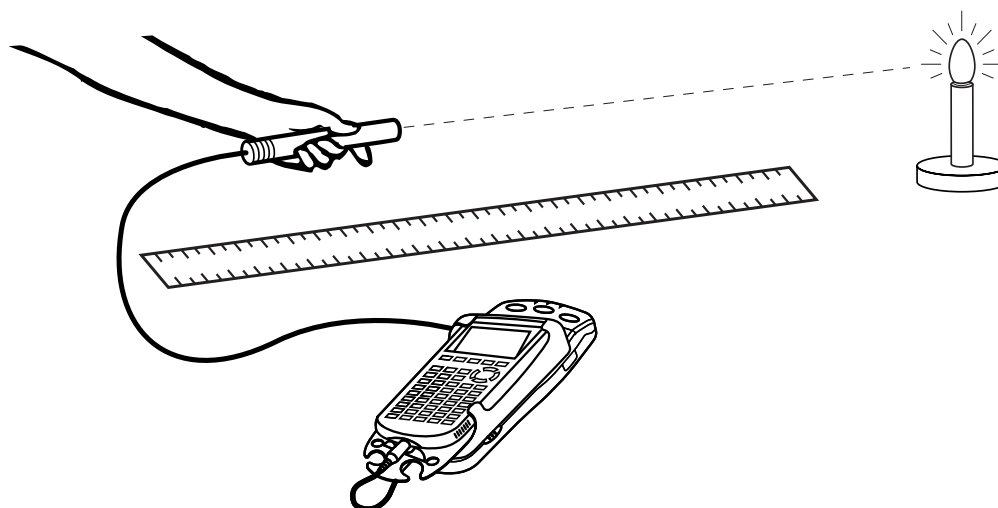


# Light at a Distance: Distance and Light Intensity

## Activity 16

While traveling in a car at night, you may have observed the headlights of an oncoming vehicle. The light starts as a dim glow in the distance, but as the vehicle gets closer, the brightness of the headlights increases rapidly. This is because the light spreads out as it moves away from the source. As a result, light intensity decreases as the distance from a typical light source increases. What is the relationship between distance and intensity for a simple light bulb?

In this activity you can explore the relationship between distance and intensity for a light bulb. You will record the intensity at various distances between a Light Sensor and the bulb. The data can then be analyzed and modeled mathematically.



## OBJECTIVES

- Collect light intensity versus distance data for a point light source.
- Compare data to an inverse-square model.
- Compare data to a power law model.
- Discuss the difference between an inverse-square model and a power law model.

## MATERIALS

TI-83 Plus, TI-83, or TI-73  
CBL 2™ or LabPro® data collection device  
DATAMATE software

Light Sensor  
Meter stick or tape measure  
DC-powered point light source

## PROCEDURE

1. Arrange the equipment. There must be no obstructions between the bulb and the Light Sensor during data collection. Remove any surfaces near the bulb, such as books, people, walls or tables. There should be no reflective surfaces behind, beside, or below the bulb. The filament and Light Sensor should be at the same vertical height. This makes the light bulb look more like a point source of light as seen by the Light Sensor. While you are taking intensity readings, the Light Sensor must be pointed directly at the light bulb.
2. Attach the Light Sensor to CH 1 on the CBL 2™ or LabPro® data collection device. Use the unit-to-unit link cable to connect the data collection device to the TI Graphing Calculator. Firmly press in the cable ends.

*Note: If the sensor has a range switch, set it to 600 lux for a small light source, or 6000 lux for a larger, brighter source.*

3. Turn on the calculator and start the DATAMATE software. Press **CLEAR** to reset the software.
4. Set up DATAMATE and the data collection device for the Light Sensor.
  - a. Select SETUP from the main screen.
  - b. If CH 1 displays the Light Sensor, skip to Step 5.
  - c. Press **ENTER** to select CH 1.
  - d. Choose LIGHT from the SELECT SENSOR list.
  - e. Choose 600 LUX or 6000 LUX from the LIGHT list to match the switch setting you used. The sensor will read in units of lux.
5. Set up the calculator and the data collection device for the events with entry data collection mode.
  - a. Press **▲** to select MODE and press **ENTER**.
  - b. Select EVENTS WITH ENTRY from the SELECT MODE menu to collect light intensity data as a function of distance. In this mode you will trigger the interface to record the light intensity for each position you choose.
  - c. Select OK to return to the main screen.
6. Dim the lights to darken the room. A very dark room is critical to obtain good results.
7. Hold the Light Sensor about 10 cm from the light bulb filament. Move the sensor away from the bulb and watch the displayed intensity values on the calculator screen.

⇒ Answer Question 1 on the *Data Collection and Analysis* sheet.

8. To account for the particular brightness of your light source, choose a starting distance that gives a reading less than the maximum reading for your sensor (600 or 6000 lux for the Vernier sensor, or 1 for the TI sensor), but as large as possible. However, do not get any closer than 5 cm for small (<5 mm) bulbs, or 10 cm otherwise. Choose the starting distance, and enter it as  $X_L$  in the Data Table on the *Data Collection and Analysis* sheet.
9. Again place the Light Sensor your planned starting distance from the light bulb filament.  
**Important:** The distance must be measured carefully. Be sure you measure from the filament of the lamp to the sensor tip on the Light Sensor.
10. Select START from the main screen to prepare for data collection.

11. Wait for the value displayed on the calculator to stabilize. Press  $\boxed{\text{ENTER}}$ , and then enter the distance between the Light Sensor and the light source in meters on the calculator. Press  $\boxed{\text{ENTER}}$  to conclude your entry.
12. Move the Light Sensor 1 cm farther away from the light source and repeat the previous step.
13. Continue moving the sensor in 1-cm increments until the readings fall to less than 10% of the initial reading, collecting data as before. After the final data point, press  $\boxed{\text{STO}}\blacktriangleright$  to end data collection.
14. Inspect the graph of light intensity versus distance. Trace to read the  $x$  and  $y$  values of the left-most point, round the values to three significant figures, and record them as  $X_L$  and  $Y_L$  in the Data Table.
15. Press  $\boxed{\text{ENTER}}$  to return to the main screen, and select QUIT to leave DATAMATE. Follow any instructions on your calculator to return to the home screen.

## ANALYSIS

1. Redisplay your graph outside of DATAMATE.
  - a. Press  $\boxed{\text{ZOOM}}$ .
  - b. Press  $\boxed{\blacktriangledown}$  until ZoomStat is highlighted; press  $\boxed{\text{ENTER}}$  to display a graph with the  $x$  and  $y$  ranges set to fill the screen with data.
2. Inspect your graph of the light intensity versus distance.  
 $\Rightarrow$  Answer Question 2 on the *Data Collection and Analysis* sheet.
3. One model for light intensity holds that the intensity is proportional to the inverse square of the distance from a point light source; that is, a graph would be of the form  $y = C/x^2$ , where  $C$  is an adjustable parameter. Does your data follow this model? You can check it out by finding an approximate value for  $C$ , and then graphing the model with the data. First, enter the model equation.
  - a. Press  $\boxed{\text{Y=}}$ .
  - b. Press  $\boxed{\text{CLEAR}}$  to remove any existing equation.
  - c. Enter  $C/x^2$  in the  $Y_1$  field.
  - d. Press  $\boxed{2\text{nd}}\ \boxed{\text{QUIT}}$  to return to the home screen.
4. Set a value for the parameter  $C$  and then look at the resulting graph. To obtain a good fit, you will need to try several values for  $C$ . Use the steps below to determine an initial guess for the parameter. One way to find an approximate value for the parameter is to use the left-most point. If you solve for  $C$ , then  $C = yx^2$ . Use the  $x$  and  $y$  values for the left-most point to calculate an initial value for  $C$ . Record this value in the Data Table on the *Data Collection and Analysis* sheet.
  - a. Enter a value for the parameter  $C$ . Press  $\boxed{\text{STO}}\blacktriangleright\ C\ \boxed{\text{ENTER}}$  to store the value in the variable  $C$ .
  - b. Press  $\boxed{\text{GRAPH}}$  to see the data with the model graph superimposed.
  - c. Press  $\boxed{2\text{nd}}\ \boxed{\text{QUIT}}$  to return to the home screen.

5. If the model is systematically high or low, you may want to adjust the value of  $C$  to improve the fit. As you did before, store a new value in  $C$ , and then display the graph and model. Once you have optimized the model, record the complete equation in the Data Table.

⇒ Answer Question 3 on the *Data Collection and Analysis* sheet.

6. Another model can be used to compare to your data. The general power law of  $y = ax^b$  may provide a better fit than the inverse square function, especially if the light source is not small or if there are reflections from walls or other surfaces. The difference between this new model and the inverse square model is that the exponent is not fixed at  $-2$ . Instead, the exponent is now an adjustable parameter. The calculator can be used to automatically determine the parameters  $a$  and  $b$  in the general power law relation to the data.

TI-73

(The TI-73 cannot perform this analysis.)

TI-83 and TI-83 Plus

- Press **STAT** and use the cursor keys to highlight **CALC**.
- Press **▼** repeatedly to scroll down to **PwrReg**. When it is highlighted, press **ENTER** to copy the command to the home screen.
- Press **2nd** [L1] **,** **2nd** [L2] **,** to enter the lists containing the data.
- Press **VARS** and use the cursor keys to highlight **Y-VARS**.
- Select **Function** by pressing **ENTER**.
- Press **ENTER** to copy **Y1** to the home screen.
- On the home screen, you will now see the entry **PwrReg L1, L2, Y1**. This command will perform a power law regression with **L1** as the  $x$  and **L2** as the  $y$  values. The resulting regression curve will be stored in equation variable **Y1**. Press **ENTER** to perform the regression. Use the parameters  $a$  and  $b$ , rounded to two significant figures, to write the power law model equation in the Data Table.
- Press **GRAPH** to see the graph of your data and the power regression function.

⇒ Answer Questions 4 and 5 on the *Data Collection and Analysis* sheet.

## EXTENSIONS

- Suppose that your patio is illuminated by an overhead light fixture with two bulbs. You decide to save on electricity by removing one of the bulbs. If the light is currently mounted 5 m off the ground, to what height should the light fixture be moved in order to retain the same amount of light on the patio with one bulb? Does your answer depend on the model you use?
- Two identical light bulbs shine on your favorite reading chair from different locations in the room. The first bulb is 3 m from your chair and provides an intensity of  $0.6 \text{ mW/cm}^2$ . The second is 2 m from your chair. What intensity does this bulb provide? Does your answer depend on the model you use?

**DATA COLLECTION AND ANALYSIS**

Name \_\_\_\_\_

Date \_\_\_\_\_

**DATA TABLES**

Left-most point X value $X_L$	
Left-most point Y value $Y_L$	
Initial model parameter $C$	
Optimized inverse-square model $y = C/x^2$	
Power law model $y = ax^b$	

**QUESTIONS**

1. What is your prediction for the relationship between intensity and the distance to a light source?
2. Is the graph of the light intensity versus distance consistent with your earlier prediction?
3. How well does the inverse-square model  $y = C/x^2$  fit the experimental data?
4. How well does the power law model fit the data? Could it fit any better than the inverse-square model? Could it fit more poorly?
5. How would using a brighter light bulb affect the parameters  $a$ ,  $b$ , and  $C$  in the two models?