S7a: Measuring Sound Speed by Air Column Resonance

Introduction:

In a wind musical instrument, such as an organ pipe, the sound is produced as a vibration inside an air column in the instrument. The sound wave travels through the air causing a sinusoidal pressure variation. The back and forth air motion in the propagation direction of the sound describes a longitudinal wave. The desired result is a standing wave inside the tube. If the frequency of the vibration and the wavelength of the standing wave are known, it is possible to calculate the velocity of the sound wave.

In this experiment, you will be using different frequencies produced by a frequency generator interface to determine the velocity of sound in air. Since the frequencies used will be known, to calculate the velocity of sound you need to find the wavelength corresponding to that sound. By holding the speaker connected to the frequency generator over a variable length tube, the sound waves will travel down the air column in the tube, and once reaching the bottom, they will be reflected back up. If the length of the air column is such that the returning waves are in phase with those being produced by the generator, they will reinforce each other and produce a noticeable increase in the sound level known as resonance.

By manipulating the water level in the tube, you can change the length of the air column (L). Resonance occurs if this length of the air column is an odd number of a quarter wavelength (λ) according to the frequency being used (when L= $\frac{1}{4}\lambda$, $\frac{3}{4}\lambda$, $\frac{5}{4}\lambda$, etc).

Apparatus:

- Resonance tube with water reservoir
- Interface and computer system
- Temperature and sound sensors
- Speaker
- Caliper

Figure 1

Discussion:

Sound waves are differences in pressure that result in displacement of the surrounding medium (air in most cases). The changes in the displacement of the air can be modeled as a sine function, with the node producing the least displacement and the antinode producing the greatest. At the closed end of the air column (at the water level), the air molecules cannot move freely, but at the open end they are free to do so. Resonance will take place when the sound's wavelength fits into the air column such that there is a node at the closed end and an antinode at the open end.

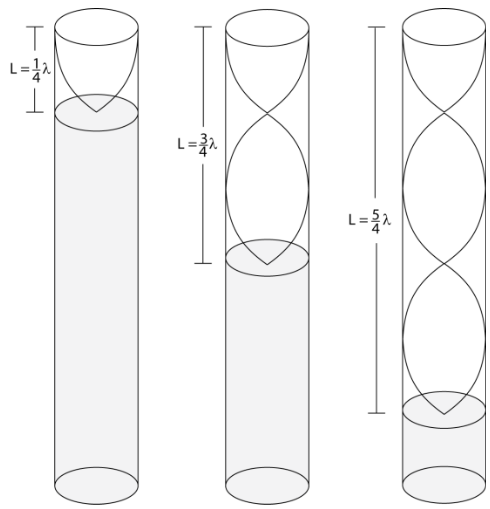

Figure 2

Figure 2 shows the three first resonance positions. The relation between the length of the tube and the length of the sound wave is given by:

$L = \frac{n\lambda}{4}$ where $n = 1, 3, 5, \ldots$

Then,

$\lambda = \frac{4L}{n}$ where $n = 1, 3, 5, \ldots$

However, there is a small adjustment to make to the length, because the antinode is not exactly at the open end of the tube but rather slightly above it. This distance is mainly dependent on the diameter of the tube and is called the End Correction Factor. It is equal to approximately 0.6 of the radius of the tube. Keep in mind that this adjustment becomes unnecessary when dealing with the difference between two consecutive resonance positions, because the open end of the tube is not involved.

$$ECF = Radius \times 0.6$$ (End-Correction Factor)

Once the wavelength is known, it is possible to calculate the velocity of the sound using the frequency of the generator by the equation:

$$v = f\lambda$$

Result can then be compared with the theoretical value for a particular room temperature:

$$v_T = 331.4 + 0.6\,T$$

Procedures:

Part I:

1. The air column length is adjusted by raising or lowering the water reservoir. Begin with the air column at a length of about **22 cm**.
2. Position the speaker, fixed on the lab stand, over the resonance tube. It should be approximately 2 cm above the resonance tube.
3. Adjust the function generator to a frequency of **350 Hz**. Volume may be decreased or increased as needed, by adjusting the Amplitude.
4. Increase the air column length (by lowering the water level) until you hear a sharp increase in volume. When you hear the increased volume, stop the water from continuing to lower (by raising the water reservoir). Continue adjusting the water in the air column until it remains stationary on the exact location that produces the loudest sound. Note that the increased volume will stop if the speaker is moved away from the tube. Record the exact water position that creates the greatest volume. This is the first resonance position and corresponds to 1⁄4 of the wavelength.
5. Next, lower the water level until resonance occurs a second time. This position is about three times further down the tube and corresponds to 3/4 of the wavelength.
6. Repeat these steps for **550 Hz** and **750 Hz**. For the 550 Hz frequency begin with the air column at a length of about **13 cm**. For the 750 Hz frequency begin with the air column at a length of about **8 cm**.
7. Calculate the wavelength for each resonance position; **don't forget to include the ECF before calculating the wavelength**. For each frequency, use the calculated wavelength to find the experimental velocity for each resonance position.

Part II:

1. Adjust the air column height to **30.0 cm**. Keep this air column length constant. Using the function generator find the two frequencies between **200 Hz and 900 Hz** that produce resonance. Note, adjust the frequencies slowly.
2. The first resonance frequency you will hear occurs at its ¼ λ position, the second frequency will correspond to ¾ λ position.
3. Calculate the wavelength and experimental velocity for each resonance position.

Experiment S7a: Measuring Sound Speed by Air Column Resonance

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor____

Experiment Start Date_____________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: S7a: Measuring the Speed of Sound Using Air Column Resonance

NAME: ______________________________ **DATE:** __________________

Room Temperature (   ) = _______________ V_T (   ) = _________________

Diameter of Resonance Tube (   ) = ________________

Radius of Resonance Tube (   ) = ________________ ECF (   ) = ________________

Part 1

Frequency	**350 Hz**		**550 Hz**		**750 Hz**	
Column Length ( )	l_1		l_1		l_1	
	l_2		l_2		l_2	

$L_1 = l_1 + ECF$ ( )			
$\lambda = 4 * L_1$ ( )			
Velocity $= \lambda * f$ ( )			

$L_2 = l_2 + ECF$ ( )			
$\lambda = 4/3 * L_2$ ( )			
Velocity $= \lambda * f$ ( )			

Part II

Air Column Height: ____________ (   )

Resonance Length L= Air Column Height + ECF = _________________ (   )

Resonance Position	$L = 1/4\ \lambda$	$L = 3/4\ \lambda$
λ ( )		
f ( )		
Velocity ( )		