

**Experiment 13**

**Sound Resonance In Air Columns**

In this experiment you set up resonant standing wave vibrations in an air column. A speaker emitting sound at a fixed frequency is placed near the air column and the column length is adjusted. Standing waves are set up in the air, analogous to the standing waves in a stretched string. One result of the lab is a determination of the speed of sound in air.

**Preliminaries.**

This experiment investigates the resonance conditions of a simple system consisting of a column of air closed at one end and driven at the other by an external speaker.

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![Figure 1. Schematic for Standing Sound Waves](image)

Any vibrating object that can compress and rarify a gas can produce traveling sound waves in that gas. These waves are **longitudinal** waves, where the transporting medium oscillates in the same direction as the wave velocity (i.e. molecular motion is parallel to the direction of wave energy flow). In this experiment, a speaker sends traveling waves from the open end down a column of gas (air). See Figure 1. If the length of the column is adjusted properly by moving the adjusting sleeve, a loud sound characteristic of a standing wave is heard.

The standing wave pattern is fixed in space, as shown in Figure 2. The planes in the tube where, on average, there is no net molecular motion are the displacement nodal planes or simply displacement **nodes**, while the points where molecules undergo maximum oscillation about their equilibrium positions are called displacement **antinodes**.

➤ **Note:**

The **displacement** designation is to specify that the wave being considered is parameterized by molecular displacement from equilibrium. It is also common in the study of sound waves to consider **pressure** waves, which are related to the density of gas molecules. The nodes of the pressure waves...
wave correspond to the antinodes of the displacement wave, and vice versa.

![Figure 2. Example of a Standing Wave Pattern](image)

Since gas molecules are not free to longitudinally oscillate at the surface of the plug, any standing wave produced in the tube must have a node at the plug surface, as shown in Figure 3. Although the antinodes are found one quarter of a wavelength from the nodes, they are not simply related to the physical properties of the tube. There is an antinode close to the physical open-end of the tube. The distance between the antinode and the physical open tube end is the **end correction**, labeled $\delta$ in Figure 3. $\delta$ is positive if the antinode is outside the tube, as shown.

![Figure 3. The Standing Wave in the Tube](image)

Adjustment of the position of the plug in order to produce a loud sound characteristic of a standing wave determines the node positions, allowing the wavelength $\lambda$ of the sound wave to be determined. The frequency $f$ of the wave from the speaker (source) can then be used to calculate the speed of sound $v$ in the gas according to

$$v = f\lambda \quad \text{(eq. 1)}$$

There is also a theoretical expression for the speed of sound in air, based on the kinetic theory of gases. This relationship (for air only) is

$$v = (331 + 0.606T_C) \text{ m/s} \quad \text{(eq. 2)}$$

where $T_C$ is the temperature of the air medium, expressed in Celsius degrees.

The end correction may be measured as shown in Figure 3.

$$\delta = \lambda/4 - L_1 \quad \text{(eq. 3)}$$

where $L_1$ is the distance from the first node to the physical open end of the tube. The end correction is approximately given by a theoretical analysis beyond the scope of this course as

$$\delta = 0.305 D \quad \text{(eq. 4)}$$

where $D$ is the tube diameter.

In this experiment, the presence of a standing wave is detected by a microphone placed in the tube. The output from the microphone is displayed on a computer. This output is a sinusoidal waveform. As the plug is moved, changing the effective length of the tube, the amplitude of the microphone signal varies. **Resonance occurs when the output amplitude passes through a local maximum.**

**Procedure**

- Measure and record the tube diameter $D$ and room temperature $T_C$.

- Connect the speaker to the LO/GND terminals of the function generator. Turn on the function generator. Adjust the waveform selector so that a sine wave is generated. The function generator starts with a default frequency of 1000 Hz. This is a good frequency for the size of the tube being used, although the frequency may be adjusted to any value. Record the frequency $f$.

- The microphone should be attached to the computer through an interface box. Turn on the computer and double click on the “Sound” icon. It starts up and a set of axes appears. Everything is working as it should if the “Collect” arrow in the upper right of the screen is green. Place the microphone anywhere in the open end of the tube. Its precise placement is not critical. Hold the speaker **slightly away from and off to the side** of the tube end.

- Click on the (green) “collect” button. The computer displays the microphone output, continually refreshing the screen. Start with the
plug at the open end of the column. Move the plug into the tube until the amplitude of the microphone signal gets larger. Eventually, as the plug is moved farther from the open end, the amplitude of the microphone signal drops. Move the plug back. Find the position of the plug at the exact location of the node where the amplitude of the signal is a distinct, clear maximum. Measure the distance $L_1$ of the face of the plug from the open end of the tube.

➤ Note:
The computer is trying to collect and display a lot of data from the microphone. It takes a while to do this. The data refresh rate, the rate at which the computer updates the microphone output, is low. Rapid changes in the microphone output can be missed. Therefore, the plug must be moved very slowly so that the computer can keep up. Make sure the plug is moved slowly enough so that the variation of amplitude observed on the computer display is smooth.

- Continue moving the plug down the tube. Determine all the nodal positions by determining where the amplitude of the signal is a distinct, clear maximum. Record the distances $L$ of the nodes from the open end of the tube.

- Calculate the internodal distance, $\Delta$, from each node to the node immediately before it by subtracting nodal positions. The internodal distances should all be the same (or, at least, close. Why?). Determine the best value of internodal distance by computing the average.

- Calculate the wavelength $\lambda$ of the wave from the average internodal distance using Figure 2.

- Calculate the experimental wave speed $v$ of the sound wave from eq. 1.

- Calculate the theoretical wave speed from eq. 2.

- The experimental calculation of wave speed should agree with the theoretical determination of the wave speed. Determine the percent difference of the experimental value from the theoretical value.

- Calculate the end correction $\delta$ from eq. 3.

- Calculate the theoretical end correction from Eq. 4.

- The experimental calculation of end correction should agree with the theoretical determination. Determine the percent difference of the experimental value from the theoretical value.

Questions (Answer clearly and completely).
1. How is the distance between adjacent nodes related to the wavelength?

2. Can a sound wave reflect back from an open (unplugged) tube end?

3. As the plug is moved from one standing wave position to another, how does the wave frequency change? How does the wave wavelength change? How does the wave speed change?

4. What value do you determine experimentally for the wave speed? What value do you determine theoretically for the wave speed? What is the percent difference of the experimental value from the theoretical value?

5. What value do you determine experimentally for the end correction? What is the percent difference of this value from the theoretical value?

6. If the experiment were to be redone at the same frequency with the speaker held firmly against the end of the tube, what would change: the locations of the cap at resonance? the internodal distance? the wave speed in the tube?