Sound Intensity – ID: 10543

By Irina Lyublinskaya

Time required
45 minutes

Topic: Light and Sound

- *Perform calculations relating sound intensity and decibels.*
- *Describe the relationship between sound intensity and distance from the sound source.*

Activity Overview

In this activity, students investigate the relationship between sound intensity and distance for a commercial loudspeaker. They use collected data to identify a mathematical model for the relationship. They then compare this model with the inverse square law for an ideal point source.

Materials

To complete this activity, each student will require the following:

- *TI-Nspire™ technology*
- *Vernier Sound Level Meter*
- *Vernier EasyLink™ or Go!® Link interface*
- *loudspeaker and sound generator*
- *meterstick*
- *copy of student worksheet*
- *pen or pencil*
- *blank sheet of paper*
- *ear plugs (optional)*

TI-Nspire Applications

Graphs & Geometry, Lists & Spreadsheet, Notes

Teacher Preparation

Before carrying out this activity, you should review with students the definitions and units of power and intensity, including the decibel scale.

- *As a point of interest, you may want to discuss the reasons for using the decibel scale, namely, the large range of intensities that human ears can hear (10^{-12}–10^{3} W/m^2).*
- *If time permits, you may have students repeat the experiment using another set of speakers and have them compare their results with those obtained in the main activity.*
- *The screenshots on pages 2–7 demonstrate expected student results. Refer to the screenshots on page 8 for a preview of the student TI-Nspire document (.tns file). Pages 9–11 show the student worksheet.*
- ***To download the .tns file and student worksheet, go to education.ti.com/exchange and enter "10543" in the search box.***

Classroom Management

- *This activity is designed to be **student-centered**, with the teacher acting as a facilitator while students work cooperatively. The student worksheet guides students through the main steps of the activity and includes questions to guide their exploration. Students may record their answers to the questions on blank paper or answer in the .tns file using the Notes application.*
- *The ideas contained in the following pages are intended to provide a framework as to how the activity will progress. Suggestions are also provided to help ensure that the objectives for this activity are met.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

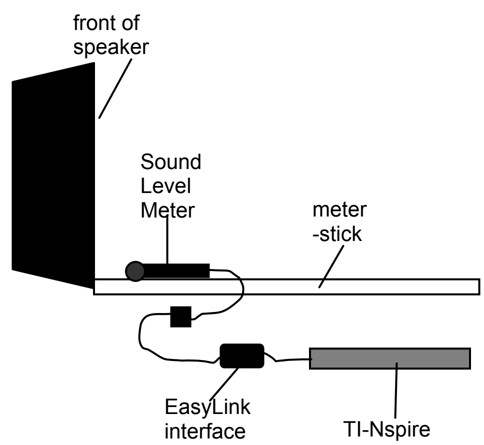
The following questions will guide student exploration during this activity:

- How does sound intensity change with the distance away from a commercial loudspeaker?
- What is the mathematical model for this relationship?
- How does the model for the commercial source of sound compare with the theoretical results for a point sound source?

The purpose of this activity is for students to explore how commercial loudspeakers propagate sound and to compare the relationship between intensity and distance for a commercial loudspeaker with the theoretical relationship predicted for a point source. Students collect data on sound intensity as a function of distance, analyze these data, develop a mathematical model for sound intensity, and compare this model to the theoretical formula for the ideal point source. If time allows, students may explore several different loudspeakers.

Part 1 – Collecting sound intensity data

Step 1: Students should set up the equipment according to the instructions provided in the student worksheet. A diagram of the setup is shown to the right.



Step 2: Students will use a Vernier EasyLink (if using a handheld) or Go!Link (if using a computer) interface. Students should first connect a Vernier Sound Level Meter to its cable and then connect the cable to the EasyLink or Go!Link interface. On the Sound Level Meter, students should slide the power switch to the 75–130 dB (“Hi”) level, set the time-weighting switch to “S,” set the maximum level hold switch to “Reset,” and set the frequency weighting to “A.” Students should then answer questions 1–4.

Q1. Define sound intensity.

A. *Intensity is defined as the amount of energy that is transported through a given area of medium per unit time. Its units are units of power per unit area.*

Q2. How does sound intensity change with distance away from a point sound source?

A. *Intensity (I) is defined as power (P) per unit area. Sound from a point source travels in spherical wavefronts. The surface area of a sphere is $4\pi r^2$, so the equation for intensity from a point sound source is $I = \frac{P}{4\pi r^2}$. Therefore, the intensity of sound should decrease according to an inverse square law.*

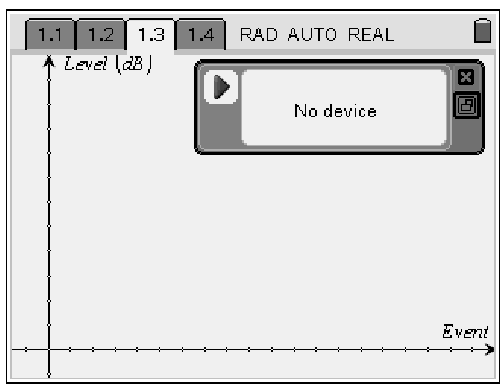
Q3. How do you think sound intensity changes with distance away from a commercial loudspeaker?

A. *Answers will vary, but students will probably state that the intensity should decrease with distance away from the speaker. Encourage student discussion, and ask students to try to be more specific about the hypothesized relationship. Do they think it will follow an inverse square law? Why or why not?*

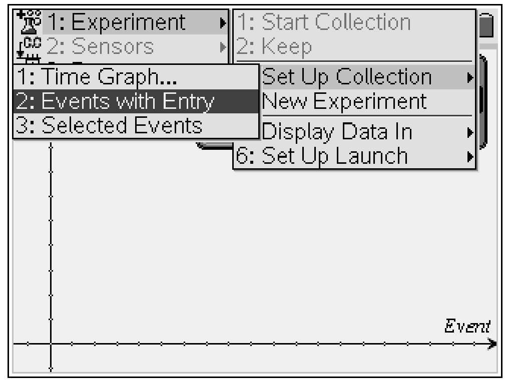
Q4. Why do we measure sound intensity in decibels? What is a decibel?

A. *The range of intensities that the human ear can detect is very large (many orders of magnitude). Therefore, scientists use a logarithmic scale, which is based on powers of 10, to describe sound intensity. The scale for measuring intensity is the decibel scale. The intensity of a sound in decibels (I_{dB}) is given by the following equation: $I_{dB} = 10 \log_{10} \frac{I_1}{I_0}$, where I_0 is the threshold of hearing and I_1 is the measured intensity of the sound.*

Step 3: Students should open the file **PhysWeek25_SoundIntensity.tns**, read the first two pages, and then move to page 1.3. When students reach page 1.3, they should insert a new data collection box and then connect the interface to their handhelds or computers. A Sound Level Meter display should appear in the data collection box on page 1.3.



Step 4: Next, students should set up the data collection to **Events with Entry** mode.



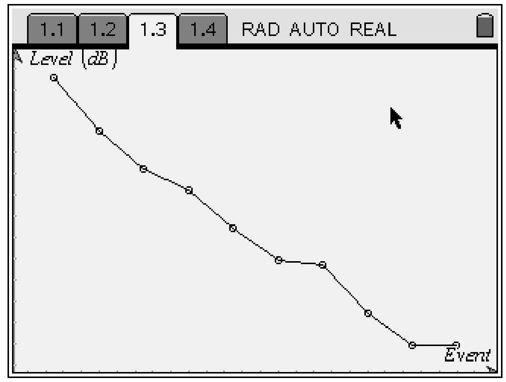
Step 5: Next, students should turn on the speaker and adjust its volume to be between 90 and 100 dB. Note: The 90–100 dB intensity level suggested in the student worksheet may be too loud for students to work with comfortably, especially in a small room. If you wish, you may instruct students to reduce the volume of the sound to 80 dB or lower. If the sound is below 90 dB to begin with, students should use the 35–90 dB ("Lo") setting on the Sound Level Meter. You may also wish to allow students to use earplugs to reduce the volume of the sound. It is recommended that students use speakers connected to a computer capable of playing a single-frequency tone. There are many Web sites and downloadable programs that will generate single-frequency tones. If this type of setup is not possible, an electronic keyboard connected to a speaker should also work. It is most important that the tone used be of a constant intensity (loudness). The sample data shown here were collected using an online tone generator producing a 400 Hz tone with an initial intensity of about 85 dB.

Step 6: Next, students should zero the intensity read in the data collection box. Note that this will not affect the intensity reading on the Sound Level Meter itself.

Step 7: Next, students begin data collection. They should collect their first data point at a distance of 0.05 m (5 cm) from the speaker.

Step 8: Students should move the meter to the 10 cm mark and collect another data point. Note: Make sure students wait until the intensity reading has stabilized before recording the data point.

Step 9: Students should collect a total of ten data points using the methods in steps 7 and 8. A graph of the data points will form on page 1.3 as students collect the data.



Step 10: When students have finished collecting data, they should close the data collection box and disconnect and deactivate the Sound Level Meter. They should then answer questions 5 and 6. Note: If a graph does not form on page 1.3 automatically, students can create one by changing the graph type to scatter plot and plotting **dc01.level1** vs. **dc01.event**.

Q5. Describe and explain the shape of the graph.

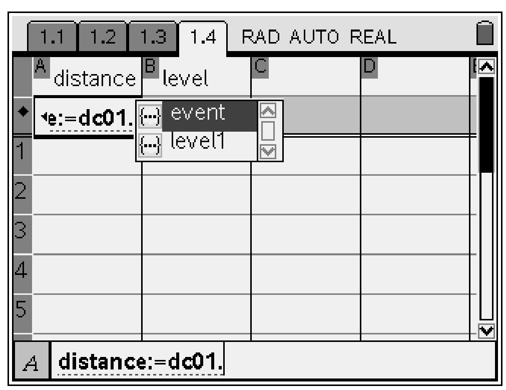
A. *The answers will vary depending on the quality of the speakers. In general, intensity should decrease with distance. Student explanations for the data could refer to the increase of the surface area reached by the sound as distance increases.*

Q6. What mathematical model appears to best fit your data?

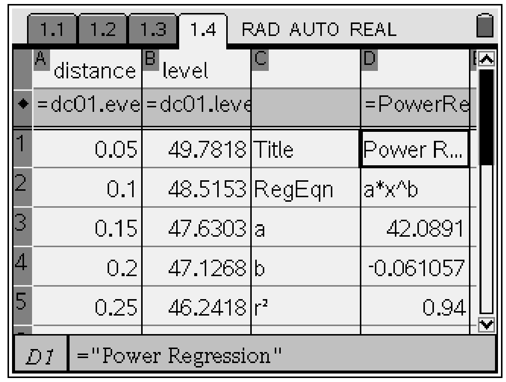
A. *Answers will vary. Encourage student discussion of their results. Most students should be able to infer that some sort of inverse relationship could fit their data. Guide students to realize that they can use a regression to determine the best-fit equation for their data. They will carry out this regression in the next part of the activity.*

Part 2 – Mathematical modeling

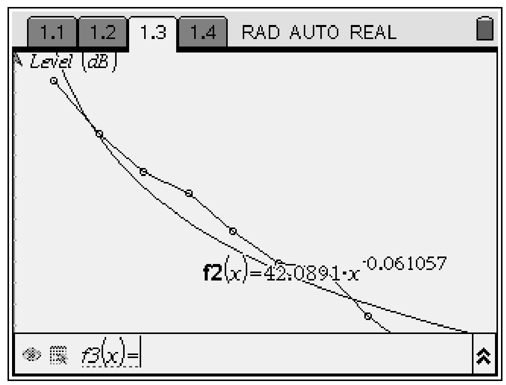
Step 1: Next, students should move to page 1.4, which contains a *Lists & Spreadsheet* application. They should assign column A to the variable **distance** and populate it with the distance data they collected. They should assign column B to the variable **level** and populate it with the intensity data they collected.



Step 2: Next, students should use the **Power Regression** tool to calculate the best-fit equation for their data set. Note: Some data sets (including the sample data set shown here) may be better fit by a linear function (i.e., $y = -x$) than by an inverse power function. If you wish, you may have students carry out both power and linear regressions and observe which fits the data better. Encourage students to discuss their results, paying specific attention to the r^2 values in each case. Have students discuss the implications of each type of equation. In particular, they should consider why a linear relationship may not be appropriate. For example, a linear equation will yield negative intensity values for large distances from the speaker, but a negative intensity is a physical impossibility. Therefore, a power regression (which is never negative) is a more appropriate functional form.



Step 3: Finally, students should plot the best-fit equation on the graph of the data on page 1.3. They should then answer questions 7 and 8. If you wish and time allows, you may have students repeat the data collection and analysis with different speakers or with a different frequency or intensity of sound.



Q7. Compare your mathematical model with the theoretical formula for the relationship between intensity and distance for a point sound source. Which sound source produces the greatest decrease in intensity for a given distance from the source?

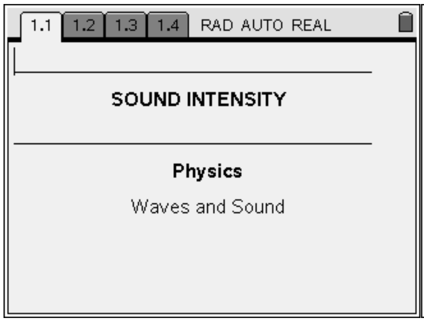
A. *For an ideal point sound source, intensity (I) and distance (r) are related by the expression $I \propto \frac{1}{r^2}$. Students' best-fit equations will vary, but the sound produced by most commercial speakers will decrease in intensity less quickly than that from a point source. For example, the sample data set yields a best-fit relationship of $I \propto \frac{1}{r^{0.06}}$. If you wish and time allows, you may have students plot an inverse square function on page 1.3, along with the function for their data. Students should plot a function of the form $y = \frac{a}{x^2}$ that passes through their first data point (i.e., they should solve the equation for a using the coordinates of the first data point). Plotting the two functions together will illustrate more clearly the difference in functional forms between the speaker and a point source. Also, students are likely to generate data that are nearly linear. In this case, using a power function to fit the data may seem counterintuitive to students. You may wish to discuss with them how "real" scientists go about deciding what functional form fits a given data set best. You could discuss the importance of thinking critically about the characteristics of the phenomenon under investigation, trying different models, performing statistical analyses, and collecting sufficient amounts of data.*

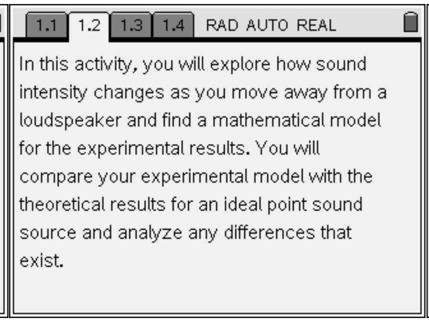
Q8. Why do you think commercial speakers do not follow the theoretical model for a point sound source?

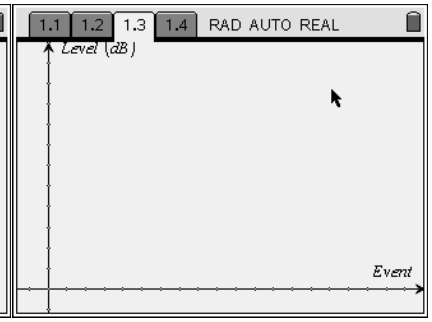
A. *Answers will vary. Encourage students to think critically and discuss the possibilities. Ask them to consider what commercial speakers are designed to do. This should help them realize that, in the theoretical situation of a point sound source, energy is distributed uniformly over a spherical surface, but commercial speakers are designed to project sound in a specific direction. The shape of the speaker (a parabolic dish) effectively reflects most of the sound in that one direction. This increases the amount of energy that propagates in that direction and increases the intensity of sound at a given distance from the speaker. You may also wish to discuss the similarities between a speaker's parabolic dish and a flashlight's parabolic reflector.*

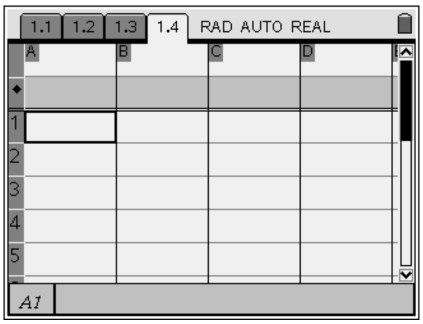
Sound Intensity – ID: 10543

(Student)TI-Nspire File: *PhysWeek25_SoundIntensity.tns*









Sound Intensity

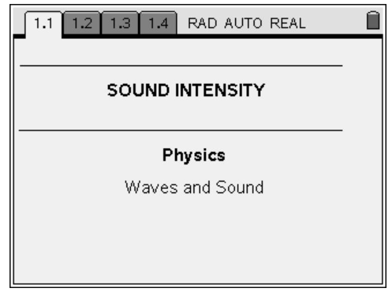
ID: 10543

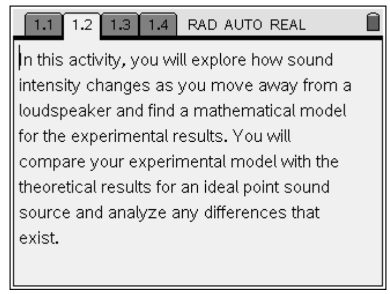
Name ____________________

Class ____________________

In this activity, you will explore the following:

- *how the sound intensity changes with the distance away from the commercial loudspeaker*
- *how to make mathematical models of physical phenomena*
- *the difference between the sound produced by an ideal point source and that produced by a commercial loudspeaker*

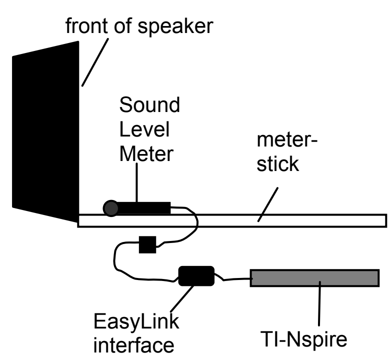




A loudspeaker is a device for transforming electric signals into audible sound, most frequently used to reproduce speech and music. The energy is carried away through the air by sound waves. The loudness of the sound is known as its intensity. Human ears are capable of detecting sound waves of extremely low intensity. The faintest sound that the typical human ear can detect has an intensity of 1×10^{-12} W/m^2. The intensity of this faintest audible sound is known as the threshold of hearing. The most intense sound that the ear can safely detect without suffering any physical damage is more than a billion times more intense than the threshold of hearing. Because the range of intensities that the human ear can detect is so large, the scale that is frequently used by physicists to measure intensity is a logarithmic scale based on multiples of 10.

In this activity, you will collect sound intensity data from a commercial loudspeaker, analyze these data, and develop a mathematical model for the sound intensity as a function of distance from the sound source. You will then compare this model with the theoretical model developed for an ideal point sound source and analyze the differences.

Part 1: Collecting sound intensity data



Step 1: Align the zero end of the meterstick with the front of the loudspeaker, as shown to the right. Align the microphone part of the Sound Level Meter with the 5 cm mark on the meterstick. You will measure sound intensity starting at the 5 cm mark and ending at the 50 cm mark in 5 cm increments.

Step 2: Connect the Sound Level Meter to its cable, and then connect the cable to the EasyLink interface (if you are using a TI-Nspire handheld to collect data) or the Go!Link interface (if you are using a computer to collect data). On the Sound Level Meter, slide the power switch to the 75–130 dB (“Hi”) level, set the time-weighting switch to “S,” set the maximum level hold switch to “Reset,” and set the frequency weighting to “A.”

Q1. Define sound intensity.

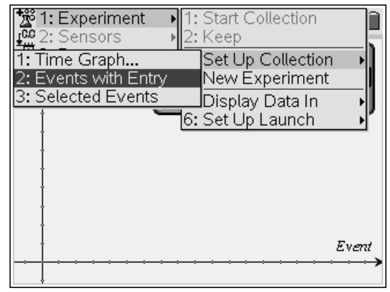
Q2. How does sound intensity change with distance away from a point sound source?

Q3. How do you think sound intensity changes with distance away from a commercial loudspeaker?

Q4. Why do we measure sound intensity in decibels? What is a decibel?

Step 3: Open the file **PhysWeek25_SoundIntensity.tns**, read the first two pages, and then move to page 1.3. Insert a new data collection box on page 1.3 by pressing ctrl D. Then, connect the EasyLink or Go!Link interface to your handheld or computer. An intensity reading should appear in the data collection box.

Step 4: You will be collecting sound intensity readings at specific distances from the loudspeaker. To do this, you will use the **Events with Entry** experimental setup. Select **Events with Entry** from the **Experiment** menu (**Menu > Experiment > Set Up Collection > Events with Entry**).



Step 5: Turn on the loudspeaker and adjust its volume to be between 90 and 100 dB. (Note: Make sure to read the intensity from the Sound Level Meter, not the TI-Nspire data collection box.) Turn off the loudspeaker.

Step 6: Make sure the room is relatively quiet. Once the reading in the data collection box has stabilized, zero the sensor (**Menu > Sensors > Zero**).

Step 7: Turn the loudspeaker back on. Press the “play” button (►) on the data collection box. When the decibel reading has stabilized, click on the box in the lower left side of the data collection box. This is the “Keep” button; it tells the TI-Nspire that you want to record a data point. A dialog box will pop up. In the dialog box, enter the distance (in meters) between the speaker and the Sound Level Meter, and then click OK. (For the first reading, this number will be 0.05.)

Step 8: Move the Sound Level Meter 5 cm farther from the speaker (so the microphone is aligned with the 10 cm mark). Wait for the reading to stabilize, and then “Keep” the data point. (Make sure to enter the correct distance in the dialog box.)

Step 9: Repeat steps 7 and 8 eight more times, moving the Sound Level Meter 5 cm each time. (You should have a total of 10 data points.) As you move the meter, keep an eye on the sound level reading on the meter itself. If the intensity of sound drops below 90 dB, you will need to slide the power switch on the Sound Level Meter to the 35–90 dB (“Lo”) setting.

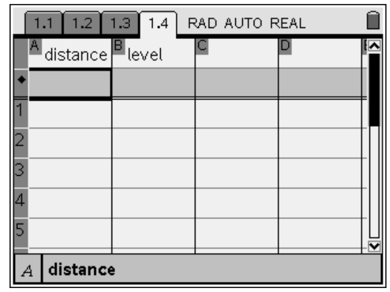
Step 10: After data are collected, close the data collection box and disconnect the sensor.

Q5. Describe and explain the shape of the graph.

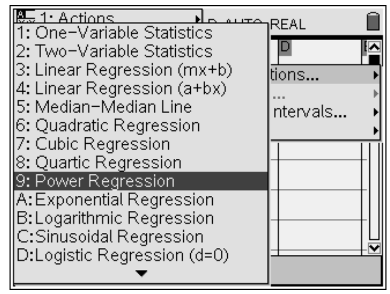
Q6. What mathematical model appears to best fit your data?

Part 2: Mathematical modeling

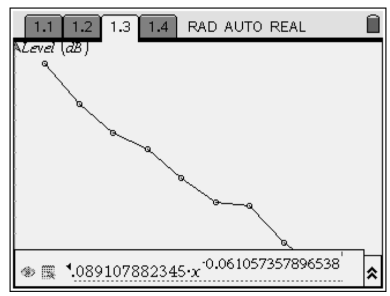
Step 1: Next, move to page 1.4, which contains a *Lists & Spreadsheet* application. Label column A **distance** and column B as **level**. In the formula bar (light gray box) of column A, type **=dc01.event**. This assigns the distance values you collected in part 1 to the variable **distance**. In the formula bar of column B, type **=dc01.level1**. This assigns the sound intensity values you recorded to the variable **level**.



Step 2: An idealized point sound source produces an inverse square relationship between intensity and distance. To determine whether your data conform to this relationship, carry out a **Power Regression** on your data. Highlight columns A and B, and then select **Power Regression** from the **Statistics** menu (**Menu > Statistics > Stat Calculations > Power Regression**). Use **distance** (column A) as your XList and **level** (column B) as your YList.



Step 3: Go back to page 1.3. Change the graph to a function graph, and then plot the regression curve along with the experimental data.



Q7. Compare your mathematical model with the theoretical formula for the relationship between intensity and distance for a point sound source. Which sound source produces the greatest decrease in intensity for a given distance from the source?

Q8. Why do you think commercial speakers do not follow the theoretical model for a point sound source?