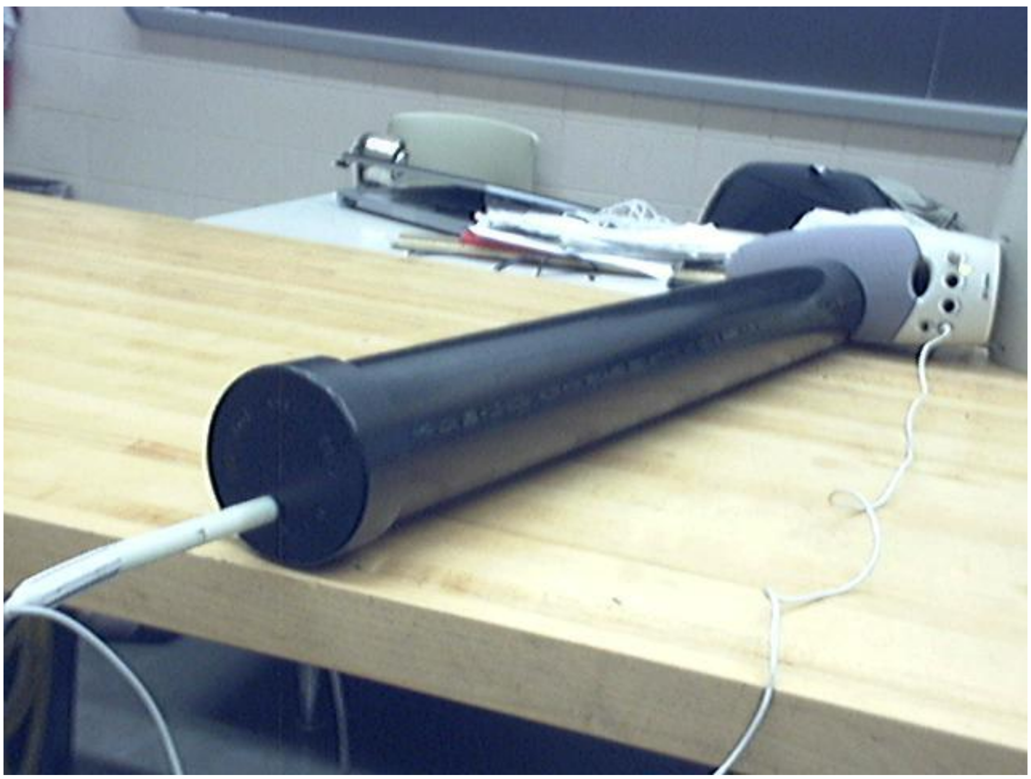
STANDING WAVES
IN AN AIR COLUMN

The objective of the experiment is:

- To study the harmonic structure of standing waves in an air column.

APPARATUS: Computer, FFTSCOPE software, PC speaker, meterstick, sound tube apparatus, thermometer, microphone



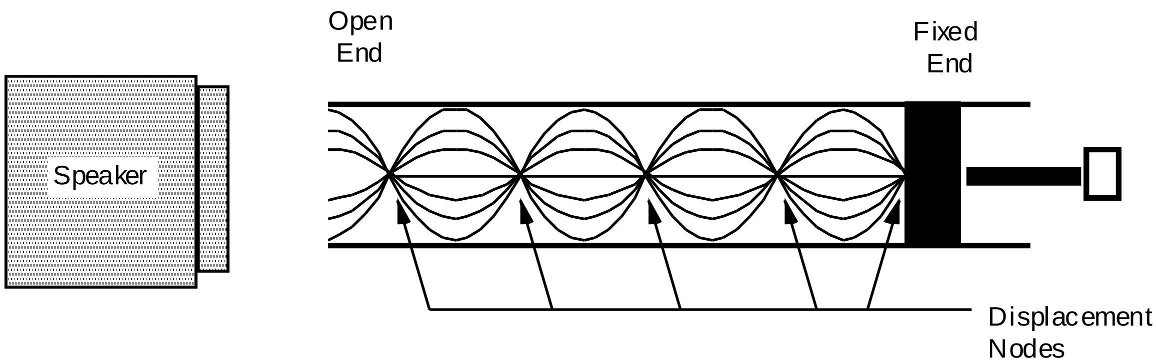
INTRODUCTION

A traveling wave of sinusoidal shape goes a distance λ (the wavelength) in one period interval, T. The wave velocity c is therefore equal to λ/T . Because f (the frequency) is defined as $1/T$, we can also write $c = f\lambda$.

Consider the set up pictured above. It is identical to that of the Speed of Sound Lab you completed earlier in the semester. The speaker is driven by an electrical source that produces a single frequency sound wave that is directed towards the open end of a tube. The other end of the tube is closed. When the sound wave enters the tube it travels down to the closed end, is reflected and returns to the open end of the tube. For most sound waves the incoming and reflected waves will have no particular phase relationship and will produce nothing noteworthy. But, if the phase relationship is correct, standing waves can be formed. This condition of constructive interference is when

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

where λ is the wavelength of the sound wave and L is the effective length of the tube, that is the distance from the closed end to slightly beyond the open end.



The reason for this condition is easily seen. A displacement antinode forms at the open end of the tube. Displacement is the range of the vibrating air molecules, and an antinode is where it oscillates as a maximum. The pressure variation is, however, minimal here. The boundary condition for the pressure wave is that the pressure variation go to zero at the open end of the tube. Actually this occurs a little beyond the end: there is an "end correction". One must add 0.61 times the radius of the tube's cross section to determine its acoustic length (i.e. the place where the pressure goes to atmospheric pressure). At the closed end the displacement variations are very small as the waves compress the air molecules and are reflected at the surface (pressure variation, however, is a maximum at this surface). So a displacement node forms at the closed end. The displacement and pressure waves associated with the sound are always 90 degrees out of phase.

The distance between each node is the same as between each antinode, namely λ /2. Thus, the distance between a node and an antinode is λ /4. The fundamental or lowest frequency harmonic occurs for $L = \lambda/4$ which is when we have one antinode at the open end and one node at the closed end. As the sound frequency is increased, additional standing wave patterns occur whenever the wavelength has decreased enough that another half λ can fit into the tube. The reflected waves must then travel an additional full wavelength. Thus, we see only odd harmonic standing waves develop in a column of air with one end closed. From this argument we can also see that if the frequency were kept constant and the length of the tube were varied, standing waves would reoccur each time the tube's length were altered by $\lambda/2$.

Procedure:

The waves in this setup are made by an amplified PC speaker driven by the function generator option of the FFTSCOPE software. The speaker sets the air molecules into longitudinal vibration (vibration in the direction of wave propagation). The speaker always acts as a displacement antinode because the surface of the vibrating diaphragm sets the air molecules into motion.

Move the white microphone to the very end of the tube (the closed end). Click FFT/OSC icon to go from oscilloscope to FFT mode. Click the icon labeled "Time" and set to 2 seconds. Click the green icon with the arrow which is in between the GO/STOP and FFT/OSC icons. This will turn FFT averaging on. Select "Function Generator" from the pull down menu and choose "White Noise". This will give you a frequency spectrum in which the prominent peaks are the resonance frequencies of the tube (i.e. normal modes where large amplitude standing waves will occur). List these frequencies on your lab report form.

Having determined the resonance frequencies, choose "Function Generator" from the menu and select "Frequency". Input one of the prominent resonance frequencies determined above, preferably within or close to the range 700 to 1500 Hz. Change the setting of the "Time" icon back to 0.1 sec. Choose "Function Generator" again and select "Sine wave". Adjust the volume on the speaker to an appropriate level and return to oscilloscope mode with the FFT/OSC button. Watch the oscilloscope screen. Move the microphone down the length of the tube and observe the growth and decay of the amplitude of the waveform displayed on the screen. Determine all positions of the microphone for maximum sound intensity. Maxima of voltage amplitude are maxima of pressure variation and sound intensity. You should observe that the pressure variation is a maximum at the closed end and a minimum at the open end as claimed above. The distance between two adjacent positions of maximum intensity is equal to $\lambda/2$. Repeat for two other frequencies. From f and λ determine the speed of sound c for each pattern. Collect the data for three frequencies and calculate $\bar{c}$.

Compare your average experimental value with the theoretical value

$$c = (331.4 + 0.6T) \text{ m/s}, \quad (4)$$

where T is the temperature in degrees centigrade. A thermometer should be on the wall by the door. If not, assume $T = 22$ C.

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Name:____ Section:_________

Partner:____Date:___________

List the resonance frequencies of the air column determined from the FFT spectrum:

Temperature:_________ Assume 22 C if there is no thermometer.

Theoretical wave velocity 331.4 + 0.6T_C: _________

Frequency f_1 _______

Record the locations of the nodes; the difference between these gives λ/2.

Positions of intensity maxima:						
Take the difference between intensity max. to get =λ/2						--
Average λ/2						
Average wavelength, λ						

Experimental wave velocity fλ: ________ **Ratio R = c_{exp}/c_{th} =** ________

Frequency f_2 _______

Positions of intensity maxima:						
Take the difference between intensity max. to get =λ/2						--
Average λ/2						
Average wavelength, λ						

Experimental wave velocity fλ: ________ **Ratio R = c_{exp}/c_{th} =** ________

Frequency f_3 _______

Positions of intensity maxima:						
Take the difference between intensity max. to get =$\lambda/2$						--
Average $\lambda/2$						
Average wavelength, λ						

Experimental wave velocity $f\lambda$: _________ Ratio $R = c_{exp}/c_{th}$ = _________

QUESTION

In light of your data, does the velocity of sound, c, depend on the frequency, f, for the air column? Discuss the evidence by which you arrived at your conclusion.