Lab # 7A
Speeds of Mechanical Waves in Various Media
(Exit Interview)

In this lab we will carry out measurements of the speed of sound in air using three different methods: (1) the resonance column apparatus, (2) the propagation of ultrasonic waves in air, and (3) measuring the time-of-flight of pulses of sound waves. (Recall that the speed of sound in air is about 331 m/s at 0^oC. However, our measurements will be sufficiently precise that you will need to take into account the temperature dependence of the speed of sound in air.) We will also use the dust tube apparatus due to Kundt to measure the speed of sound in a thin aluminum rod. We will study the patterns of vibration of strings under tension.

I. Resonance Column Apparatus

In this experiment we excite a length of air column to resonate with a tuning fork of known frequency. The length of the air column is simply related to the wavelength of sound waves in air. The basic relationship among frequency, wavelength, and speed for a wave is $v = f\lambda$. Thus the speed can be calculated.

The apparatus depicted in the figure below consists of a long plastic tube partially filled with water, connected at the bottom via a flexible rubber hose to a plastic reservoir of water. By raising and lowering the reservoir, the length of the column of air can be adjusted.

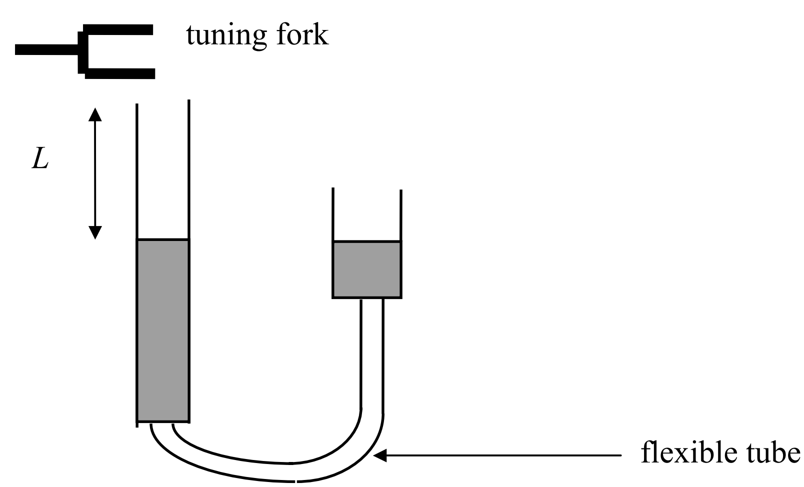
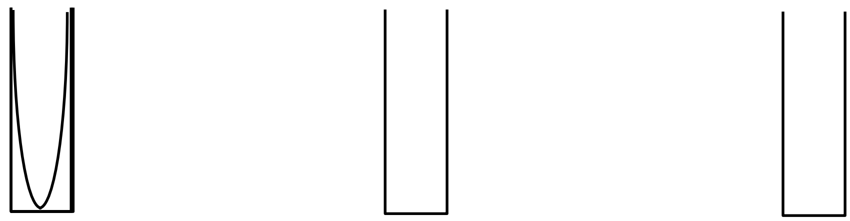


Figure 1. Resonance Column Apparatus

By striking a tuning fork of known frequency on a rubber mallet and placing it close to, but not touching, the mouth of the plastic tube, we can set up forced vibrations of the air in the tube. But we note that the air column supports natural vibrations, in the form of standing waves of wavelength (and hence frequency) characteristic of the length of the column. The boundary conditions are such that one always gets a displacement node (a point of zero disturbance in the medium sustaining the wave) at the air-water interface and an antinode (a point of maximum wave disturbance) very near the mouth of the tube. The three lowest frequency modes for an air column of a given length are pictured below. The distance of the curved lines from the center indicates the displacement amplitude.



Fundamental $\lambda_0 = 4L$

First Overtone $\lambda_0 = \frac{4}{3}L$

Second Overtone $\lambda_0 = \frac{4}{5}L$

As we adjust the length of the air column with a tuning fork of a given frequency exciting the column, we should approach lengths where either the fundamental for that length or one of the harmonics will equal the frequency of the tuning fork. At these lengths, the amplitude of the forced vibrations reaches a sharp peak, and one hears a loud response. By listening for maximum loudness, we can measure the lengths of air columns whose fundamental or one of the harmonics are in resonance with each of several tuning forks.

NOTE: The fact that we can hear the resonance vibrations of the air in the tube tells us that we do not get a perfect reflection at the open end. The fact that some small amount of the energy incident on the open end escapes from the tube produces a very small correction to the wave-length of the standing waves. It can be shown that (See *Theory of Sound*, J.W.S. Rayleigh, Vol. II, Dover Reprint, page 181)

$$\lambda_n \approx \frac{4}{(2n+1)}(L + 0.4d)$$

where d is the inner diameter of the tube, and L is the length of the air column.

In your lab notebook, discuss whether or not this correction is important (in light of experimental uncertainty) in your determination of the velocity of sound in air.

II. Ultrasonic Waves

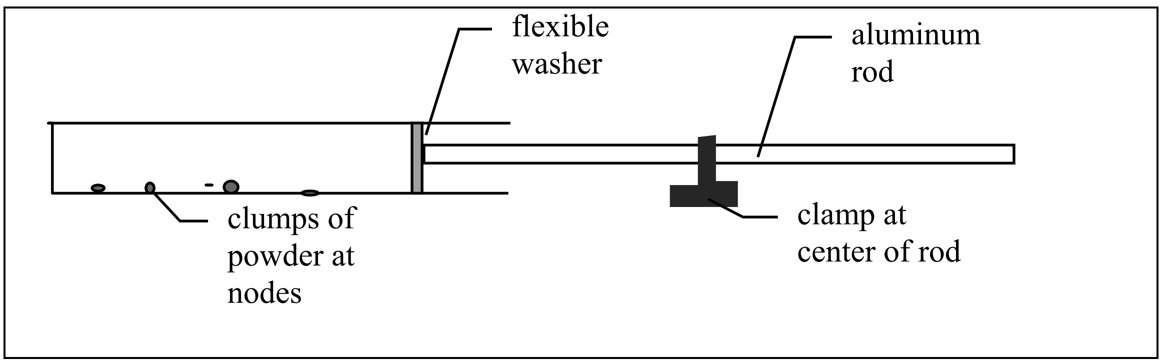
Ultrasonic waves are sound waves of very high frequency. We would like to find out how the speed of sound in air changes with frequency. The source and detector are a matched pair of ultrasonic sound wave generators of fixed frequency. The source is powered by a function generator and the detector is connected to an oscilloscope. Initially, place the detector flush against the source. Turn on the function generator and the scope and adjust the function generator frequency to about 14 kHz. Then as you move the detector slowly away, you should see a succession of nodes and antinodes. Measure the distance for 10 - 15 nodes. Calculate the wavelength. Measure the frequency on the scope or using a frequency meter. Calculate the speed of very high frequency sound in air. Compare the speed you find here with the result of Part I.

III. Time-of-flight of Sound Waves in Air

In this experiment you will produce a pulse of sound waves by clapping your hands. A microphone placed close to your hands receives the sound relatively quickly. Another microphone located some distance away "hears" the sound a bit later. We will use a digital oscilloscope to record the two pulses. The oscilloscope trace allows us to measure the time-of-flight of the sound pulse to determine the speed of sound. NOTE: You may need to adjust the trigger level on the 'scope to record the signals properly. Be sure to estimate an experimental uncertainty in your measured value of the speed.

IV. Kundt's Dust Tube Experiment

The apparatus consists of a glass tube held horizontally on the table. One end of the glass tube is closed with a cork; the other end is open. An aluminum rod clamped in the middle, has a shellac or leather disc attached at the other end, so that the disc fits comfortably in the glass tube as shown in the figure.



Initially a thin layer of lycopodium powder is spread at the bottom of the glass tube. Then the free half of the aluminum rod is stroked by a piece of leather roughened with rosin. This sets up longitudinal vibrations in the aluminum rod with a node at the center and antinodes at the ends. The sound waves of this frequency then propagate in the air column in the glass tube. If the length of the tube is just right then standing waves of this frequency are set up in the tube. When the glass tube is gently rotated and moved back and forth to get its length just right, the lycopodium powder collects gradually at the nodes of the wave in the air and moves away from the antinodes. Thus you can obtain the wavelength in air directly. Since you have determined the speed of sound in air earlier, you can compute the frequency of this note. Since the wavelength in aluminum for this note is determined by the length of the rod, you have a means of calculating the speed of sound in aluminum.

CAUTION: The hard part in this experiment is the setting up of longitudinal waves in the rod. Use plenty of rosin. Make sure the rod is firmly clamped. Stroke the rod firmly and smoothly. If you are doing this part right, the sound emitted should be an annoying, high-pitched squeal. If you can produce seven or eight such squeals that should be enough to clump the powder at the nodes. Try your best.

V. Vibrating String:

We will have set up several sonometers, devices for producing vibrations in a wires under tension. One of them has a steel wire driven electromagnetically. Measure the frequency of vibration for several values of the tension. Calculate the speed of the waves and hence the mass per unit length of the wire. If you are musical, you could adjust the pitch of the wire to exactly that of one of the tuning forks (listen for beats) and thereby determine the frequency. The other sonometer has bridges with which you can select the length of the string set in vibration.

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