

## **Physics 3, Summer 03**

### **Lab 6 - Sound Waves**

#### Theory

Energy can be transported from one point in space to another by two means: by particles (such as a baseball traveling from a bat to a neighbor's window) or by waves (such as electromagnetic waves which are our radio and television signals). Suppose you were concerned about the speed with which sound can transport energy. How could you measure this speed?

If we don't concern ourselves with the nature of sound, we might set up this simple procedure. Develop a device that will emit a short pulse of sound, a device that will receive the sound and a device that can measure the time between when the sound leaves the first device and when it is received by the second device. Place the device that emits the sound a known distance from the device that receives the sound. Measure the time it takes the sound to travel the known distance and then divide the distance by the time to get the speed.

Theoretically, this sounds very simple and straight forward. However, things that are theoretically simple may be experimentally difficult. When this is the case, there are basically two ways to approach the problem. One method is to use an indirect approach in which we measure other more easily measurable quantities from which we can then calculate the quantity we are really interested in. The second method is to develop sophisticated instrumentation with which we can more directly measure the appropriate quantity. In this lab, we will use the second method. Throughout the laboratory concentrate on what these instruments do and how to use them rather than on how they work. We will consider these instruments as black boxes which do things for us without ever knowing how they do it. (This is like the relationship between the average person and his television set. He knows how to use the TV and what it does for him, but not how it works. Indeed, he doesn't need to know.)

We will measure the speed of sound in air in two ways. The first method is essentially that which was described in paragraph two. The second method makes use of the fact that sound is a wave phenomenon and as such we need only measure the wavelength and the frequency of the sound to calculate the speed.

#### Method 1

This is the method described in paragraph two. The experimental apparatus is shown in figure 1.

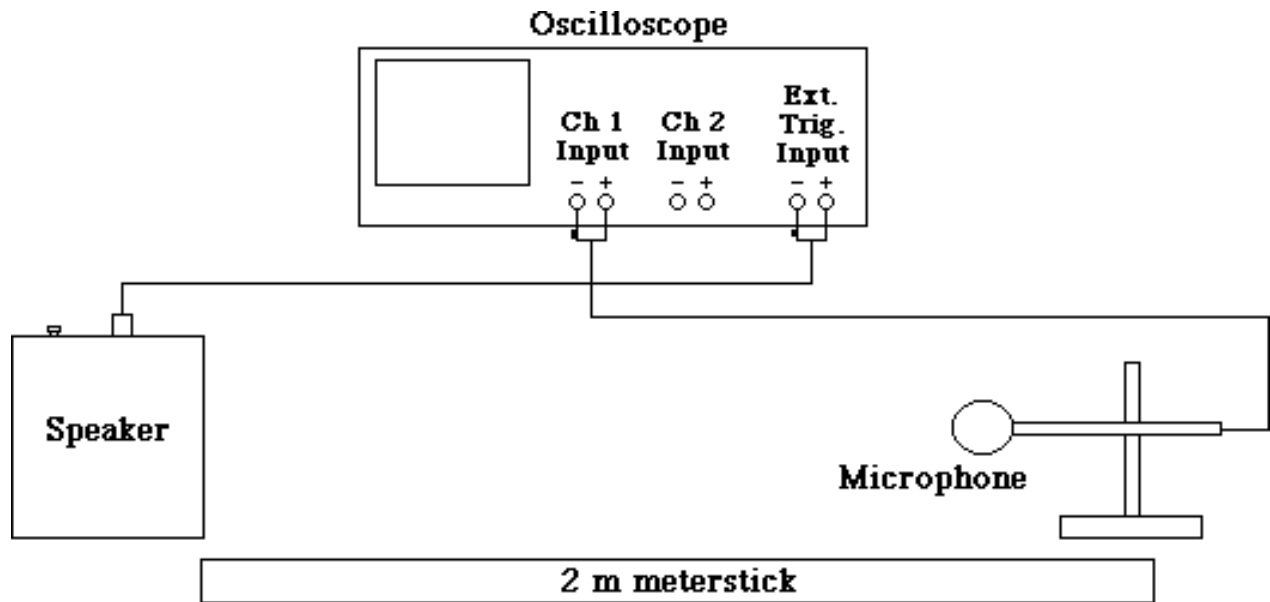


Figure 1

On the top of the speaker box there is a red button switch which is connected to the speaker inside the box and to the external trigger on the oscilloscope. When it is pushed, a capacitor is discharged through the speaker creating a sharp pulse of sound and simultaneously the horizontal trace on the scope is started (triggered). The sound that radiates outward from the speaker is picked up at a later time by a microphone which has been placed a known distance away from the speaker. The microphone changes the sound into electrical impulses which are fed into the vertical input (channel 2) of the oscilloscope and displayed on its screen (see figure 2). Since we know the horizontal trace

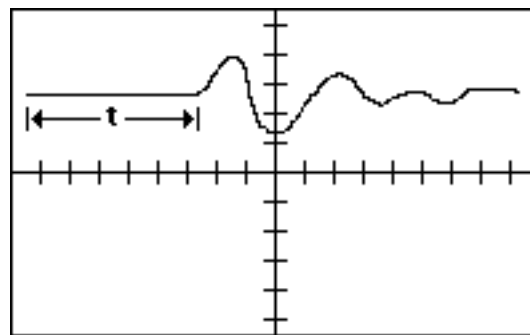


Figure 2

started when the pulse left the speaker, the time it took the pulse to reach the microphone is represented by the flat portion of the display. Using the calibrated time base of the scope, the time can be determined; and from that and the known distance, the speed of sound in open air can be (figure 2) calculated.

## Method 2

In this method the wave nature of sound is used to measure its speed in air in a tube. To calculate the speed of any wave, we need to know its frequency and its wavelength. The product of these two parameters gives us the speed of the wave,  $v = \lambda f$ . The experimental apparatus is shown in figure 3.

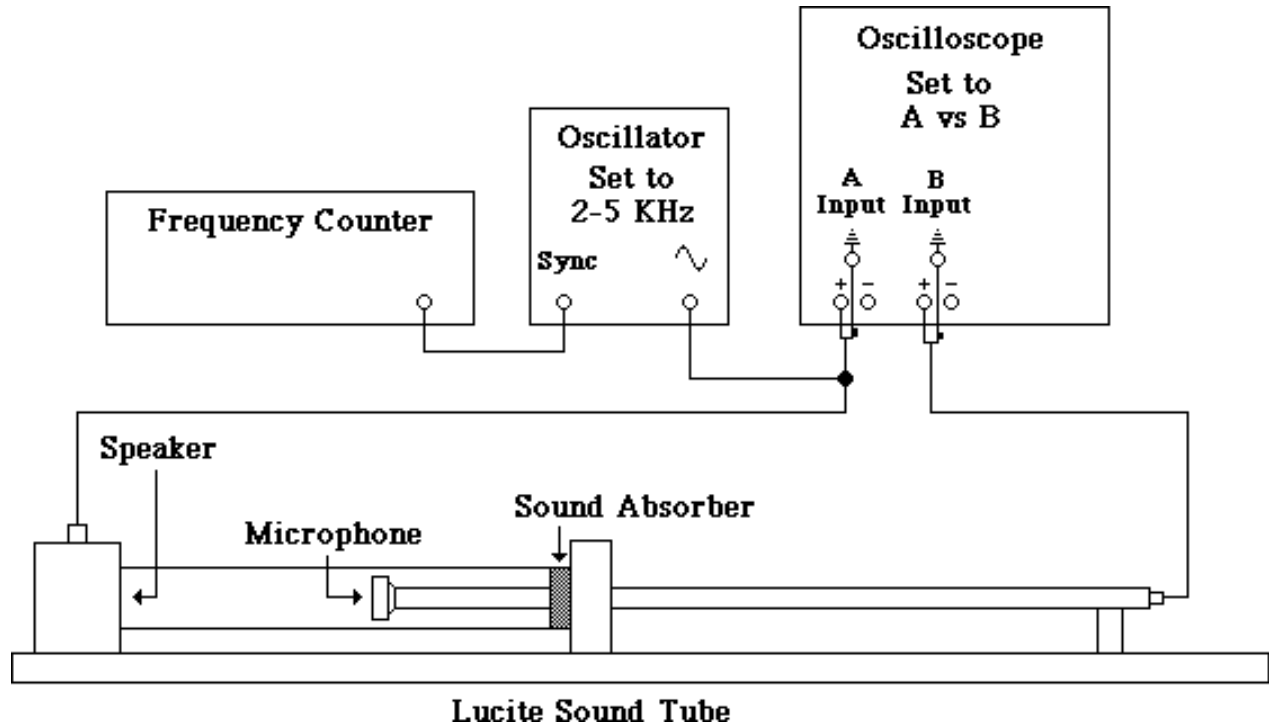


Figure 3

A small speaker is mounted at one end of a Lucite tube which is about 2.5 inches in diameter and about 4 feet long. A sinusoidal electronic signal is fed from an oscillator to the speaker producing longitudinal sound waves which travel along the tube and are almost completely absorbed by a layer of surgical cotton at the far end. A microphone fastened to one end of a smaller aluminum tube can be moved along the axis of the larger tube.

The alternating voltage that drives the speaker is also connected across the horizontal input of the oscilloscope so that the horizontal motion of the oscilloscope beam corresponds to the oscillations of the sound waves at the position of the speaker. The output of the microphone is connected across the vertical input of the scope so that the vertical motion of the oscilloscope beam corresponds to the oscillations of the sound waves at the position of the microphone.

The oscilloscope beam traces out a graph of y-input vs. x-input known as a Lissajous figure. The shape of the Lissajous figure depends on the relative amplitudes, frequencies and phase of the two signals. In this case the oscillations necessarily have the same frequency since they both derive from the same source; and the oscilloscope controls can be adjusted so the oscillations have the same amplitude on the display. The shape of the resulting Lissajous figures then depends solely on



## Experimental Purpose

The purpose of this lab is to measure the speed of sound in air by the two methods described above.

## Procedure

1. Familiarize yourself with the two modes of operation of the oscilloscope: y-input vs. t and y-input vs. x-input.
  - a. Apply a sinusoidal voltage signal from a small transformer to channel 1. With the oscilloscope set to channel 1, obtain a clear display on the scope. Observe what happens to the display when you change amplification and time scales. Using the calibrated time-base scale (the divisions in the horizontal direction), measure the frequency of the displayed wave. It should be 60 Hz (cycles per second).
  - b. Turn the oscilloscope to the x-y display mode. With the transformer still input to channel 1, input a sine wave from the oscillator into channel 2. Turn the oscillator to about 60 Hz and try to obtain a stable pattern. (What must be true to obtain a stable pattern). With the display as stable as you can get it, vary the amplitude of the signal from the oscillator. Observe what happens to the display. Vary the frequency of the signal from the oscillator from 0-200 Hz. Observe what happens to the display. For a more complete description of the operation of an oscilloscope see Appendix IV.
2. Observe the wave form of some actual sounds. Connect a microphone to channel 1 and display several voice vowels at various gain settings and time base settings. Note the similarity of waveform for the same vowel with different speakers. Determine which vowels can be held as a sustained sound without a change in waveform.
3. Measure the speed of sound in open air by method 1. Use several distances and plot the time of the pulse as a function of distance. From the graph, the velocity of sound in air can be calculated. Compute the percent deviation from the theoretical value of the speed of sound. The theoretical value is temperature dependent and is given by

$$v_{\text{theo}} = 332 \text{ m/sec} + (.61 \text{ m/sec-C}^{\circ})T$$

where T is the temperature in centigrade degrees.

4. Measure the speed of sound in the Lucite tube by method 2 for three frequencies between 2 and 5 KHz. When measuring a position where the x and y inputs are in phase, you will find that measurement of that same position another time will not yield the same result. In other words

if by looking at the scope you determine a position where the x and y inputs are in phase, moving the microphone slightly and remeasurement of that same position will not yield the same result. There is a certain amount of uncertainty introduced by the equipment used. Make four readings of one position and use the average of those four readings in the calculation of the wavelength. The four readings can also be used to estimate the

Accuracy is improved if instead of measuring the distance between successive "in phase" positions you measure the distance between the first "in phase" position and the last microphone away from the speaker counting the number of "in phase" positions you pass along the way. When you get to the last measurable "in phase" position measure that position. To calculate the wavelength, subtract the scale reading of the last "in phase" position from the scale reading of the first "in phase" position and then divide by the number of "in phase" positions passed through in going from the first position to the last. Compare the measured values with the theoretical value.

### Lab Report

Your analysis should contain the following:

1. Data table for method 1 - distance from speaker to microphone vs. time of arrival.
2. Graph of the data for method 1 and calculation from that graph of the speed of sound in open air.
3. Data table for method 2 containing four measurements of each in phase position and the average of those four readings. Indicate the pairs of data used to calculate the wavelengths. Indicate how the wavelengths were calculated.
4. Data table for method 2 - wavelength vs. frequency. Include in your table the calculation of the speed of sound for each pair.
5. Comparison of the results of method 1 and method 2. Discuss any discrepancies you find.
6. Comparison of experimental and theoretical values for the speed of sound. Discuss any discrepancies you find.