

Dependence of Light Intensity on Distance

Suggested Level: High School Physics or Physical Science

LEARNING OUTCOME

After determining through measurement the relationship between the intensity of a point light source and the distance from the light source, students are able to make predictions on the basis of the inverse square law and relate that law to other phenomena such as gravitational and electrical forces.

LESSON OVERVIEW

The purpose of this lesson is for students to determine the relationship between the intensity of a point light source and the distance from the light source. Measuring this relationship gives students experience with the “inverse square” relationship that also characterizes the gravitational force between two point masses and the electric force between two point charges. Data from the lesson *Efficiency of Energy Conversion*, can be used in this lesson. Two versions of this lesson are provided in the student section; which one you use depends on the equipment you have available. Version One uses TI-83+/LabPro or a standalone LabQuest 2, and Version Two uses TI-83/CBL.

MATERIALS

Version One: Student handout (Version One), meterstick, 40 W incandescent light bulb and fixture, TI-83+ graphing calculator, Vernier LabPro unit or LabQuest 2 alone, and TI or Vernier UVB Light Probe

Version Two: Student handout (Version Two), meterstick, 40 W incandescent light bulb and fixture, TI-83 graphing calculator, TI CBL unit, and TI light probe

SAFETY

- Students need to take the usual precautions for handling electric appliances when setting up the bulb.

TEACHING THE LESSON

Display a lighted light bulb in a fixture on a lab table. Given the supposition that the intensity of the light is “ x ” at a distance of 1 meter, ask students to predict what the intensity of the light will be at a distance of 2 meters (as a fraction of x). Explain to students how they will be carrying out an investigation to test their prediction. If it is appropriate, in conjunction with previous learning about the dependence of gravitational and electric force on distance between point masses and/or charges, point out that the same relationship applies between those forces and the distance between objects.

ACCEPTABLE STUDENT RESPONSES

The following data and calculations were obtained with a TI-83+/LabPro or LabQuest 2 system:

Version One:

| Distance from center of bulb (m) | Intensity (W/m^2) |
|----------------------------------|-----------------------|
| 0.4 | 4.5265 |
| 0.5 | 4.4366 |
| 0.6 | 2.7715 |
| 0.7 | 2.2618 |
| 0.8 | 1.7302 |
| 0.9 | 1.3297 |
| 1.0 | 1.0554 |

These data fit a power regression on the TI-83+ of the following form: Intensity = $1.15 \cdot \text{distance}^{-1.686}$.

If the exponent equaled -2 , the relationship would have been exactly that of intensity varying as the square of the distance from the light source.

Version Two:

The following data and calculations were obtained with a TI-83/CBL system:

| Distance from center of bulb (m) | Intensity (W/m ²) |
|----------------------------------|-------------------------------|
| 0.4 | 4.6559 |
| 0.5 | 3.4764 |
| 0.6 | 2.1411 |
| 0.7 | 1.874 |
| 0.8 | 1.2175 |
| 0.9 | 1.0061 |
| 1.0 | 0.9727 |

These data fit a power regression on the TI-83 of the following form:

$$\text{Intensity} = .890 \cdot \text{distance}^{-1.842}.$$

If the exponent equaled -2 , the relationship would have been exactly that of intensity varying as the square of the distance from the light source.

BACKGROUND INFORMATION

In the film *Coulomb's Law*, the late Eric Rogers made an analogy between rays from a point source of light and butter sprayed from a gun. At a distance of 1 meter, the butter from the gun covered one piece of toast. At a distance of 2 meters, the butter spread out twice as wide and twice as high, thus covering four pieces of toast. But each piece of toast received only one quarter as much butter at 2 meters as it did at 1 meter. Placing the toast 3 meters away was the "giant economy treatment," buttering nine pieces of toast but providing only one ninth as much butter per piece of toast as at 1 meter.

Thus, the intensity of butter from the gun varies inversely as the square of the distance from it. This is the famous inverse square law of physics, which is found to hold for not only light from point sources and butter from spray guns but also the strengths of gravitational and electric forces and fields, the last of which can be viewed in terms of field lines radiating equally in all directions from a point mass or electric charge.

Note: The data from the lesson, *Efficiency of Energy Conversion*, can also be used in this lesson.

(STUDENT HANDOUT FOLLOWS)

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Version One: Dependence of Light Intensity on Distance (TI-83+/LabPro or LabQuest)

The dependence of the intensity from a point source of light on the distance from the light source is a fundamental relationship in nature.

DEVELOP YOUR UNDERSTANDING

The intensity of light from an incandescent light bulb can be measured at various distances with a light probe interfaced to a TI-83+/LabPro system, using the DataMate application, as follows:

1. Connect the light probe to CH 1 of the LabPro or LabQuest unit.
2. Make sure that the link cord is connected between the calculator and the LabPro unit (link ports are on the bottom of each unit).
3. Turn on the calculator and connect the AC adapter for the LabPro unit to a wall outlet.
4. Press the <APPS> key on the calculator.
5. Use the arrow keys on the calculator to highlight the application DataMate. Press <ENTER>. At this point the LabPro automatically checks for and identifies the probes connected to it. The calculator monitors and displays readings from the probes.
6. Press <1.Setup>.
7. Move the cursor to “Mode” and press <ENTER>.
8. Press <3.Events With Entry>.
9. Press <1.OK>.
10. Place a 40 W incandescent light bulb on a table and a meter stick with the “0” end at the center of the light bulb. Position the light probe so that it points directly to the light bulb and away from outside light, 40 cm from the center of the bulb. Eliminate all other ambient light in the laboratory.
11. Press <2.Start>. You will then be asked to press <ENTER> to collect data. Press <ENTER> when the reading on the calculator screen is stable, in order to register the intensity of the light at a distance of 40 cm from the bulb.

12. The calculator will now prompt you to input a value. Input 0.40 <ENTER> to indicate that this reading corresponds to a bulb-to-probe distance of 0.40 m.
13. Reposition the light probe so that it is 50 cm from the center of the bulb. Press <ENTER> when the reading is stable, in order to register the intensity of the light at a distance of 50 cm from the bulb. When prompted to input a value, input 0.50 <ENTER> to indicate that this reading corresponds to a bulb-to-probe distance of 0.50 m.
14. Repeat Step 13 for distances of 60 cm, 70 cm, 80 cm, 90 cm, and 100 cm, entering, respectively, values of 0.60, 0.70, 0.80, 0.90, and 1.00.
15. After your last measurement press <STO-> to see a graph of the light intensities versus distance from bulb to probe (the window for the x-axis will match the range of distance values you have input). When you are finished with the graph, press <ENTER>.
16. Press <6.Quit>. You will be told that the distances will be displayed in L₁ and the light intensities in L₂. This can be verified by pressing <ENTER> (to exit the DataMate application), then pressing <STAT> and selecting EDIT.
17. The light intensities in L₁ are measured in units of milliwatts per square centimeter. To convert them to watts per square meter, multiply these values by 10. Enter the intensities (in watts per square meter) in the following data table:

| Distance from center of bulb (m) | Intensity (W/m ²) |
|----------------------------------|-------------------------------|
| 0.40 | |
| 0.50 | |
| 0.60 | |
| 0.70 | |
| 0.80 | |
| 0.90 | |
| 1.00 | |

18. To display your data graphically, activate a plot by pressing <2nd> and <Y=> to get <STAT PLOT>, then press <WINDOW> and select appropriate values of Xmin, Xmax, etc., and finally press <GRAPH>.
19. To determine which mathematical function best fits your graph, press <STAT> and select <CALC> from the menu with the arrow keys. Use the arrow keys to select which type of function you wish to match your data to. For examining the relationship between light intensity and the distance from a light source, “A.PwrReg” is used. This will list as “b” the exponent of the relationship between light intensity and distance:

$$[\text{light intensity}] = a * [\text{distance}]^b.$$

Question: On what power of the distance from the light source does the light intensity depend?

Suggestion for further experimentation: Repeat the above procedure with an incandescent bulb of a different power rating or with a compact fluorescent bulb. What differences do you observe? (Note: A 100 W incandescent bulb is found to “overload” a TI light probe at distances closer than 0.50 m.) Using Vernier, the UVB probe does not overload.

Version Two: Dependence of Light Intensity on Distance (TI-83/CBL)

The dependence of the intensity from a point source of light on the distance from the light source is a fundamental relationship in nature.

DEVELOP YOUR UNDERSTANDING

The intensity of light from an incandescent light bulb can be measured at various distances with a light probe interfaced to a TI-83/CBL system, using the PHYSICS program, as follows:

1. Connect the light probe to CH 1 of the CBL unit.
2. Connect the link cord between the calculator and the CBL unit (link ports are on the bottom of each unit). Make sure that the link cord is firmly inserted into each unit (a twisting motion helps to ensure this).
3. Turn on the CBL unit and calculator.
4. Press the <PRGM> key on the calculator.
5. Use the arrow keys on the calculator to highlight the program PHYSICS. Press <ENTER>. At this point the calculator screen should have “prgmPHYSICS” showing; press <ENTER> again.
6. When the program title screen appears, press <ENTER>, as prompted on the screen.
7. If it is not already highlighted, highlight 1:SET UP PROBES and press <ENTER>.
8. At the prompt, “ENTER NUMBER OF PROBES,” press <1> and <ENTER>.
9. Select <7.MORE PROBES>. (This can be done by pressing <7> or using the arrow keys to select <7.MORE PROBES> and pressing <ENTER>.) Then select <1.LIGHT>.
10. When prompted to select a channel, press <1> and <ENTER>.
11. You should now be back at the main menu screen. Select <2.COLLECT DATA>.
12. From the data collection menu choose <3.TRIGGER PROMPT>. The CBL/Calculator pair is now prepared to gather data.

13. Place a 40 W light bulb on a table and a meterstick with the “0” end at the center of the light bulb. Position the light probe so that it points directly to the light bulb and away from outside light, 40 cm from the center of the bulb. Eliminate all other ambient light in the laboratory.
14. Monitor the CBL and press <TRIGGER> on the CBL unit when the reading is stable. The calculator will now prompt you to input a value. Input 0.40 <ENTER> to indicate that this reading corresponds to a bulb-to-probe distance of 0.40 m.
15. Reposition the light probe so that it is 50 cm from the center of the bulb. From the data collection menu choose <1.MORE DATA>. Monitor the CBL and press <TRIGGER> on the CBL unit when the reading is stable. The calculator will now prompt you to input a value. Input 0.50 <ENTER> to indicate that this reading corresponds to a bulb-to-probe distance of 0.50 m.
16. Repeat Step 15 for distances of 60 cm, 70 cm, 80 cm, 90 cm, and 100 cm, entering, respectively, values of 0.60, 0.70, 0.80, 0.90, and 1.00.
17. After your last measurement choose <2.STOP AND GRAPH> from the data collection menu. The calculator will display a graph of light intensity (in L_2) versus distance (in L_1).
18. After you have finished viewing your graph, press <ENTER> and respond to the prompt “REPEAT?” If you wish to collect more data, input <2.YES>; otherwise <NO>, and <7.QUIT> from the main menu.
19. The light intensities in L_2 (which can be viewed by pressing <STAT> and selecting EDIT from the menu) are measured in units of milliwatts per square centimeter. To convert them to watts per square meter, multiply these values by 10. Enter the intensities (in watts per square meter) in the following data table:

| Distance from center of bulb (m) | Intensity (W/m^2) |
|----------------------------------|-----------------------|
| 0.40 | |
| 0.50 | |
| 0.60 | |
| 0.70 | |
| 0.80 | |
| 0.90 | |
| 1.00 | |

20. To determine which mathematical function best fits your graph, press <STAT> and select <CALC> from the menu with the arrow keys. Use the arrow keys to select which type of function you wish to match your data to. For examining the relationship between light

intensity and the distance from a light source, “A.PwrReg” is used. This will list as “b” the exponent of the relationship between light intensity and distance:

$$[\text{light intensity}] = a * [\text{distance}]^b.$$

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Suggestion for further experimentation: Repeat the above procedure with an incandescent bulb of a different power rating or with a compact fluorescent bulb. What differences do you observe? (Note: A 100 W incandescent bulb is found to “overload” a TI light probe at distances closer than 0.50 m.) Using Vernier, the UVB probe does not overload.