this will cut down on a major source of reflection.
   - Place a cylindrical shield over the end of the Light Sensor to reduce errors caused by reflected light striking the sensor. Mark the location of the sensing unit carefully, so distances will be more accurate.
   - Use a light bulb with a straight filament. Verify that the filament is pointing toward the Light Sensor and the Light Sensor is at the same height as the filament. These steps make the filament act like a point source. Only point sources obey the inverse-square law.



2. In 2016, Vernier Software & Technology stopped producing the Vernier Dynamics System (order code: VDS) with black aluminum tracks and green metal dynamics carts and started producing the Dynamics Cart and Track System (order code: DTS) with gray aluminum tracks and molded plastic dynamics carts. The tracks are interchangeable for use in this experiment.

3. This experiment can be performed with a Vernier Light Sensor or the TI Light Sensor. The TI and Vernier sensors do not measure the same quantity, but for the purposes of this experiment, the units are not important.

4. The light source assembly from the Optics Expansion Kit needs to warm up for 15 minutes prior to data collection so that the LED has time to come to thermal equilibrium. Students can complete the Initial Setup and Steps 1–3 of the Procedure (investigating illumination and distance using a pencil) during this time in order to ensure that the experiment can be completed within your class period.

5. Students are instructed to line up the back edge of the foot of the light source assembly with the 10 cm mark on the track (and not the notched arrow at the base of the light source assembly). In this position, the light source is at 10 cm.

6. The units of light intensity are complex. The Vernier Light Sensor reports measurement in lux, measuring illuminance, or the power falling on a surface, weighted by the sensitivity of the human eye. These details are not central to student understanding of this activity—the key is that they relate the rate of something (in this case, photons) falling on a surface.

DATA COLLECTION AND ANALYSIS TIPS

1. Make the room as dark as possible. Or, you can take a background reading and subtract this from the original reading by using a new column called Adjusted Illuminance. If you use this method, do not zero the Light Sensor.

2. This experiment has students develop the inverse-square model. For this reason, it makes best sense to test this model by fitting an inverse-square function to the data, rather than a general power law function.

   Students can deepen their understanding in the Extensions by deducing the inverse-square model mathematically. In this activity, students examine the intensity of a light source passing through the surface area of spheres of different radii.

ANSWERS TO PROCEDURE QUESTIONS

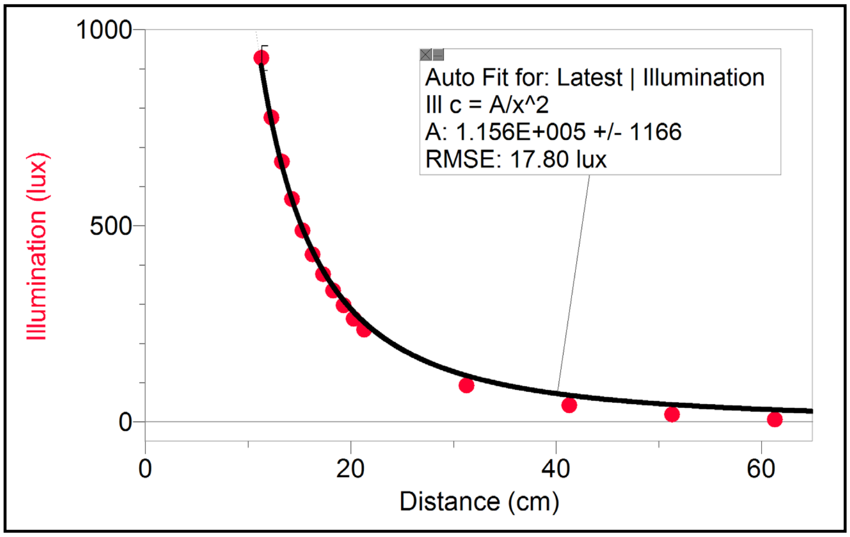
1. Student answers may vary. Student graphs will likely show that illumination decreases with distance. However, they may not predict that the relationship is a curve, with the illumination decreasing more rapidly at first. The relationship is an inverse square.

2. The shadow grows larger as the pencil is brought closer to the light source.

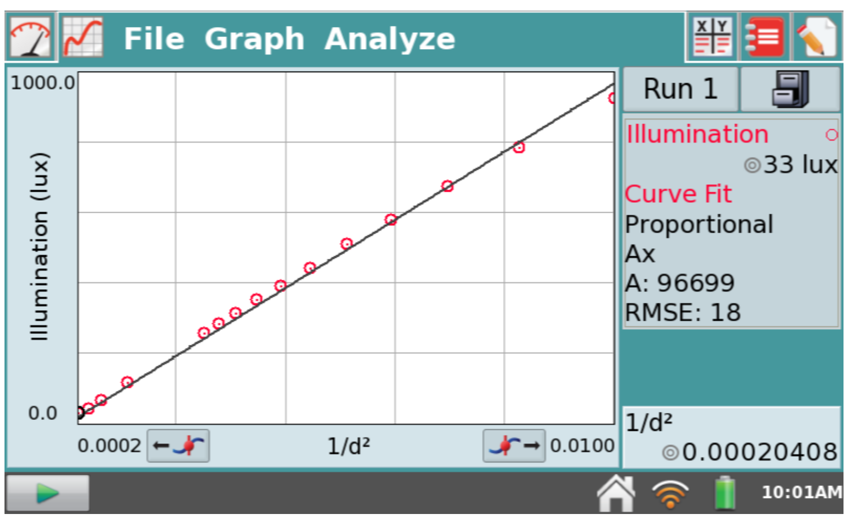
3. The pencil must catch more light when it is closer to the light source. This can be seen from the level of illumination on the pencil.

Answers regarding the sketch will vary depending on the student's original sketch. It is possible that students will recognize that the size of the shadow changes more drastically when the pencil is near the light source, though it is not necessary for all students to make that observation.

SAMPLE RESULTS



Comparison to inverse-square fit in Logger Pro



Linearized analysis in LabQuest App

ANSWERS TO ANALYSIS QUESTIONS

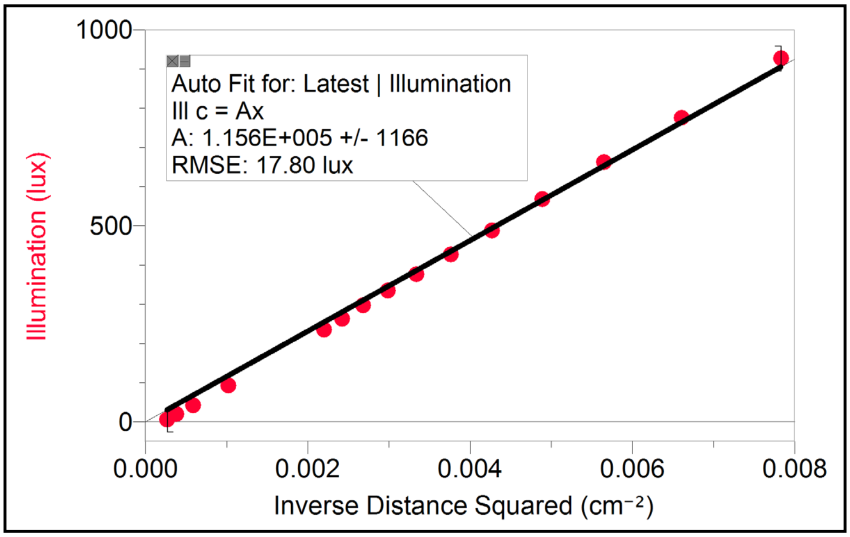
2. The data are close to 1/Distance^2. An inverse function does not fit well, while an inverse-square function does fit well.

3. The inverse-square model fits the data well. Based on the data shown in the Sample Results, the equation is

$$I = 11{,}000\ /d^2$$

ANSWERS TO EXTENSION QUESTIONS

1. (Computer and EasyData only) The graph of adjusted illuminance *vs.* distance $^{-2}$, in which the straight line passed through the origin, confirms the inverse square relationship.



6. (5. LabQuest) The inverse square relationship investigated in this experiment can be deduced from a concentric spheres model. All of the light leaving the source passes through each sphere since there is no absorption. The area of a sphere is $4\pi R^2$. If the light is emitted equally in all directions, then the intensity I passing through the surface of radius R is $I/4\pi R^2$. For the larger sphere of radius $2R$, the number per unit area is $I/4\pi(2R)^2$, or one-fourth as much. The light intensity was reduced by a factor of four by doubling the distance from the source. In other words, there is an inverse-square relationship between light intensity and distance from a point source. This is true only for a light source that emits light equally in all directions; that is, a point source.

7. The concentric spheres model predicts an inverse-square relationship. The data also follow an inverse-square rule, confirming the spheres model.

8. (7. LabQuest) The reasoning used in the spheres model of Extension 6 (Extension 5 in LabQuest) assumed that light is emitted equally in all directions. If light is not emitted uniformly, then the illumination may not vary exactly as the inverse square of the distance from the source.

Introduction to Solar Panels and Solar Energy

Experiment Number: 2

Book: *Solar Energy Explorations*

Software: Graphical Analysis 4 app

Sensor: Go Direct Energy

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Introduction to Solar Panels and Solar Energy

Solar energy is used in many different ways, such as providing heat and light in buildings, powering school zone speed signs, heating swimming pools, and charging electronic devices.

When we burn oil, natural gas, and coal to drive a car or heat a classroom, we are also using energy that came from the sun. Oil, natural gas, and coal were formed long ago from plants and animals. Plants use solar energy to grow and then store the energy in their roots and leaves. When animals eat the plants, they are consuming energy that came from the sun. When you ride in a car that runs on gas, you are using energy from the sun to travel.

Because it takes millions of years to form oil, natural gas, and coal, people are developing ways to use solar cells to quickly convert solar energy into electricity.

Solar cells are made of two thin pieces of silicon (an element that forms glass-like crystals) that are connected together. When radiant energy from the sun strikes the solar cell, energy is transferred to electrons in the silicon. When the solar cell is connected to a closed circuit, the electrons start to flow through the circuit.

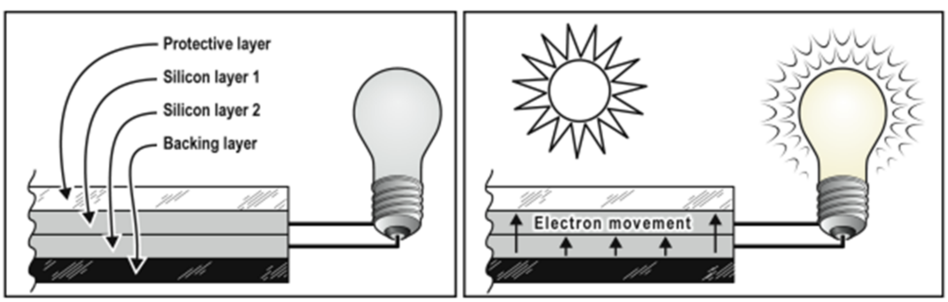

Figure 1

A single solar cell can only convert a small amount of energy, so engineers connect many solar cells together to build a device called a solar panel as shown in Figure 2.

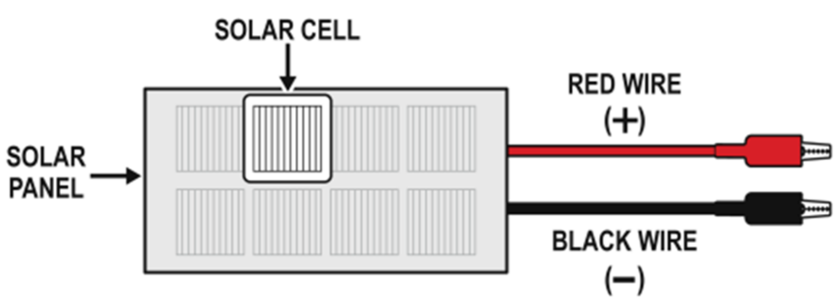

Figure 2

OBJECTIVES

- Use electricity generated by a solar panel to make sound.
- Build and understand a basic circuit.
- Verify that energy is transferred by electric currents in a closed circuit.

MATERIALS

KidWind 2V/400mA Solar Panel
KidWind Sound and Light Board
sunlight **or** lamp with 100 W equivalent bulb

PROCEDURE

? Answer the Pre-Lab Questions.

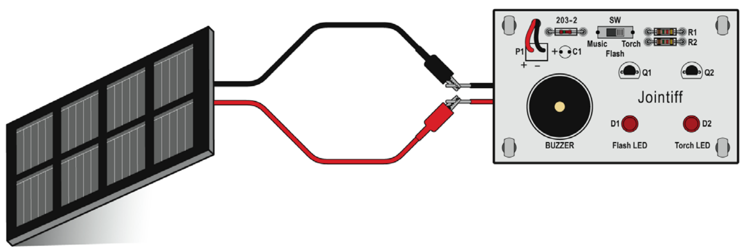

Figure 3

1. Connect the Sound and Light Board and the solar panel to build a closed circuit.
   a. Connect the **red** wire on the Sound and Light Board to the **red** wire of the solar panel (see Figure 3). Make sure the alligator clip attaches to the bare metal end of the Sound and Light Board wire.
   b. Connect the **black** wire on the Sound and Light Board to the **black** wire of the solar panel. Make sure the alligator clip attaches to the bare metal end of the Sound and Light Board wire.

2. Use light to power the circuit.
   a. Place the solar panel under the light source chosen by your teacher. **Caution**: Never look directly at the light source or sun. If using a desk lamp, be careful to not touch the light bulb once it has been turned on.
   b. Turn on the lamp or go outside to an area with direct sunlight.
   c. Move the switch marked SW on the Sound and Light Board to the Music setting.
   d. Do you hear a sound? If so, you have correctly connected the parts.
   e. If there is no sound, move the solar panel closer to the light source or make sure the panel is facing the sun. If the Sound and Light Board still does not make sound, ask your teacher for help.

? Answer Procedure Questions 1–3.

3. Create a plan to make the sound slower or faster.

> **?** Answer Procedure Questions 4–5.

4. Disconnect something in the circuit to create an open circuit.

> **?** Answer Procedure Questions 6–8.

Name ______________________

Date ______________________

Introduction to Solar Panels and Solar Energy

PRE-LAB QUESTION

What are some ways you could use solar energy in your life?

PROCEDURE QUESTIONS

1. When creating a circuit, why do you have to make sure that the alligator clip attaches to the bare metal end of a wire and not the plastic coated part?

2. Draw a picture of the closed circuit you built, including all components. Draw arrows showing the direction in which the electrons flow through the circuit.

3. What evidence do you have that electric current flowed through the closed circuit?

4. Describe your plan to make the sound slower or faster.

5. What happened to the sound when you carried out your plan?

6. Describe what happened when you disconnected something in the circuit. Why did this happen?

7. Was energy transferred through the open circuit? How do you know?

8. Summarize what you have learned about solar energy transfer. Where does it come from? What type of energies did solar energy transform into during your experiments with the Solar panel and the buzzer?

Introduction to Solar Panels and Solar Energy

A solar cell converts light energy from the sun into electrical energy. Solar cells are made out of two thin pieces of silicon that are adjacent to each other. The silicon is *doped*, or mixed with a small amount of a different element during production in order to change its properties. One piece, known as n-type silicon, is often doped with phosphorus or arsenic, which gives it an excess of electrons. The other layer, the p-type silicon, is usually doped with boron, which creates a deficiency of electrons—"holes" into which the available electrons can move.

When radiant energy from the sun strikes the n-type silicon, the energy is transferred to the free electrons. When a solar panel is connected in a closed circuit, the energized electrons move to the p-type silicon through the circuit, doing work such as turning on a light along the way.

A helpful video that was developed with younger audiences in mind and that explains how solar panels work can be found at **https://youtu.be/f01UyQj0feM** (or search YouTube for the student project called "How Does a Solar Cell Work").

In this experiment, students are introduced to solar panels. They get acquainted with the materials and then learn how to set up a basic circuit with a KidWind 2V/400mA Solar Panel and a Sound and Light Board.

Students explore the concept of energy transfer by connecting the Sound and Light Board to the solar panel (to build a closed circuit). They are then instructed to disconnect something in the circuit to test if energy is transferred through an open circuit.

ESTIMATED TIME

We estimate that set up, exploration, and clean up can be completed in one 45–60 minute class period.

RELATED SKILLS

Equipment and Data-Collection Skills

- Connect the Sound and Light Board to the solar panel

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and using models Planning and carrying out investigations Obtaining, evaluating, and communicating information Constructing explanations and designing solutions	PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer	Cause and effect Scale, proportion, and quantity Systems and system models Energy and matter

SAFETY NOTES

1. If performing this experiment outdoors, you and the students will potentially be in direct sunlight for most of the class period. Encourage students to drink plenty of water and wear light-colored, loose fitting clothing and/or sunblock, as appropriate. Monitor students for side effects of prolonged exposure to sunlight and heat.

2. Warn students against looking directly at the sun or light bulb during the experiment. If using lamps, remind students that they should not touch the hot light bulb.

EQUIPMENT TIPS

1. If performing this experiment indoors, several types of light bulbs are readily available, including compact fluorescent lamps (CFL), light emitting diodes (LED), and halogen incandescent bulbs (which are more energy-efficient versions of the traditional incandescent bulbs). We recommend halogen or traditional incandescent bulbs due to their accessibility, affordability, and effectiveness.

2. If using lamps, keep an eye on the solar panel to ensure that it does not get damaged from heat.

TEACHING TIPS

1. Demonstrate or review how to connect the solar panel and the Sound and Light Board, especially if this is the first time that students use the equipment.

2. Emphasize correct polarity from the Sound and Light Board to the solar panels. When making connections, connect positive (red) to positive (red) and negative (black) to negative (black).

3. This experiment can be conducted indoors or outdoors, depending on the weather.

4. If performing this experiment outdoors, have students record the current weather conditions. This could include temperature, cloud cover, and any other observations. You may want to teach students how to estimate percent cloud cover.

5. NEED, an organization that develops materials for teaching about energy, offers excellent resources for background information about solar energy. The teacher and student versions of their e-publication, *Energy from the Sun*, are written specifically for teaching intermediate-aged students. Download *Energy from the Sun* for free at **need.org/solar**

SAMPLE DATA

Student results will vary depending on light source.

ANSWER TO PRE-LAB QUESTION

Answers will vary.

ANSWERS TO PROCEDURE QUESTIONS

1. Electricity is passed through the metal and not through the plastic.
2. Arrows should show that the electrons travel in a loop. The arrows should go from the solar panel, to the Sound and Light Board, and back to the solar panel. It is not necessary for the direction to be correct.
3. Energy was transferred through the closed circuit because the solar energy from the solar panel changed to electrical energy then into sound energy on the Sound and Light Board.
4. Possible responses: Move the solar panel away from the light. Move the solar panel closer to the light. Cover the solar panel. Cover part of the solar panel.
5. Possible responses: Moving the solar panel away from the light made the sound get quieter and slower. Moving the solar panel close to the light made the music faster and louder. Covering the solar panel made the sound turn off. Covering part of the solar panel made the sound quiet and slow.
6. Energy is not transferred through an open circuit because the path for electricity (electrons) is broken, thus making the conversion of solar energy to electrical energy impossible.
7. Possible response: When the circuit was broken, no sound was produced, so no (solar or electrical) energy was transformed into sound energy.
8. Answers will vary. Possible responses: Energy comes from the sun in the form of light energy. The light energy becomes electrical energy as the electrons start moving. This electrical energy is converted to sound energy by the Sound and Light Board.

Solar Panel Output: Effect of Angle

Experiment Number: 7

Book: *Solar Energy Explorations*

Software: Graphical Analysis 4 app

Sensor: Go Direct Energy

This experiment is an excerpt from the *Solar Energy Explorations* lab book available from Vernier Software & Technology. For more information, visit **www.vernier.com/msb-solar**

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Solar Panel Output: Effect of Angle

Have you ever seen solar panels on a house or a building? Do you remember how they were positioned? Were they lying horizontally? Standing vertically? Set at an angle? Why do you think they are installed in such a way?

In this experiment, you will use your previous experience with solar panels and data-collection equipment to develop a plan to explore the variable of angle and its affect on power output.

OBJECTIVES

- Measure power output of three solar panels with Go Direct Energy.
- Explore how power output is affected by changes in the angle of the solar panels.
- Investigate the relationship between angle and maximum power output.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Energy
Vernier Resistor Board
3 KidWind 2V/400mA Solar Panels
box from the Solar Energy Exploration Kit
2 wires with clips
5 pieces of chipboard
ruler
scissors
Parallel Circuit Connection Tool (if needed)
sunlight

PROCEDURE

? Answer the Pre-Lab Questions.

1. Using a ruler, the chipboard pieces, and scissors, cut the chipboard into the following lengths, 12.5, 14.5, 17.5, 20.5, 23, and 26 cm.
2. Launch Graphical Analysis. Connect the Energy Sensor to your Chromebook, computer, or mobile device.
3. Set the switch on the Energy Sensor to External Load and use wires to connect the External Load terminals to the resistor you plan to use on the Resistor Board. Record the resistor value in Table 1.
4. Attach the number of solar panels you plan to use to the lid of the Solar Energy Exploration Kit. Record the number used in Table 1.
5. Connect the solar panels in series or parallel to the Source wires on the Energy Sensor. Record type of circuit used in Table 1.
6. Before collecting data, check that everything is set up correctly.
7. Measure the first angle you are collecting data for, the lid is closed with no chipboard holding the lid open, and record the angle in the correct row in Table 2.
8. Click or tap Collect to start data collection. Data collection will stop after 30 seconds.
9. Determine the mean power value and record the value in Table 2.
10. Prop the lid at an angle of using the 12.5 cm long chipboard. Measure the angle and record the angle in the correct row in Table 2. **Important**: When propping the lid at an angle, the underside of the lid must be resting on the piece of chipboard in the correct position (Figures 1 and 2). Ask your teacher for help if you are not sure what to do.

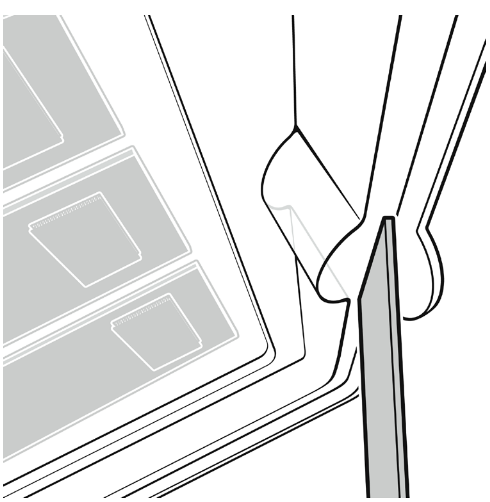

Figure 1

Figure 2

11. Before collecting data for the next angle, make a prediction about the effect of changing the angle on the power output. Record your prediction in Table 3.

12. Collect data for the current angle and record the mean power value in the correct row in Table 2.

13. Repeat Steps 10–12 for the next size of chipboard.

14. Continue collecting data for each size of chipboard.

Name ___________________________

Date ___________________________

Data Sheet for Experiment **7**

Solar Panel Output: Effect of Angle

PRE-LAB QUESTIONS

1. What variable will you change in this experiment?

2. List at least three variables that you will keep the same during the experiment.

3. How many solar panels will you use? **Note**: You can use a maximum of three panels.

4. If you use more than one solar panel, will you connect the panels in series or in parallel?

5. Which resistor will you use?

6. Draw a diagram of the circuit, including all components and connections, that you will build for this experiment.

DATA

Table 1 Experimental Setup	
Number of solar panels	
Type of circuit	
Resistor (Ω)	

Table 2 Data		
Chipboard (cm)	Angle (°)	Mean power (mW)
none		
12.5		
14.5		
17.5		
20.5		
23		
26		

Table 3 Prediction	
Angle (°)	Mean power prediction
0 to 25	*decrease*
______ to ______	
______ to ______	
______ to ______	
______ to ______	
______ to ______	
______ to ______	

DATA ANALYSIS

1. Use the data in Table 2 to create a bar graph of power *vs*. angle.
2. What is the optimum angle for your solar panels? How do you know?
3. Describe in detail what happened to the power as the angle increased.
4. Imagine that your neighbors are going to put solar panels on their house. What advice would you give them about deciding on an angle for their solar panels?

Solar Panel Output: Effect of Angle

The angle of a solar panel relative to horizontal affects the power output of the panel. In this experiment, students find the optimum angle for their solar panels. This experiment can be interesting to perform at different times of day and of the year in order to explore changes in optimum angle.

We designed this experiment to allow students to build on their experience from Experiments 3–6. There is less detail in the Procedure so that students can think critically about how to build circuits and set up the equipment rather than simply following step-by-step directions. If you do not have time to conduct Experiments 4–6, we recommend that students perform Experiment 3, "Measuring Energy," at the very least, so they can develop some familiarity with the equipment.

ESTIMATED TIME

We estimate that this experiment can be completed in one to two 45–60 minute class periods with set up, exploration, and clean up occurring in each class session.

RELATED SKILLS

Equipment and Data-Collection Skills

- Connect Go Direct Energy, the Resistor Board, and solar panels
- Use Graphical Analysis 4 to collect data
- Use the Statistics tool to determine mean power

Math Skills

- Read, write, and compare decimals and whole numbers
- Understand mean (average) data
- Collect and record data in a table
- Construct and plot data on a bar graph

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking	PS3.B: Conservation of Energy and Energy Transfer	Cause and effect Scale, proportion, and quantity Systems and system models Energy and matter

SAFETY NOTES

1. If performing this experiment outdoors, you and the students will potentially be in direct sunlight for most of the class period. Encourage students to drink plenty of water and wear light-colored, loose fitting clothing and/or sunblock, as appropriate. Monitor students for side effects of prolonged exposure to sunlight and heat.

2. Warn students against looking directly at the sun or light bulb during the experiment. If using lamps, remind students that they should not touch the hot light bulb.

EQUIPMENT TIPS

1. We recommend performing this experiment outside with sunlight as the light source. If this is not possible, lamps can be used in the classroom. Data will not be as dramatic when using a lamp instead of sunlight. Using multiple lamps may alleviate this problem.

2. The student experiment has students cut their own chipboard to specific lengths and then measure the angle each length produces with the KidWind Solar Energy Experiment Kit box. To save time the pieces of chipboard can be cut and labeled ahead of time. Each group needs pieces cut and labeled as follows:
   - 12.5 cm/10º
   - 14.5 cm/20º
   - 17.5 cm/30º
   - 20.5 cm/40º
   - 23 cm/50º
   - 26 cm/60º

   For example, cut a piece of chipboard to a length of 12.5 cm and write 12.5 cm/10º on one side of the piece of chipboard.

3. The Materials list in the student experiment includes a 17.5 cm piece of chipboard. Students will use this piece in several other experiments. For this reason, encourage students to keep the chipboard from getting bent. At the end of the experiment, collect the pieces of chipboard and save them for later experiments.

4. The student experiment was written with the assumption that the hook-and-pile pieces that connect the solar panels to the lid of the Solar Energy Exploration Kit box have already been attached to the solar panels and box. We recommend attaching the pile pieces (soft to the touch) to the solar panels so that the panels do not stick to each other. This will also ensure that the solar panels are interchangeable from group to group.

5. We recommend separating the red and black wires on the solar panels (simply pull the wires apart carefully). Separating the wires does not affect the performance of the panels, but makes it easier for students to build their circuits.

6. Students are instructed to set the switch on Go Direct Energy to External Load and use wires to connect to the Resistor Board to the sensor. **Note**: The color of the wires does not matter; any color will work. However, students may find it easier if they have one black wire and one red wire.

7. If performing this experiment indoors, several types of light bulbs are readily available, including compact fluorescent lamps (CFL), light emitting diodes (LED), and halogen incandescent bulbs (which are more energy-efficient versions of the traditional incandescent bulbs). We recommend halogen or traditional incandescent bulbs due to their accessibility, affordability, and effectiveness. If you are using a lamp, keep an eye on the solar panel to ensure that it does not get damaged from heat.

8. If you are using light bulbs instead of sunlight, you will need to make adjustments in the amount of load resistance. For CFL light bulbs and series circuits, connect the 100 Ω resistor on the Resistor Board to the Go Direct Energy External Load terminals. For CFL bulbs and parallel circuits, use the 50 Ω resistor. If you are using LED light bulbs, for series circuits you should use the 50 Ω resistor and for parallel circuits you should use the 30 Ω resistor.

TEACHING TIPS

1. Check in with each group before they start data collection to ensure that they are connected to the correct resistor and that the circuit is wired correctly.

2. If performing this experiment outdoors, have students record the current weather conditions. This could include temperature, cloud cover, and any other observations. You may want to teach students how to estimate percent cloud cover.

3. If all groups' panels are pointing in the same direction during this experiment, students are better able to compare their results.

4. A familiarity with basic angles between 0° and 90° will help students better understand the experiment and draw conclusions about their data.

5. Note that this experiment was designed as a way for students to use the knowledge they had gained in the previous experiments about series and parallel circuits. If students have not done Experiment 5, "Solar Panel Output: Effect of Load," you may decide to edit the instructions to indicate which resistor to use. We recommend 20 Ω for three solar panels in series and 10 Ω (or 5 Ω, if you have a 5 Ω resistor) for three solar panels in parallel.

CHALLENGE IDEAS

1. Perform the same experiment at different times of day and different parts of the year. Compare the data sets.

2. For students who are ready for an engineering-based project, you may consider building a solar tracker. Vernier includes student procedure and teacher information for building a solar tracker in our *Vernier Engineering Projects with LEGO® MINDSTORMS® Education NXT* and *Vernier Engineering Projects with LEGO® MINDSTORMS® Education EV3* lab books. Many other do-it-yourself projects are available on the Internet.

ANSWERS TO PRE-LAB QUESTIONS

1. The angle of solar panels is the variable being changed in this experiment.

2. Answers could include, light source, temperature, load, and circuit type (series or parallel).

3. Answers will vary.
4. Answers will vary.
5. Answers will vary.
6. Drawings will vary.

SAMPLE DATA

Student results will vary depending on light source.

Chipboard (cm)	Angle (°)	Mean power (mW)
none	0	576.0
12.5	10	706.6
14.5	20	799.4
17.5	30	858.3
20.5	40	868.5
23	50	834.6
26	60	732.7

ANSWERS TO DATA ANALYSIS

1. Students should create a bar graph using the data in their data table.
2. Responses will vary based on data. The optimum angle for the sample data was 40°.
3. Responses will vary based on data. It is likely that students will find that as angle increases, power output also increases. However, at angles above a certain value, the power output decreass as angle increases.
4. Responses will vary based on student understanding.

Solar Panel Output: Effect of Shade

Experiment Number: 6

Book: *Solar Energy Explorations*

Software: Graphical Analysis 4 app

Sensor: Go Direct Energy

This experiment is an excerpt from the *Solar Energy Explorations* lab book available from Vernier Software & Technology.
For more information, visit **www.vernier.com/msb-solar**

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Solar Panel Output: Effect of Shade

Some days it is very sunny all day—there are no clouds in the sky, and it is very bright. In these conditions, lots of sunlight reaches the solar panels.

Other days it is cloudy. The sky might be completely covered in clouds or clouds may pass in front of the sun on and off during the day. Less sunlight reaches the solar panels on cloudy days.

Other things that could shade solar panels would be large trees next to houses or buildings. Do you think shade caused by trees or clouds will affect the power output of solar panels? In this experiment, you will use the Energy Sensor to help you answer this question.

OBJECTIVES

- Measure the power output of three solar panels with Go Direct Energy.
- Use data-collection software to calculate mean (average) values.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Energy
Vernier Resistor Board
3 KidWind 2V/400mA Solar Panels
2 wires with clips
box from the Solar Energy Exploration Kit
17.5 cm piece of chipboard
piece of cardboard large enough to cover all three panels (approximately 15 × 30 cm)
Parallel Circuit Connection Tool
sunlight

PROCEDURE

? Answer the Pre-Lab Questions.

1. Launch Graphical Analysis. Connect the Energy Sensor to your Chromebook, computer, or mobile device.

2. Set the switch on the Energy Sensor to External Load and use wires to connect the External Load terminals of the Energy Sensor to the 20 Ω resistor on the Resistor Board (see Figure 1).

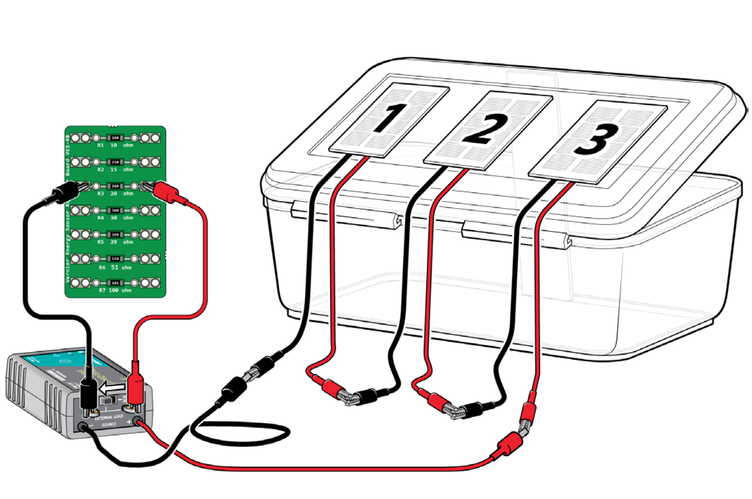

Figure 1

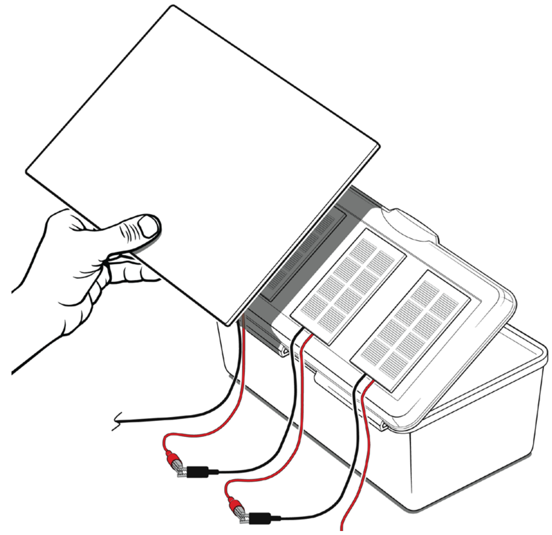

Figure 2

Part 1 Solar panels connected in series

3. Set up the solar panels and the box of the Solar Energy Exploration Kit.
   a. Attach the three solar panels to the lid using the hook-and-pile pieces.
   b. Use the piece of chipboard to prop the lid of the box at an angle.

4. Connect the solar panels in series and use wires to connect the solar panels to the Source wires on the Energy Sensor (see Figure 1).

5. Position the box so the panels are pointed toward the sun and check that everything is set up correctly. **Caution**: Never look directly at the sun.

6. Click or tap Collect to start data collection. Data collection will stop after 30 seconds.

7. Determine the mean power value.
   a. Click or tap View, ⊞, and choose 1 Graph. A single graph is shown.
   b. Click or tap the y-axis label. Select Power and deselect the other options to see a graph of power *vs*. time.
   c. Click or tap Graph Tools, ⟋, and choose View Statistics.
   d. Record the mean power value in the data table.

8. Repeat Steps 6–7 two more times. Each time, cover an additional panel with the piece of cardboard (see Figure 2). You need to hold the cardboard in the same place for 30 seconds while the data are collected.

? Answer the Part 1 Data Analysis questions.

Part 2 Solar panels connected in parallel

9. Set up the equipment for Part 2.
   a. If the equipment is still set up for Part 1, disconnect the solar panels and the Energy Sensor.
   b. If the Energy Sensor is not connected to Graphical Analysis, launch Graphical Analysis. Connect the Energy Sensor to your Chromebook, computer, or mobile device.

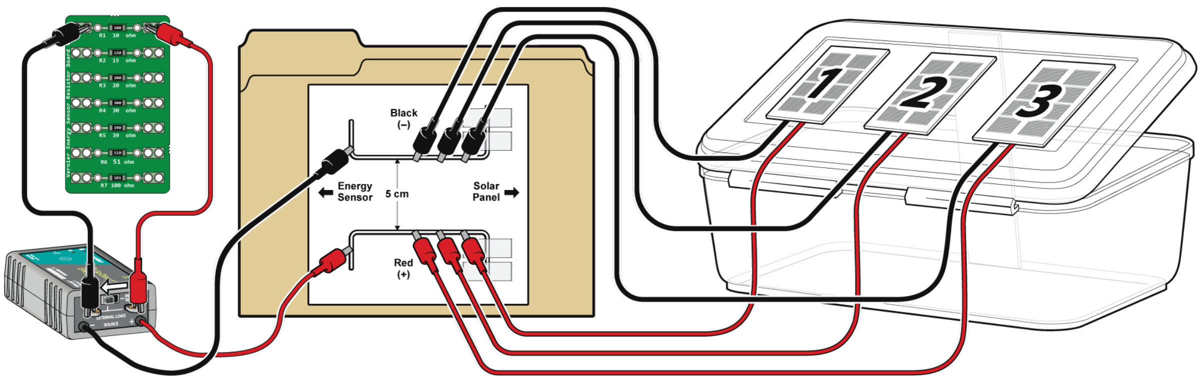

Figure 3

10. Set the switch on the Energy Sensor to External Load and connect the 10 Ω resistor on the Resistor Board to the Load terminals (see Figure 3).
11. Connect the Energy Sensor to the paper clips on the Parallel Circuit Connection Tool.
12. Connect the three solar panels in parallel to the paper clips.
13. Repeat Steps 6–8 to collect and record data.

? Answer the Part 2 Data Analysis questions.

EXTENSIONS

1. Following a similar procedure, investigate the effect of shading solar cells on power output rather than shading entire solar panels.
2. Determine if dust on solar panels affects power output. Can you use this information to determine if it is important to clean solar panels on a home?
3. Determine if the amount of cloud cover during the day affects power output of solar panels.

Name ___________________________

Date ___________________________

Data Sheet for Experiment **6**

Solar Panel Output: Effect of Shade

PRE-LAB QUESTIONS

1. How many solar cells are on the solar panel?

2. If two of the solar cells are covered on the solar panel, what fraction of the solar panel would be shaded?

3. If three of the solar cells are covered on the solar panel, what fraction of the solar panel would be shaded?

4. When you cover one of the solar panels, what fraction of the solar panels is shaded? What percent is shaded?

5. When you cover two of the solar panels, what fraction of the solar panels is shaded? What percent is shaded?

6. When you cover all three solar panels, what fraction of the solar panels is shaded? What percent is shaded?

7. What variable will you change in this experiment?

8. List at least three variables that you will keep the same during the experiment.

DATA

Record your data for Part 1 and Part 2 in Table 1.

Table 1		
Fraction of solar panels that is shaded	Series circuit Mean power (mW)	Parallel circuit Mean power (mW)

DATA ANALYSIS

Part 1 Solar panels connected in series

1. What happened to the power when you shaded one panel when the panels were connected in series?

2. What happened to the power when you shaded two panels when the panels were connected in series?

3. What happened to the power when you shaded all three panels when the panels were connected in series?

Part 2 Solar panels connected in parallel

4. What happened to the power when you shaded one panel when the panels were connected in parallel?

5. What happened to the power when you shaded two panels when the panels were connected in parallel?

6. What happened to the power when you shaded all three panels when the panels were connected in parallel?

7. Examine the data in Table 1. Did you get more power when the panels were connected in series or when they were connected in parallel?

8. Summarize what you learned about the effect of shade on solar panels and how the type of circuit they are connected in also affects power output.

9. Imagine that a local business wants to set up solar panels on the roof of its building. Use what you have learned about the effect of shade to give the owners of the business advice about how they should connect the panels. Would your recommendation change if there is a big tree near the building?

Solar Panel Output: Effect of Shade

In Part 1 of this experiment, students connect three solar panels in series and then cover panels to learn about the effect of shade. In Part 2, students repeat the experiment with the solar panels connected in parallel. We encourage you to take the time to perform Part 2, especially if you did Part 2 in the "Making Connections" experiment. Students will learn that shade has a much greater affect when panels are connected in series than when panels are connected in parallel.

This experiment was designed to allow students to build on their experience from previous activities. We included less detail in the Procedure about how to set up the equipment so that students would have a chance to think critically about building circuits and setting up the equipment instead of simply following step-by-step directions. If you do not have time to conduct Experiments 4 and 5, we recommend performing Experiment 3, "Measuring Energy" at the very least.

If your students need more detail than is included in the Procedure, you can edit the word-processing files or make the Experiment 3 Procedure available as a reminder.

ESTIMATED TIME

We estimate that this experiment can be completed in one or two 45–60 minute class periods with set up, exploration, and clean up occurring in each class session.

RELATED SKILLS

Equipment and Data-Collection Skills

- Connect Go Direct Energy, the Resistor Board, and solar panels
- Use Graphical Analysis 4 to collect data
- Use the Statistics tool to determine mean power

Math Skills

- Read, write, and compare decimals, fractions, and whole numbers
- Understand mean (average) data
- Collect and record data in a table

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and using models Analyzing and interpreting data Using mathematics and computational thinking	PS3.B: Conservation of Energy and Energy Transfer	Cause and effect Scale, proportion, and quantity Systems and system models Energy and matter

SAFETY NOTES

1. If performing this experiment outdoors, you and the students will potentially be in direct sunlight for most of the class period. Encourage students to drink plenty of water and wear light-colored, loose fitting clothing and/or sunblock, as appropriate. Monitor students for side effects of prolonged exposure to sunlight and heat.

2. Warn students against looking directly at the sun or light bulb during the experiment. If using lamps, remind students that they should not touch the hot light bulb.

EQUIPMENT TIPS

1. We recommend performing this experiment outside with sunlight as the light source. If this is not possible, lamps can be used in the classroom. Data will not be as dramatic when using a lamp instead of sunlight. Using multiple lamps may alleviate this problem.

2. Each group needs a piece of cardboard that is large enough to cover all three panels when they are attached to the box of the Solar Energy Exploration Kit. We found that opaque clipboards also work well. Something thinner, such as manila folder, will work but is not quite as effective as cardboard at blocking light.

3. The Materials list in the student experiment includes a 17.5 cm piece of chipboard. Students will use this piece in several other experiments. For this reason, encourage students to keep the chipboard from getting bent. At the end of the experiment, collect the pieces of chipboard and save them for later experiments.

4. The student experiment was written with the assumption that the hook-and-pile pieces that connect the solar panels to the lid of the Solar Energy Exploration Kit box have already been attached to the solar panels and box. We recommend attaching the pile pieces (soft to the touch) to the solar panels so that the panels do not stick to each other. This will also ensure that the solar panels are interchangeable from group to group.

5. We recommend separating the red and black wires on the solar panels (simply pull the wires apart carefully). Separating the wires does not affect the performance of the panels, but makes it easier for students to build their circuits.

6. Students are instructed to set the switch on Go Direct Energy to External Load and use wires to connect to the Resistor Board (20 Ω resistor for Part 1 and 10 Ω resistor for Part 2). **Note**: The color of the wires does not matter; any color will work. However, students may find it easier if they have one black wire and one red wire.

7. If performing this experiment indoors, several types of light bulbs are readily available, including compact fluorescent lamps (CFL), light emitting diodes (LED), and halogen incandescent bulbs (which are more energy-efficient versions of the traditional incandescent bulbs). We recommend halogen or traditional incandescent bulbs due to their accessibility, affordability, and effectiveness. If you are using a lamp, keep an eye on the solar panel to ensure that it does not get damaged from heat.

8. If you are using light bulbs instead of sunlight, you will need to make adjustments in the amount of load resistance. For CFL light bulbs and series circuits, connect the 100 Ω resistor on the Resistor Board to the Go Direct Energy External Load terminals. For CFL bulbs and parallel circuits, use the 50 Ω resistor. If you are using LED light bulbs, for series circuits you should use the 50 Ω resistor and for parallel circuits you should use the 30 Ω resistor.

TEACHING TIPS

1. Check in with each group before they start data collection to ensure that they are connected to the correct resistor and that the circuit is wired correctly.

2. If performing this experiment outdoors, have students record the current weather conditions. This could include temperature, cloud cover, and any other observations. You may want to teach students how to estimate percent cloud cover.

3. If all groups' panels are pointing in the same direction and are at the same angle, students are better able to compare their results.

4. Note that this experiment was designed to teach students about both series and parallel circuits. If you prefer to study only series circuits (Part 1), students can use the Internal 30 Ω Load setting on Go Direct Energy; the Resistor Board is not necessary. Since the 30 Ω resistor is not the optimal resistance for three solar panels in series, power values will be lower than those in the sample results.

5. If students get similar data to those that we collected, they may wonder why the power for one panel is not the same for Parts 1 and 2. To encourage students to solve the question on their own, ask them identify all variables that changed between the two parts. Remind students that they used two different resistors—20 Ω for the series circuit and 10 Ω for the parallel circuit.

6. Part 2 assumes that you will provide a simple aid called the Parallel Circuit Connection Tool to students. Follow the directions in the Teacher Information for the "Making Connections" experiment to make the Parallel Circuit Connection Tool.

7. If you are curious about the use of a different load (resistor) in Parts 1 and 2, we found that during tests of the effect of load on output, three panels connected in series have a maximum output at about 20 Ω and three panels connected in parallel have maximum output at about 5 Ω. We have chosen the load resistances to optimize the power output for three solar panels. This ensures that students are able to see the greatest difference between power output levels when comparing one, two, and three panels. If we had chosen a single resistor for Parts 1 and 2, the difference between the power output values for one, two, and three panels would not have been as great. For additional information about effect of load, see the "Solar Panel Output: Effect of Load" experiment in this book and **www.vernier.com/til/4372**

ANSWERS TO PRE-LAB QUESTIONS

1. Depending on the solar panel there can be 6–10 solar cells. We use 8 cells to answer the remaining questions.
2. 1/4
3. 3/8
4. 1/3, 33%
5. 2/3, 66%
6. 3/3, 100%
7. The variable that is changing is the amount of shade covering the solar panels.
8. Possible answers: light source, temperature, angle, load, type of circuit (series or parallel)

SAMPLE DATA

Student results will vary depending on light source.

Fraction of solar panels that is shaded	Series circuit Mean power (mW)	Parallel circuit Mean power (mW)
0/3	997.2	399.5
1/3	0.0278	355.1
2/3	0.005	298.7
3/3	0.001	0.002

ANSWERS TO DATA ANALYSIS

1. When one panel was shaded, the power went down a lot—almost to zero.
2. When two panels were shaded, power was about the same, but went down a little.
3. When all three panels were shaded, power was about the same, but went down a little more.
4. When one panel was shaded, power went down a little.
5. When two panels were shaded, power went down a little more.
6. When all three panels were shaded, power was close to zero.
7. Responses will vary based on data.
8. Responses will vary based on data.
9. Responses will vary based on student understanding, but will likely recommend solar panels set up in parallel.