SND-VEL

Velocity of Sound in Air

revised June 2, 2006

(PHYS 115 and PHYS 121 students perform this experiment as well as the Standing Waves on a String Experiment. PHYS 123 students will perform the Chaos experiment)

Learning Objectives:

During this lab, you will

1. estimate the uncertainty in a quantity that is calculated from quantities that are uncertain.
2. test a physical law experimentally.

A. Introduction

The velocity of sound in air can be measured by two very different methods; you can make a direct measurement by measuring the time Δt it takes a sound pulse to travel a known distance ΔL (so $v=\Delta L/\Delta t$), or you can measure the wavelength λ of sound of a known frequency f and determine the velocity from the expression $v = f\lambda$.

You will measure the speed of sound using the first method, using an apparatus illustrated in Figure 1. It involves a microphone, a tube which is closed at one end, and a sound source which produces a short pulse. If you make a click at one end of the tube, a microphone near that end will pick up the initial sound pulse as well as its echo from the far end. A computer will record and time the pulses.

You will not write a paper for this lab.

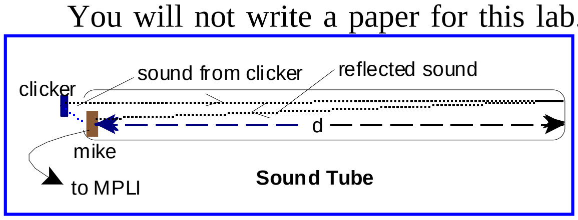

Figure 1: Sound Tube and Clicker

Rather, you should fill out a worksheet for this and for the accompanying lab on standing waves and turn both in before you leave. Each lab experiment is set up at a different station; you will switch between the stations halfway through the lab period.

B. Apparatus

The apparatus consists of a sound source, a microphone and a sound tube with a reflector. Measurements will be recorded using a computer running *Logger Pro.*

C. Theory

The frequency of a simple oscillator is proportional to the square root of the elastic (*spring*) constant over the inertial constant (*mass*), or

$$\omega = \sqrt{k/m} \qquad (1)$$

The propagation of a wave in a medium such as water or air can be modeled as a signal passing along a line of coupled oscillators, each oscillating with frequencies defined in a way analogous to Equation 1. In this model, the velocity of a sound wave is related to the square root of the ratio of the elastic property of the medium to its inertial property.

For a sound wave in air, the useful elastic property is the bulk modulus B. The bulk modulus characterizes the compressibility of air and is given by

$$B = -\frac{\Delta P}{\Delta V/V} \qquad (2)$$

where $\Delta V/V$ is the fractional change in the volume of the gas that occurs for a pressure change ΔP.

The inertial property of air is the density ρ, so that the velocity of sound in air is given by

$$v = \sqrt{B/\rho} \qquad (3)$$

The density of air is a function of temperature, barometric pressure and moisture content. The CRC Handbook of Chemistry and Physics (54^{th} edition) lists a value for dry air at 20º C and 760 Torr of 0.001205 grams per milliliter.

D. Procedure

You need to produce a burst of sound that is very short compared to the time it takes the sound to travel the length of the tube and return to the microphone. It's not hard to estimate this time. You might know that you can measure the distance to a lightning strike by counting out the seconds between the flash of light and the resulting clap of thunder. Multiplying this time by the velocity of sound gives you the distance. For those of us raised in backwards countries using Neanderthal units, $v \approx 1000$ ft/sec. A glance at the sound tube tells us that the traverse time for today's experiment is on the order of 10 msec or 1/100 of a second. This means that you must produce a sound that lasts for a fraction of this interval, perhaps a few msec. This can be done with a variety of methods, including a sharp snap of the fingers or knocking of two metal balls. You may need to experiment a bit to find a technique that works for you, given some of the materials that are provided.

Start by setting up your microphone just outside one end of your sound tube. Measure the distance d from the microphone element to the reflecting end of the tube and estimate the uncertainty in your measurement.

Start the *Logger Pro* program and load the file *P:Logger Pro 3__Mech Labs\ SND_VEL*. Experiment collecting data using various sound sources until you find one that produces nice, sharp pulses. Make sure the room is quiet while you are taking data so that outside noises do not interfere. If your neighbor is talking too loudly, hit him. Practice until you can produce clear signals similar to those in Figure 2.

When you look at the graph of voltage versus time, you should notice

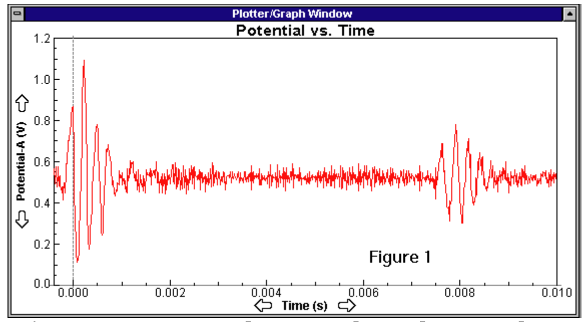

Figure 2: Initial Sound Pulse and its Reflection

1) a large voltage oscillation corresponding to the initial sound;
2) a period of relative quiet;
3) a smaller-amplitude echo.

The echo usually has a smaller amplitude than the original waveform, but it could be as large or larger than the original depending on where you produce the sound. Note that the microphones overload slightly above 3 volts, so you should produce waveforms with amplitudes below this value in order to distinguish features on the plot. You may decrease the amplitude of your waveform simply by moving the sound source further away from the opening of the tube.

Use the *Logger Pro* cursor to measure the time from a particular spike on the initial signal to the corresponding spike on the reflected pulse. (*Click on ANALYZE → EXAMINE to call up a box that will read out the position of the mouse as you move it along the plot.*) Estimate the uncertainty in your time measurement. Explain the basis for your estimate in your notebook.

Perform the experiment at least 10 times, recording the transit times after each run. Print out one of your plots and staple it to your worksheet.

E. Analysis

Calculate the speed of sound from each of your transit-time measurements. Calculate the mean velocity of sound <v>, its standard deviation and standard error. If your calculator does not include statistical functions, you may use an *Origin* worksheet to perform these calculations, or do them '*by hand*' using the formulae in the appendices.

For one typical run, calculate the uncertainty in your measurement of v from the uncertainty in the distance between the active element of the microphone and the end of the tube, and from the estimated uncertainty in your determination of the transit time. This latter uncertainty should be based on your ability to read the *Logger Pro* plot; you may assume that the timing circuits and software contribute negligibly to any error. Find the total uncertainty in v and compare this "external error" to the measurements of the "internal error" (the standard deviation and the standard error). Do the results agree as expected?

Apply Equation 3 to calculate the bulk modulus B of air from $\langle v \rangle$ and the density of air ρ. Calculate the uncertainty in B.

If you finish early, feel free to experiment with different sound sources such as clapping hands, whistling etc. The speed of sound should be the same but the shape of the waveform will be quite different.

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