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.

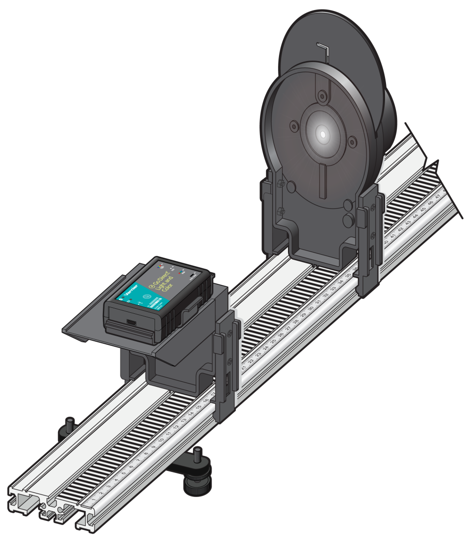

Figure 1

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?

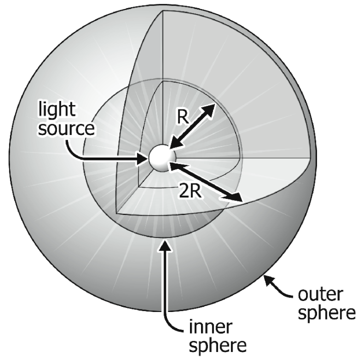

Figure 2

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

In the Electronic Resources you will find multiple versions of each student experiment—one for each supported data-collection software or app (Logger *Pro*, Graphical Analysis 4, LabQuest App, and EasyData). Deliver to your students the version that supports the software and hardware they will use. Sign in to your account at **vernier.com/account** to access the Electronic Resources. See Appendix A for more information. **Note**: The printed version of the book and the PDF of the entire book (found in the Electronic Resources) include only the Logger *Pro* versions of the experiments.

RELATED SKILLS

- Change what is graphed on the axes (Graphical Analysis 4, LabQuest App, and EasyData)
- Create calculated columns

ESTIMATED TIME

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

NEXT GENERATION SCIENCE STANDARDS (NGSS)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and interpreting data Using mathematics and computational thinking	PS3.A Definitions of Energy	Patterns Cause and Effect Energy and Matter

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.

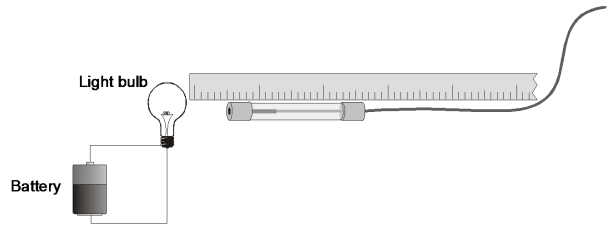

Figure 1

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 Go Direct Light and Color Sensor (order code: GDX-LC), a Vernier Light Sensor (order code: LS-BTA), or the TI Light Sensor (order code: TILT). The Vernier and TI 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. Vernier Light Sensors and Go Direct Light and Color Sensors report 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

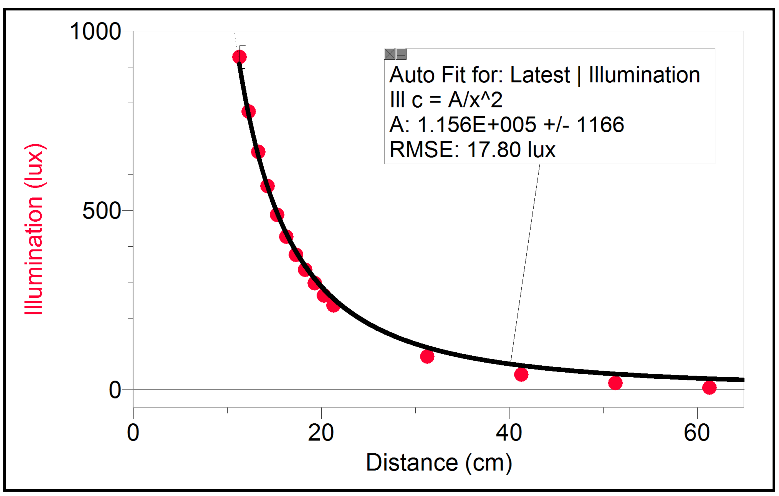

Figure 2 Comparison to inverse-square fit in Logger Pro

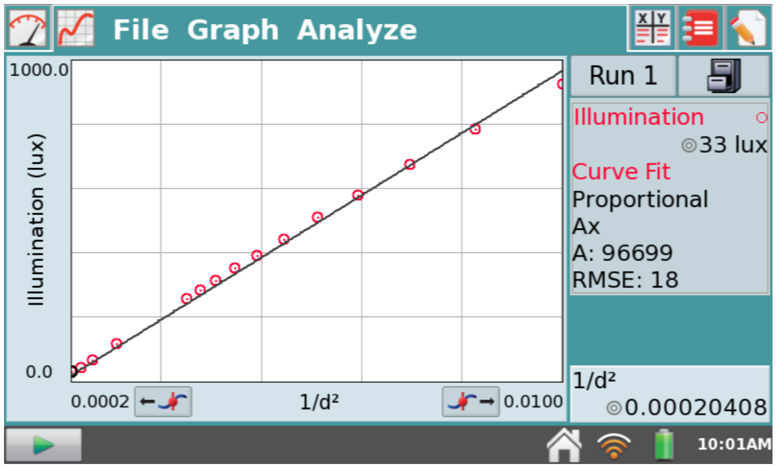

Figure 3 Linearized analysis in LabQuest App

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.

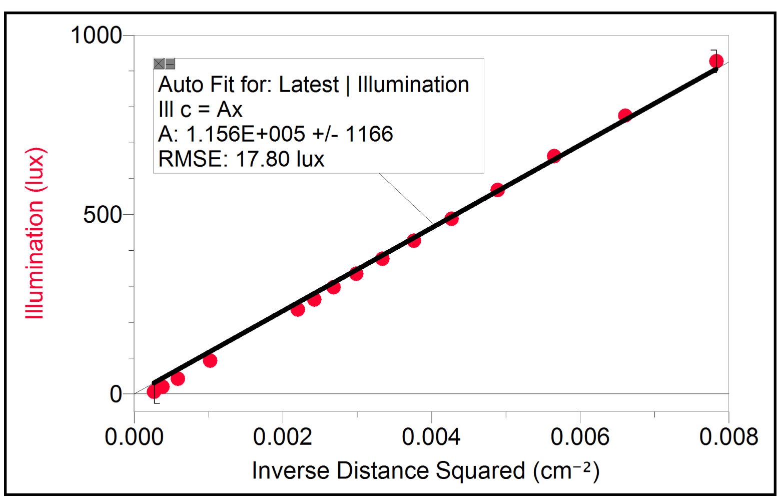

Figure 4

6. (5. Graphical Analysis and LabQuest App) 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. (6. Graphical Analysis and LabQuest App) The concentric spheres model predicts an inverse-square relationship. The data also follow an inverse-square rule, confirming the spheres model.

8. (7. Graphical Analysis and LabQuest App) The reasoning used in the spheres model of Extension 6 (Extension 5 in Graphical Analysis and LabQuest App) 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.