Investigation of Standing Waves in Air In a Resonant Air Column

The experimental apparatus used for this demonstration can be used to determine the speed of sound in air. It can also be used to investigate the pattern of (over-pressure) maxima and minima in a resonant air column.

In this activity you will use the properties of standing sound waves in a tube to find the velocity of sound in air. Sound waves are called *longitudinal* waves because the oscillating displacement of the molecules of the medium (air in our case) is parallel to the direction of the wave's propagation. This displacement is hard to see or measure in air. Instead, we will use a microphone to measure the compressions and rarefactions caused by the "displacement wave." These compressions and rarefactions comprise a "pressure wave" where the air pressure oscillates around the atmospheric pressure in the tube. The microphone senses this pressure wave, which is a quarter-wavelength out of phase with the displacement wave; i.e., where the displacement wave has maximum amplitude, the pressure deviation is zero and where the displacement is zero, the pressure wave has maximum amplitude.

A sine wave from the function generator is used to drive a speaker near the open end of a glass tube, as shown below in Figure 1. A cork on a rod inside the tube is used to close the other end of the tube and adjust the length of the tube. Sound from the speaker enters the tube and multiple reflections occur at both the closed and open ends. A microphone is inserted a few centimeters into the open end to pick up the resultant sound pressure wave. Like the string setup, for a given length of the tube only a certain set of frequencies (the resonant frequencies) are amplified by the tube and the destructive interference of multiple reflections largely cancel out other frequencies. Unlike the string setup, however, we now have one end where the medium is not free to move (the cork end) and one end where it is free to move (the open end of the tube). To establish the maximum standing wave in this case, the following conditions are necessary: at the cork the displacement wave must be at a node and at the open end of the tube there must be a displacement anti-node. These conditions are satisfied when the wavelength λ of the sound wave satisfies

$$L_n + \delta = (2n+1)\frac{\lambda}{4} \qquad n = 0, 1, 2, 3, \ldots \qquad \text{(Eq. 1)}$$

where L_n is the length of the tube to the cork and δ is the end correction factor. The correction factor is necessary since in actuality the displacement anti-node at the open end is slightly beyond the opening.

From Equation 1, it can be seen that the values for $L_n + \delta$ are successively equal to $\lambda/4$, $3\lambda/4$, $5\lambda/4$, $7\lambda/4$, and so on. If we measure these points, we can find λ. From λ and the frequency f of the function generator we can find the speed of sound in air, given by:

$$v_{air} = f\lambda \qquad \text{(Eq. 2)}$$

Your experimentally-determined value for the speed of sound can be compared to the theoretical value

$$v_{air} = 332\sqrt{\frac{T}{273\ ^\circ\mathrm{K}}}\ \text{[m/s]} \qquad \text{(Eq. 3)}$$

which depends only on the absolute temperature *T*, measured in degrees Kelvin.

In this activity we will find the lengths of the air column necessary for a fixed frequency to be one of the resonant frequencies.

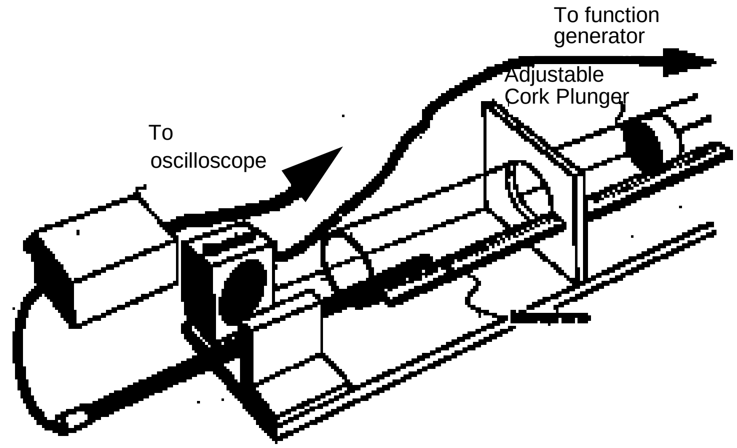

Figure 1. Setup for the resonant air column

Prediction	Use Equation 3 to predict the theoretical value for the speed of sound in the lab room. Determine the room temperature *T* from the wall thermometer, and remember to convert to degrees Kelvin. v_{air} = __________________ [m/s]

1. Set up the equipment for testing the prediction.

- Turn the amplitude of the function generator to zero.
- Plug in the banana plug cables from the speaker into the same receptacles.
- Adjust the frequency of the function generator to 1800.0 Hz.
- Turn on the oscilloscope power. The trace should appear in about ten seconds.
- Now adjust the position of the microphone support so that the microphone is parallel to and slides along the inside surface of the tube. If necessary, tighten the support in place with the wing nut, and position the microphone's face at the 2 cm mark on the ruler tape mounted on the tube.
- Push the cork into the tube until it touches the microphone. Turn the amplitude up on the function generator until the trace on the oscilloscope has a total vertical amplitude of about 3/4 the size of the screen. Have your TA check your setup.

2. Begin taking measurements.

- The vertical amplitude of the wave you see on the scope is directly proportional to the loudness of the sound detected by the microphone. With one hand on the cork rod and the other on the microphone tube, and keeping the microphone pushed against the cork, adjust their common position while watching the scope for a maximum amplitude. There should be a maximum for this frequency somewhere in the 1–4 cm range.
- When you find the maximum, take a reading of the cork's position and enter it in the second column of Table 2 as L_0. Do not move the microphone for the rest of this activity.
- Now slowly pull out the cork while watching the oscilloscope's trace. You should notice that the trace's amplitude collapses and then increases to another maximum. Carefully adjust the cork's position to find this maximum.
- Record the cork's position as L_1. Continue pulling out the cork to find and record the positions L_2 through L_{11} where maximum signals are seen on the scope.

n	Position L_n [m]	Spacing $L_{n+1} - L_n$ [m]
0		…………
…………	…………	…………
1		…………
…………	…………	
2		…………
…………	…………	
3		…………
…………	…………	
4		…………
…………	…………	
5		…………
…………	…………	
6		…………
…………	…………	
7		…………
…………	…………	
8		…………
…………	…………	
9		…………
…………	…………	
10		…………
…………	…………	
11		…………

Table 1. Resonance position data for an air column

3. Analyze your data.

- In the third column of Table 1, calculate the successive values of $L_{n+1} - L_n$ starting with $L_2 - L_1$. Notice that we do not use the measurement of L_0; it is not considered to be very accurate.
- Study the values computed in the third column. They should all be about the same. If one or more is much different than the others, ask your TA for help.
- The difference between L_{11} and L_1 is equal to five wavelengths. (Do you know why?) Use this information to calculate the wavelength λ of the sound wave.

λ = ____________________ [m]

- Using Equation 2, your measured value for λ, and the value of the frequency from the function generator, compute the speed of sound in air.

v_{air} = ____________________ [m/s]

Q1 Compare your predicted and measured values for the speed of sound in air. How close are they? Compute a percent difference.

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Q2 Would there be any resonant frequencies in the air column if the sound waves did not reflect off the open end of the tube? Explain.

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Q3 The velocity of sound in helium is greater than that in air. If we changed the above activity to the "Resonant Helium Column" and used the same frequency setting (1800 Hz), would the spacings $L_{n+1} - L_n$ be smaller, larger, or the same? Explain.

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Making Waves Stand Still

In the first activity, you used the properties of standing waves to measure the speed of sound. In this activity you will try to "see" the standing waves by adjusting the position of the microphone in the tube. Remember that the microphone measures the (over-) pressure wave, which is an oscillation in local pressure above and below the atmospheric pressure in the tube. You see this wave over time on the scope only for the current position of the microphone. If the signal is centered around the middle line of the scope, what you see above this line represents higher pressures than the atmospheric pressure and what you see below this line represents lower pressures than atmospheric pressure. See Figure 2 below.

If you were to establish a standing wave on a string and look at a tiny piece of the string at a point other than a node, you could plot its vertical position versus time and you would get a sinusoidal curve exactly like what you see on the scope. At every point on the string except at the nodes there is a maximum positive deflection and a maximum negative deflection.

Likewise with the standing sound pressure wave in the tube, at every point except at the nodes there is a maximum positive pressure deviation and a maximum negative pressure deviation. You will find these pairs of maxima associated with specific points in the tube over a wavelength of the sound wave.

1. Set up the equipment.
- Make sure the frequency is still 1800.0 Hz and the microphone has not been moved (it should still be 3–4 cm inside the tube). If necessary, repeat the first item in step 2 of the previous activity to correctly position the microphone.
- Move the cork to a position around 22.5 cm where you achieve a maximum signal on the scope.
- Adjust the amplitude control on the function generator so that the top to bottom height of the signal is six scope divisions, as shown below in Figure 2. Check that the signal rises exactly three divisions above the centerline and falls exactly three divisions below the centerline. If it is off-center, ask your TA for help.

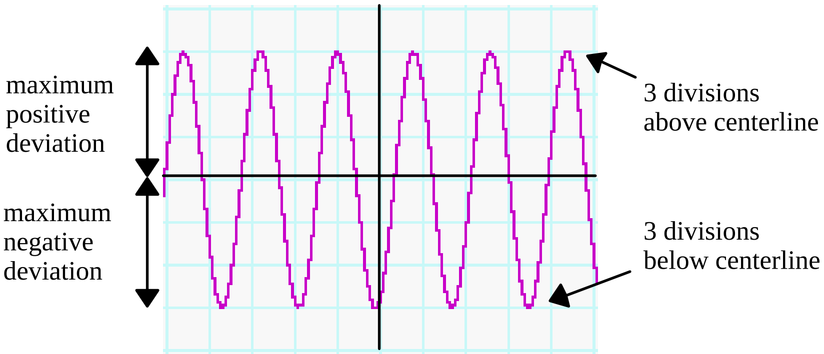

Figure 2. The microphone detects the pressure deviation in the tube and displays it as a signal on the scope. A trace above the centerline indicates pressure higher than atmospheric pressure; one below the centerline indicates pressure lower than atmospheric pressure.

2. Take and record your measurements.
- In Table 2 below, record the position of the microphone and the number of divisions above and below the centerline (i.e., the amplitude) of the signal. Record the amplitude as a pair of numbers in the form (+3,–3).
- Now you will chart the pressure deviations at other points in the column. Begin by slowly moving the microphone towards the cork until you reach a point where the amplitude is two divisions above and two divisions below the centerline. Record this new position of the microphone and the amplitude as (+2,–2) in Table 2.
- Continue moving the microphone inside the tube and when you reach a point where the amplitude is one division above and below the centerline, record this microphone position and amplitude as (+1,–1) in the table.
- The next amplitude you seek, (0,0), will not appear exactly as a flat line on the scope; however, you can still locate it by using a careful method. Slowly move the microphone inside the tube and watch the trace. Your goal is to find the point where the signal collapses as much as possible; that is, where the amplitude of the signal is a minimum. At the correct point the trace will look nearly but not completely flat. Record this microphone position and amplitude (0,0) in the table.

- Continue this process of finding amplitudes of zero, one, two, and three scope divisions above and below the centerline, recording the corresponding microphone positions and amplitudes in the table. You will finish taking data when the microphone reaches the cork.

Microphone position [m]	Amplitude [scope divisions]

Table 3. Microphone position and amplitude data at a resonant frequency

3. Make a graphical representation of your data.

- For each microphone position you found in Table 3, place a pair of dots corresponding the amplitude in Figure 3. (For the amplitude (0,0), you may just place one dot.) For each pair of dots, draw a vertical line connecting them.
- Using a different colored pencil, draw a smooth curve through all the dots above the centerline in Figure 3 and a similar smooth curve through all the dots below the centerline.
- Draw the position of the cork in the figure as well.

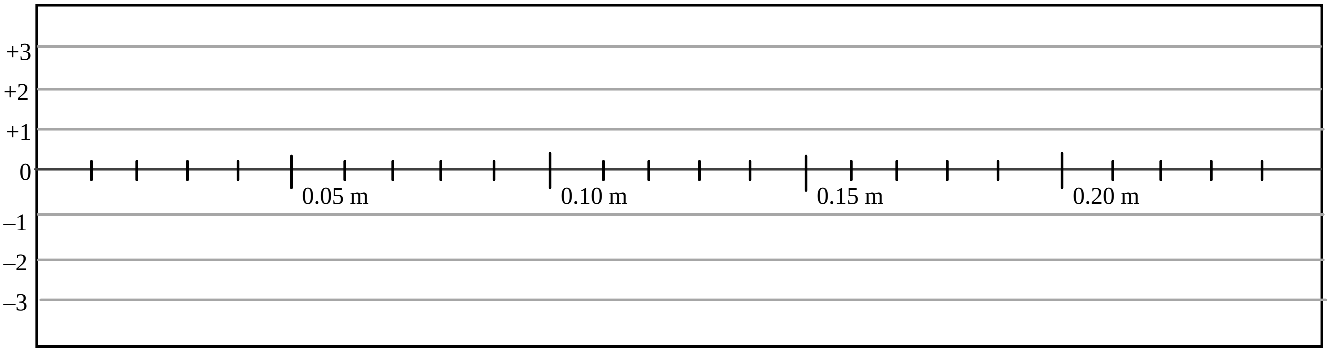

Figure 3. The pattern of pressure deviation maxima in the resonant air column

Q4 What similarities do you notice between the figure you just drew and the standing waves on the string (as shown in Figure 3)? What differences do you notice?

Q5 List the positions of the microphone that are at pressure antinodes. How were you able to identify these points?

Q6 List the positions of the microphone that are at pressure nodes. How were you able to identify these points?

Q7 What is the distance between the two nodes?

Is this distance equal to λ or $\lambda/2$ of the sound wave?

Compare this distance to the spacings $L_{n+1} - L_n$ you found in the previous activity. Is it roughly the same? Should it be?