Properties of Sound

Goals and Introduction

Traveling waves can be split into two broad categories based on the direction the oscillations occur compared to the direction of the wave's velocity. Waves where the oscillations are perpendicular to the wave's velocity are called *transverse* waves, whereas waves with oscillations parallel to the wave's velocity are called *longitudinal* waves. Sound waves are longitudinal waves.

Though we cannot plot a longitudinal wave at a moment in time (like we can for the transverse wave), it is still true that this periodic object causes there to be oscillations as it travels from one location to another. The frequency (f) of these oscillations depends on the speed (v) of the wave, and the wavelength (λ), just as it would for a transverse wave.

$$v = f\lambda \qquad \text{(Eq. 1)}$$

The wavelength for a transverse wave can be thought of as the distance between the crests of the wave. Here, regions where the air molecules are very spread out at a particular moment can be thought of as being like the crests of the longitudinal wave, and the distance between these at any moment would be the wavelength.

Sounds that we hear are the result of the vibration of materials that push the air, creating a periodic oscillation of pressure and movement of air. We hear sound as our ear feels the oscillations of pressure and works to send the information from the environment to our brain. You might be interested to know that the mechanisms by which we interpret the pitch of a sound, for example, are very complex and not completely understood to this day (there are a few competing theories).

Most objects, when plucked or struck so that they vibrate, will create a sound wave that can be thought of as a combination of many sound waves, each with a different frequency and amplitude. There is no one pattern, or mathematical relationship uniting this entire set of frequencies. These can be called *complex objects*. Other objects, when set into vibration will also produce a sound wave that is made up of many frequencies, but unlike complex objects, there is a single underlying mathematical relationship between the frequencies. These can be called *harmonic objects*. Lastly, some objects will vibrate with only one frequency, when used properly. These can be called *simple objects*.

A useful mathematical tool for determining the frequencies present within a sound is Fourier Analysis. This technique is very useful for pattern recognition and is applied with the aide of computers in forensics, materials science, biology, chemistry, geology, and of course, physics. Here, it can be used to create a plot of frequencies present within a sound wave produced by a vibrating object and measure the comparative amplitude, or amount, of each component frequency.

An example of a simple object is the tuning fork. This device is designed to vibrate ideally at only one frequency, and has a number of uses – one being that it can certainly aide in the tuning of a musical instrument. When struck, the tines of the fork have a particular frequency with which they will vibrate back and forth, pushing air, and creating a sound wave.

There are many kinds of harmonic objects, each capable of producing a *harmonic set* of frequencies, in surprisingly different ways. One example is a tube that is open at both ends. When the tube is struck, the air inside the tube is set into oscillation, and sound waves travel back and forth across the tube, interfering with each other. At the ends of the tube, the air is allowed to vibrate back and forth as much as it wants, since there is no wall to prevent it from doing so. This means that the maximum and minimum of the sound wave's air movement are able to happen there. Given that the tube has a certain length, *L*, there are particular wavelengths of sound that would fit perfectly in the tube, actualizing these boundary conditions on both sides. The result of the interference of the sound waves traveling back and forth in the tube is a set of *harmonic wavelengths* given by the following formula:

$$\lambda_n = \frac{2L}{n} \qquad \text{where } n = 1, 2, 3, \ldots \qquad \text{(Eq. 2)}$$

An examination of each harmonic wavelength reveals *nodes*, places where the air doesn't move at all, and *antinodes*, places where the maximum oscillation of air can occur. Note that the ends of the open tube are both antinodes! Each of these harmonics is called a *standing wave mode of oscillation*, because in any particular mode, the locations of these nodes and antinodes are fixed. If you check another mode, it will have a different set of nodes and antinodes, but they too will remain at fixed locations.

Because the waves that make up these standing wave modes are traveling sound waves in air, they move with a speed equal to that of sound in air, and it is possible to determine a *harmonic frequency* for each standing wave mode of oscillation using the harmonic wavelength for that mode and $v = f\lambda$. The result is seen in Eq. 3, for a tube that is open at both ends.

$$f_n = \frac{nv}{2L} \qquad \text{where } n = 1, 2, 3, \ldots \qquad \text{(Eq. 3)}$$

The story for standing waves in the tube changes if we place a cap over one end. We have then changed the boundary condition on one end of the tube, where the cap prevents the air from moving. This means there is a node on the capped end now, and an antinode on the open end.

The result of the interference of the sound waves traveling back and forth in the tube is again a set of *harmonic wavelengths* but given by the following formula:

$\lambda_n = \frac{4L}{n}$ where $n = 1, 3, 5, \ldots$ (Eq. 4)

Again, because the waves that make up these standing wave modes are traveling sound waves in air, they move with a speed equal to that of sound in air, and it is possible to determine a *harmonic frequency* for each standing wave mode of oscillation using the harmonic wavelength for that mode and $v = f\lambda$. The result is seen in Eq. 5, for a tube that is open at both ends.

$f_n = \frac{nv}{4L}$ where $n = 1, 3, 5, \ldots$ (Eq. 5)

You may want to read more at Dr. Daniel Russell's website, where he illustrates many of these principles among other wave behaviors.
(http://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html)

In today's lab, you will experience and measure the sound produced by a tuning fork, a tube open at both ends, and a tube closed at one end and open at the other. This will be accomplished by describing what you hear, and by analyzing the frequencies present within the sound produced by each object. You will also experience the nodes and antinodes of a standing wave that is continually driven within a tube.

Goals: (1) Experience and describe effects of sounds from various sources
(2) Predict, measure, and quantify the frequencies present in a tube open at both ends
(3) Predict, measure, and quantify the frequencies present in a tube closed at one end

Procedure

Equipment – tuning fork, mallet, tube with removable cap, meter stick, Kundt's tube standing wave apparatus with listening tube, audio oscillator, microphone, computer with the DataLogger interface and LoggerPro software

1) Open LoggerPro by clicking on the **Tones** link on
http://feynman.bgsu.edu/physics/phys2020/index.html

2) You should see a split window where the top window will show you a graph of the relative pressure experienced by the microphone diaphragm as a function of time, while the bottom window will show you a plot of the Fourier transform of recorded sounds, plotting intensity

versus frequency. When you hit the green button, the microphone will record sound for a brief moment and then display the results.

3) Have one person hold the tuning fork at its base and strike it with the mallet near the center of one of the tines of the fork. After the fork is struck and vibrating, the other person should hold the microphone near the tine of the tuning fork and hit the green button on the screen, in order to record the sound. You should see a waveform that looks like a sine, or cosine, wave. If you do not, try repeating this process.

4) When you click on a graph and float the cursor over any location on the graph, you will see the coordinates of the cursor displayed in the corner of the graph window. Use the cursor to find the peak frequency, as shown in the Fourier transform (the bottom graph). **Record** the peak frequency, and make note of any other frequencies you see present.

5) Click on the top graph and **record** the time coordinates for two adjacent peaks in the waveform. This can be used later to calculate the period of the wave.

6) Look at the tuning fork and identify the accepted value of the frequency produced by the tuning fork. **Record** this value.

7) Now, **measure and record** the length of the colored tube. Be sure that both ends of the tube are open (remove the cap if necessary).

8) Have one person hold the tube and prepare to strike it with the mallet. The other person should hold the microphone near an open end of the tube and then hit the green button to record sound. As soon as the person hits record on the screen, the person holding the tube should strike it with the mallet to cause it to vibrate. Ideally, you should see a Fourier transform with several equally spaced peaks. When you feel you have accurately sampled the sound from the tube, **record** the frequencies that you observe in the Fourier transform.

NOTE: It may take several trials to get a good pattern. Be sure to strike the tube AFTER the person operating the computer has hit the green button to record. This will help ensure that you sample at a volume sufficient to stand above the ambient noise.

Question 1: Suppose that you used a different tube with a smaller length, and that the tube is still open at both ends. What would you expect to be different about the observed frequencies in the Fourier transform? Explain your answer.

9) Place the cap on one end of the colored tube. **Measure and record** the length of the tube with the cap on one end. Repeat the procedure in step 8, and **record** the frequencies that you observe in the Fourier transform.

10) Now, we will use the Kundt's tube to observe the existence of a standing wave pattern in a tube when it is driven at a particular frequency. The lab instructor will set the audio oscillator to produce a particular frequency. **Record** the value given to you by the instructor. Plug the electrical wire leads coming off the tube into the BLUE terminals on the wall of the lab station.

11) The listening tube will allow you to sample and listen to the wave created in the Kundt's tube, ideally without interfering with its vibration. Remember that the Kundt's apparatus is basically a tube that is closed at one end and open at the other. **Predict** what you will hear through the listening tube if you begin with the tube pushed all the way in and then slowly slide it along the length of the tube towards the other end.

12) Begin with the listening tube pushed all the way in and then slowly slide it along the length of the tube while listening to the loose end of the listening tube. **Describe** your observations.

Question 2: How would your observations change if the instructor doubled the input frequency for the Kundt's tube? Explain and describe what would be different, and why.

13) The loudest locations in the Kundt's tube represent the locations of antinodes, or maximum oscillation of air, in the standing wave pattern being created in the tube. The distance between two antinodes is half a wavelength of the standing wave patter. **Measure and record** the distance between two antinodes in the Kundt's tube apparatus.

As always, be sure to organize your data records for presentation in your lab report, using tables and labels where appropriate.

Data Analysis

Use the times you recorded in step 5 to find the period of the tuning fork's vibration. Then, use this to calculate a frequency for the vibration.

For the tube open at both ends, used in steps 7 and 8, use the length of the tube to determine the expected fundamental wavelength, and the next three harmonic wavelengths.

Examine the list of frequencies you recorded from step 8, for the tube open at both ends. Identify and label the fundamental frequency and each successive harmonic frequency that you observed.

Use the harmonic wavelength and the harmonic frequency to calculate a value for the speed of sound in air for the tube open at both ends. Repeat this process for each harmonic mode of oscillation for which you have both a frequency and a wavelength.

NOTE: While you have calculated four harmonic wavelengths in total, you may not have observed four peaks in the Fourier transform, and thus, may not have a frequency to pair with each wavelength.

Compute a mean value for these speeds.

For the tube open at one end and closed at the other, used in step 9, use the length of the tube to determine the expected fundamental wavelength, and the next three harmonic wavelengths.

Examine the list of frequencies you recorded from step 9, for the tube open at one end and closed at the other. Identify and label the fundamental frequency and each successive harmonic frequency that you observed.

Use the harmonic wavelength and the harmonic frequency to calculate a value for the speed of sound in air for the tube open at one end and closed at the other. Repeat this process for each harmonic mode of oscillation for which you have both a frequency and a wavelength.

Compute a mean value for these speeds.

Use the distance you found between antinodes in step 13 to calculate a wavelength for the standing wave mode in the Kundt's tube. Then, use the frequency from step 10 and this wavelength to calculate the speed of sound in air for the Kundt's tube.

Error Analysis

Compare the frequency you calculated from the period to that from the Fourier transform (step 4) by determining the percent difference between these two values.

$$\%diff = \frac{|f_1 - f_2|}{((f_1 + f_2)/2)} \times 100\%$$

Compare both the frequency from the Fourier transform of the tuning fork, and the frequency you calculated from the period of the tuning fork to the accepted value you recorded in step 6, by determining the percent error in each case.

$$\%error = \frac{|f_{experimental} - f_{accepted}|}{f_{accepted}} \times 100\%$$

Question 3: How well did the experimental values match the accepted frequency of the tuning fork? What aspects of the measurement process do you feel contributed most to the differences you have calculated here?

Calculate the percent difference between the mean values of the speed of sound in air that you found for the tube open at both ends and the tube open at one end and closed at the other.

Also, calculate the percent error with each of your mean values for speed and the accepted value for the speed of sound in air at standard temperature and pressure, 343 m/s.

Finally, calculate the percent error for the speed of sound you found in the Kundt's tube compared to the same standard, 343 m/s.

Question 4: Explain the results of these examinations of the speed of sound in air and the percent differences and errors you have calculated. How well did the experimental values of speed compare in each case? How well did they compare to the accepted value of the speed of sound in air? What might explain differences observed?

Questions and Conclusions

Be sure to address Questions 1 through 4 and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for "Properties of Sound," and submit it before the start of your lab section on the day this experiment is to be run.

PL-1) Sequoia measures the wavelength of the sound in a Kundt's tube to be 0.340 m. If the instructor tells her that the frequency driving the sound in the tube is 997 Hz, she will calculate a speed of sound in air of

A) 2930 m/s

B) 343 m/s

C) She cannot calculate this with the available data

D) 339 m/s

PL-2) When Sequoia measured the sound from the tube open at one end and closed at the other, she only observed three, equally-spaced, peaks in the Fourier transform window, and thus recorded three frequencies. What are the values of the harmonic number, n, that correspond to these three peaks?

A) n = 1, 2, and 3

B) n = 1, 3, and 5

C) n = 1, 2, and 4

D) n = 0, 1, and 2

PL-3) When Sequoia measured the sound from the tube open at one end and closed at the other, she only observed three, equally-spaced, peaks in the Fourier transform window, and thus recorded three frequencies (150 Hz, 450 Hz, and 750 Hz). If the length of the tube was 0.55 m, what would be the speed of sound that she would calculate using the fundamental frequency she measured?

A) 273 m/s

B) 330 m/s

C) 165 m/s

D) 343 m/s

PL-4) When Sequoia measured the sound from the tube open at both ends, she only observed three, equally-spaced, peaks in the Fourier transform window, and thus recorded three frequencies (150 Hz, 450 Hz, and 750 Hz). If the length of the tube was 1.10 m, what would be the speed of sound that she would calculate using the fundamental frequency she measured?

A) 273 m/s

B) 330 m/s

C) 165 m/s

D) 343 m/s

PL-5) When Sequoia measured the sound from the tube open at both ends, the Fourier transform plot looked very noisy and had a lot of peaks spread out all over the graph window. She should,

A) just pick some of the peaks and move on with the next part of the lab.

B) look over at another group’s data and just copy down the peaks they found for their tube.

C) be sure she is striking the tube before her lab partner hits record, and try again.

D) be sure she is striking the tube after her lab partner hits record, and try again.