INTRODUCTION

Sound is a pressure wave in air. When we hear a sound, we are sensing a small variation in the pressure of the air near our ear. The speed of a sound wave in air is about 340 m/s or about 5 seconds to travel one mile, and this speed depends only on the properties of the air (temperature, composition, etc.) and not on the frequency or wavelength or amplitude of the wave.

Consider a sinusoidal sound wave in air with frequency $f$ and wavelength $\lambda$. The speed $v$ is related to $f$ and $\lambda$ by

\begin{equation}
    v = f \lambda.
\end{equation}

To see where this relation comes from, think:

\[
\text{speed} = \frac{\text{change in distance}}{\text{change in time}}
\]

The time it takes for one wavelength of the sound to go by is the period $T$, so $v = \lambda/T$. But $f = \frac{1}{T}$ so $v = \lambda f$. Note that as $f$ increases, $\lambda$ decreases, but the speed $v$ stays the same. The frequency range of human hearing is about 20 Hz to 20,000 Hz. (The upper end drops as we age; for people over 60, it is about 12 kHz, while dogs can hear up to about 35 kHz.)

In this experiment, we will be studying standing waves, which should not be confused with traveling waves. A traveling sinusoidal wave can be thought of as a sine (or cosine) curve that is rigidly moving to the right or to the left. The figure below shows a right-going traveling wave at two different times. The solid line is the wave at an earlier time; the dashed curve is the wave at a slightly later time.

A standing wave occurs when two travelling waves of the same wavelength $\lambda$, the same frequency $f$, and the same amplitude $A$, but moving in opposite directions, pass through each other. The two traveling waves interfere, producing a standing wave which oscillates between large amplitude (when the two waves are in phase) and zero amplitude (when the waves are out of phase).
One way to produce two travelling waves of identical $\lambda$, $f$, and $A$, but moving in opposite directions, is to generate a travelling wave that reflects from a surface. The reflection, or echo, then combines with the original wave to produce a standing wave. The figure below shows a standing wave produced on a taut string which has its right end attached to a wall. (The amplitude of the string wave is greatly exaggerated for clarity.) The figure shows snapshots of the standing wave at two different times; the solid curve is the wave at an instant when it has maximum amplitude; the dashed curve is the wave at an instant one half-period later. The standing wave oscillates between these two extremes. Points along the standing wave where the amplitude of motion is zero are called nodes; between the nodes are antinodes where the amplitude of the motion is a maximum. Notice that the nodes are one-half wavelength ($\lambda/2$) apart.

A sound wave in air can produce a standing wave in a tube. In this experiment, a sinusoidal sound wave of variable frequency is generated by a speaker at one end of a tube. The sound wave bounces from the other, closed, end of the tube. When the length $L$ of the tube is equal to an integer number of half-wavelengths, that is when $L = N (\lambda/2)$, then the tube is said to resonate, and a large amplitude standing wave forms in the tube. A movable microphone inside the tube allows us to measure the sound intensity in the tube and see where the nodes and antinodes are occurring.
The figure above showing standing waves on a taut string is a plot of the displacement \( y \) as function of position \( x \) along the string. In our experiment, however, the microphone does not sense the displacement of the air; it senses the pressure of the air. So the oscilloscope will show you where pressure nodes and antinodes are occurring. It turns out that pressure nodes occur at displacement antinodes and pressures antinodes occur at displacements nodes. This point is further explained in the Appendix. When a standing sound wave occurs in a tube with a closed end, there is a displacement node and a pressure antinode at the closed end. The displacement at the closed end of the tube must be zero, otherwise a vacuum would form there.

In this experiment, you will measure the speed of sound. You will adjust the frequency \( f \) of the sound wave and the length \( L \) of the tube until resonance occurs, and then, at resonance, you will measure the distance between nodes in the standing wave. This provides a measurement of the wavelength \( \lambda \) of the wave. Knowing the frequency \( f \) of the wave, you can compute the speed of sound from \( v = \lambda f \).

The speaker is driven by a signal generator which produces a sinusoidal voltage of adjustable frequency and amplitude. Note that there are both coarse and fine adjust knobs for the frequency.

The microphone is hooked to an oscilloscope, which is a device that displays a graph of voltage vs. time, with voltage on the vertical axis and time on the horizontal axis. Your TA will introduce you to the use of the oscilloscope. If the voltage is DC, that is, constant in time, then the oscilloscope displays is a horizontal line. If the voltage is AC, that is, sinusoidal, then the oscilloscope will display a sinusoidal wave. The oscilloscope screen has 1 cm divisions on both axes. There is a volts per division (volts/div) knob, which sets the vertical (volts) scale and a seconds per division (sec/div)
knob which sets the horizontal (time) scale. There are also knobs for setting the vertical and horizontal position of the display. There is a small knob in the center of both the volts/div and time/div knobs, called the CAL or calibration knob. This should always be in the fully CW position in order for the volt/div and sec/div scale settings to be correct. Under the volts/div knob is a 3-position switch which reads (AC - ground - DC). This should always be in the DC position.

Experimental Procedure

Before starting, make sure that the two small holes in the top of the tube are covered with the sliding clips.

Begin by familiarizing yourself with the equipment. The only way to do this is to play with the knobs and see what happens. Turn on the oscilloscope, the frequency generator, and the microphone. On the oscilloscope, turn the volts/div and sec/div knobs to see the effect on the display. Adjust the frequency and watch the signal from the microphone on the oscilloscope. Look for a maximum in the signal (resonance) when you move the piston end in or out or when you vary the frequency. If you listen carefully, you can hear when resonance is occurring; the sound from your tube will become louder (this might be difficult with several speakers on in the room). After adjusting the length and frequency for a maximum signal, move the microphone around in the tube and look for nodes and antinodes. (What can you do to make the total number of nodes in the tube larger or smaller?) Play!

Part I. Finding the nodes with fixed L and f.

In this part, we will fix the length L and the frequency f at some resonance and then measure the positions of the nodes. At resonance, the signal on the oscilloscope screen will be a maximum. Adjust the piston so that the length L is large, and then fix the piston position with the clamp. With the microphone against the piston, set the frequency at a resonance so that there are several nodes (somewhere in the range 1500 to 2500 Hz). Record the frequency f of the signal. Now slowly move the microphone from the piston...
end to the speaker end of the tube, while looking for nodes (signal minima) and antinodes (maxima) on the oscilloscope screen. Using the meter scale in the tube, record the microphone position $x$ of every node. Compute the distance $\Delta x$ between each adjacent pair of nodes, and then compute the average measured distance between adjacent nodes. Compute the wavelength using $\Delta x = \lambda / 2$. Finally, from the known $f$, and your measured $\lambda$, compute $v$, the speed of sound.

Repeat this procedure with a different frequency $f$ (but still keeping $f$ in the range 1500-2500 Hz). This time, just record the positions of the rightmost and leftmost nodes and observe how many nodes occur between these two extreme positions. From these measurements, you can quickly get an accurate measurement of $\lambda / 2$, by dividing the total distance $D$ by the number $N$ of half-wavelengths as indicated in the figure below. Recompute the speed of sound with your new wavelength.

![Diagram showing $D = N \lambda / 2$ and $\lambda / 2 = D / N$.]

**Part II. Fix $f$ and vary $L$.**

Here we will fix $f$ and vary $L$ to find the resonant positions. Set the frequency somewhere in the range 1500-2500 Hz (but different than the $f$’s used in Part I). Start with the piston pulled all the way out (maximum $L$) and the microphone positioned against the piston. Slowly push the piston in, decreasing $L$, while keeping the mike against the piston. Record the positions $x$ of the piston at which resonance occurs. Compute the distance $\Delta x$ between each adjacent pair of resonant positions, and verify that resonances occur at regularly spaced intervals according to $L = n (\lambda / 2)$, where $n$ = some integer. Quickly compute a best value of $\Delta x$ by dividing the total change in $L$, $\Delta L$, by the number $N$ of resonant intervals, $\Delta x = \Delta L / N$. Obtain the wavelength using $\Delta x = \lambda / 2$. Again, compute $v$, the speed of sound.

**Part III. Compare Theory and Experiment.**

Compare your three values of the computed speed of sound obtained in Parts I and II with each other and with the known speed of sound, which is given by the formula

$$v_{\text{sound}} = 331.5 \text{m/s} + 0.607T$$

where $T$ is the temperature in degrees Centigrade. There will be a thermometer in the room for you to check the air temperature.

When finished, please remember to turn off the microphone (or the battery dies).
Appendix  Pressure waves vs. Displacement waves

When a sinusoidal sound wave passes through air, the air molecules are displaced from their original positions. The displacements of the air molecules at an instant in time are shown by the arrows in the figure below and by the dashed line in the bottom graph. Note that displacement to the right corresponds to a positive displacement on the graph, and displacement to the left is negative on the graph. Because of the sinusoidal displacement, there is a sinusoidal density and pressure variation. [Where density is high, pressure must be high, since \( p = (N/V)kT \); that is, pressure \( p \) is proportional to density \( N/V \), according to the ideal gas law.] The solid curve on the graph is a plot of the pressure vs. position. Note that the pressure peaks where the displacement is zero. Displacement nodes corresponds to pressure antinodes, and vice-versa.
1. The frequency of a sound wave is doubled. What happens to the speed of the sound wave?

2. What is the difference between a travelling wave and a standing wave?

3. In general, what is displayed on the screen of an oscilloscope?

4. In the figure at the end of Part I, how many nodes are there in the tube?

5. At room temperature (T = 20 C), what is the wavelength of a sinusoidal sound wave of frequency f=1000Hz?

6. Dry lab.