  Graphical Analysis 32

Sound Waves and Beats

Sound waves consist of a series of air pressure variations. A microphone diaphragm records these variations by moving in response to the pressure changes. The diaphragm motion is then converted to an electrical signal. Using a microphone, you can explore the properties of common sounds.

The first property you will measure is the period, or the time for one complete cycle of repetition. Since period is a time measurement, it is usually written as T. The reciprocal of the period (1/T) is called the frequency, f, the number of complete cycles per second. Frequency is measured in hertz (Hz). 1 Hz = 1 s–1.

A second property of sound is the amplitude. As the pressure varies, it goes above and below the average pressure in the room. The maximum variation above or below the pressure mid-point is called the amplitude. The amplitude of a sound is closely related to its loudness.

In analyzing your data, you will see how well a sine function model fits the data. The displacement of the particles in the medium carrying a periodic wave can be modeled with a sinusoidal function. Your textbook may have an expression resembling this one:

y = A sin (2π f t)

In the case of sound, a longitudinal wave, y refers to the change in air pressure that makes up the wave, A is the amplitude of the wave, and f is the frequency. Time is represented by t, and the sine function requires a factor of 2π when evaluated in radians.

When two sound waves overlap, air pressure variations will combine. For sound waves, this combination is additive. We say that sound follows the principle of linear superposition. Beats are an example of superposition. Two sounds of nearly the same frequency will create a distinctive variation of sound amplitude, which we call beats.

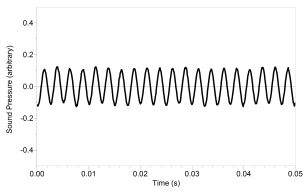


Figure 1

objectives

* Measure the frequency and period of sound waves from a keyboard.
* Measure the amplitude of sound waves from a keyboard.
* Observe beats between the sounds of two notes from a keyboard.

Materials

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Vernier Microphone

electronic keyboard

Preliminary questions

1. Why are instruments tuned before being played as a group? In what different ways do musicians tune their instruments?
2. Given that sound waves consist of a series of air pressure increases and decreases, what would happen if an air pressure increase from one sound wave was located at the same place and time as a pressure decrease from another of the same amplitude?
3. How is it that we can hear all the instruments played by a group of musicians at once? Are there conditions under which you cannot hear all instruments? Can two sounds add up to create an experience that seems less intense than either sound on its own?

Procedure

Part I  Simple Waveforms

1. Launch Graphical Analysis. Connect the Microphone to your Chromebook, computer, or mobile device. Data are collected for only 0.03 s in order to be able to display the rapid pressure variations of sound waves.
2. To center the waveform on zero, it is necessary to zero the Microphone. With the room quiet, click or tap the Sound Pressure meter and choose Zero.
3. Press and hold a key on the keyboard. Hold the Microphone close to the speaker and click or tap Collect to start data collection. When data collection is complete, a graph is displayed. The data should be sinusoidal in form, similar to Figure 1.
4. Export, print, or make a sketch of your graph.
5. Click or tap the graph to examine the data. Note: You can also adjust the Examine line by dragging the line. As you tap each data point, sound and time values will be displayed. Record the times for the first and last peaks of the waveform. Record the number of complete cycles that occur between your first measured time and the last. Divide the difference, Δt, by the number of cycles to determine the period of the note. Record the period in your data table.
6. Examine the graph again, and record in the data table the maximum and minimum sound values for an adjacent peak and trough.
7. Calculate the amplitude of the wave by taking half of the difference between the maximum and minimum y values. Record the values in your data table.
8. Calculate the frequency of the note in Hz and record it in your data table.
9. Model your data.
   1. Choose Model from the Analyze menu, then choose Sound Pressure.
   2. Select the equation, Asin(Bx + C) + D.
10. To see how well the model fits the data, you need to adjust the parameters of the model y = Asin(2πf t) and plot it with the data. The model, expressed as Y = A \* sin(B\*X + C) + D, contains four parameters; it is more complicated than the textbook model, but the basic sinusoidal form is the same. Comparing terms, listing the textbook model’s terms first, the amplitude, A, corresponds to the fit term A, and 2π f corresponds to the parameter B. The variable X represents the time, t. The new parameters C and D shift the fitted function left-right and up-down, respectively and may be necessary to obtain a good fit. Only the values of parameters A and B are important to this experiment. In particular, the numeric value of B allows you to find the frequency f using B = 2π f.
    1. Enter your estimate for the value of A, the amplitude.
    2. Enter your estimate for the value of B (start with 2πf).
    3. Initially use zero for C and D.
    4. LabQuest will plot the data and your model with the current values of A, B, C, and D. Adjust each value until you see what each one does and until you have a good match of your model to the data.
    5. After optimizing the four values, record the parameters A, B, C, and D in your data table. Select OK.
11. Repeat Steps 3–10 for an adjacent key on the keyboard.
12. Answer the Analysis questions for Part I before proceeding to Part II.

Part II  Beats

1. Two pure tones with different frequencies sounded at once will create the phenomenon known as beats. Sometimes the waves will reinforce one another and other times they will combine to a reduced intensity. This happens on a regular basis because of the fixed frequency of each tone. To observe beats, simultaneously hold down the two adjacent keys on the keyboard that you used earlier and listen for the combined sound. If the beats are slow enough, you should be able to hear a variation in intensity. When the beats are too rapid to be audible as intensity variations, a single rough-sounding tone is heard. At even greater frequency differences, two separate tones may be heard, as well as various difference tones.
2. To capture the beats, it is necessary to collect data for a longer period of time.
   1. Click or tap mode to open Data Collection Settings.
   2. Change Rate to 2500 samples/s and End Collection to 0.05 s.
   3. Click or tap Done.
3. Start the two tones sounding and click or tap Collect to start data collection.
4. Note the shape of your waveform graph. You should see a time variation of the sound amplitude. The pattern will be complex, with a slower variation of amplitude on top of a more rapid variation. Ignoring the more rapid variation and concentrating in the overall pattern, count the number of amplitude maxima after the first maximum and record it in the data table.
5. Record the times for the first and last amplitude maxima. To do this, click or tap any data point. Divide the difference, Δt, by the number of cycles to determine the period of beats (in seconds). Calculate the beat frequency in Hz from the beat period. Record these values in your data table.

Analysis

Part I  Simple Waveforms

1. Did your model fit the waveform well? In what ways was the model similar to the data and in what ways was it different?
2. Since the model parameter B corresponds to 2π f (i.e., f = B/(2π)), use your fitted model to determine the frequency. Enter the value in your data table. Compare this frequency to the frequency calculated earlier. Which would you expect to be more accurate? Why?
3. Compare the parameter A to the amplitude of the waveform.

Part II  Beats

1. How is the beat frequency that you measured related to the two individual frequencies? Compare your conclusion with information given in your textbook.

**Data Table**

Part I  Simple Waveforms

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Note | Number of cycles | Time of first max (s) | Time of last max (s) | Δt (s) | Period (s) | Calculated frequency (Hz) |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| Note | Peak (V) | Trough (V) | Amplitude (V) |
|  |  |  |  |
|  |  |  |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Note | Parameter A (V) | Parameter B (s–1) | Parameter C | Parameter D (V) | f = B/2π (Hz) |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

Part II  Beats

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Number of cycles | Time of first max (s) | Time of last max  (s) | Δt (s) | Beat (s) | Calculated beat frequency (Hz) |
|  |  |  |  |  |  |

Extensions

1. There are commercial products available called active noise cancellers, which consist of a set of headphones, microphones, and some electronics. Intended for wearing in noisy environments where the user must still be able to hear (for example, radio communications), the headphones reduce noise far beyond the simple acoustic isolation of the headphones. How might such a product work?
2. The trigonometric identity



is useful in modeling beats. Show how the beat frequency you measured above can be predicted using two sinusoidal waves of frequency f1 and f2, whose pressure variations are described by sin(2π f1 t) and sin(2π f2 t).

1. Most of the attention in beats is paid to the overall intensity pattern that we hear. Use the analysis tools to determine the frequency of the variation that lies inside the pattern (the one inside the envelope). How is this frequency related to the individual frequencies that generated the beats?
2. Examine the pattern you get when you play two adjacent notes on a keyboard. How does this change as the two notes played get further and further apart? How does it stay the same?