Name: ____________________ Partner's Name: ____________________

Wave Resonances in Air Columns

In this experiment, you will investigate the production of standing waves and the principles of resonance.

Apparatus:

Various tuning forks and adjustable length tube, rubber mallet, water.

1. Introduction

The word resonance comes from Latin and means to "resound" - to sound out together with a loud sound. Resonance is a common cause of sound production in musical instruments. One of our best models of resonance in a musical instrument is a resonance tube (a hollow cylindrical tube) partially filled with water and forced into vibration by a tuning fork. As the tines of the tuning fork vibrate at their own natural frequency, they created sound waves that impinge upon the opening of the resonance tube. These impinging sound waves produced by the tuning fork force air inside of the resonance tube to vibrate at the same frequency. Yet, in the absence of resonance, the sound of these vibrations is not loud enough to discern. Resonance only occurs when the first object is vibrating at the natural frequency of the second object. So if the frequency at which the tuning fork vibrates is not identical to one of the natural frequencies of the air column inside the resonance tube, resonance will not occur and the two objects will not sound out together with a loud sound.

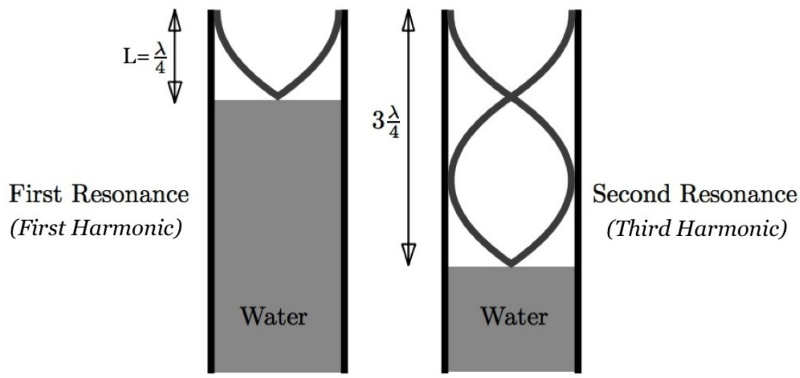


Figure 1: The first two resonances in an open air column.

In this experiment we will create longitudinal standing waves in a tube containing air. The tube, shown in Fig. 1, is open at the top and filled with water at the bottom. By adjusting the amount of water in the tube one may lengthen or shorten the length L of the column of air in the tube. If a tuning fork is held over the open end of the tube and struck, it excites the air molecules in the tube and causes a sound wave to propagate down the length of the tube to the air-water boundary where it is reflected back up the length of the tube to the open end.

In tubes, pipes or columns open at one end and closed at other, the **resonance condition** requires that a displacement *antinode* exist at the open end and a displacement *node* at the closed end of the tube. This means that the fundamental (first harmonic) standing wave in such a tube occurs when the column of air is of length $L = 4\lambda$, shown in Fig. 1(a). The second resonance, shown in Fig. 1(b), is when the water level is $L = 3\lambda/4$ beneath the mouth of the tube, the third at $L = 5\lambda/4$, etc. The series of nodes and antinodes in a tube open at one end and closed at the other form an odd harmonic series (in tubes open at both ends or closed at both ends all harmonics are possible). Thus the condition for a standing wave, or resonance, to form in a tube closed at one end is $L = n(\lambda/4)$, or

$$\textbf{Resonance Condition:} \quad \lambda = \frac{4L}{n} \qquad n = 1, 3, 5, \ldots \tag{1}$$

So by raising and lowering the water level, the natural frequency of the air in the tube can be matched to the frequency at which the tuning fork vibrates. When the match is achieved, the tuning fork forces the air column inside of the resonance tube to vibrate at its own natural frequency and resonance is achieved. **The result of resonance is always a big vibration - that is, a loud sound.** Once a resonant length L is found, you can use Eq. (1) to find the wavelength λ and, by using the given frequency value f, you will be able to calculate the speed of sound v in the column of air from

$$v = \lambda f. \tag{2}$$

Note also that a variety of musical instruments operate on the basis of open-end air columns; examples include the flute and the recorder. Even some organ pipes serve as open-end air columns.

Summary: *When sound waves travel down a close-ended tube they bounce off the closed end and reflect. When the reflected sound wave interacts with another sound wave traveling down the tube, interference occurs. When the two waves interfere constructively, it creates resonance, an increase in the amplitude of the waves, and very large sounds.*

2. Procedure:

1. Fill the reservoir of the resonance apparatus with water (position it near the bottom of the tube before doing this to prevent overflow). Note how moving the reservoir up and down the attachment rod raises and lowers the level of water in the resonance tube.

2. Begin with the highest frequency tuning fork. Strike the fork on its tines (a great deal of force is not necessary) with the rubber mallet, and hold it at the open end of the resonance tube with its prongs horizontal. Adjust the water level starting from its highest level. Gradually increase the length of the air column by lowering the water can to find the first position of resonance, where the sound coming out of the air column is loudest. You may have to strike the fork several times and move the water column up and down to precisely locate the resonance position. At resonance, record the value of L in Table 1.

3. Continue this procedure to the second (and if possible, the third) position of resonance. Record these lengths in Table 1.

4. Repeat the experiment with the three other tuning forks of different frequencies.

5. Once you have found all the resonant positions L for the four tuning forks, complete Table 1 by calculating the corresponding wavelengths λ, the average wavelengths $\bar{\lambda}$, and the speeds of sound v.

Resonance Conditions

$$
\begin{aligned}
\text{First Resonance: } \lambda &= 4L \\
\text{Second Resonance: } \lambda &= (4/3)L \\
\text{Third Resonance: } \lambda &= (4/5)L
\end{aligned}
$$

Table 1: Resonances in an Open Air Tube.

Tuning Fork Frequency $f_1 =$ hz		
Resonance #	Resonance Position L (cm)	Wavelength λ (cm)
1		
2		
3		
Average Wavelength $\bar{\lambda}_1 =$		
Speed of Sound $v_1 = \bar{\lambda}_1 f_1 =$		

Tuning Fork Frequency $f_2 =$ hz		
Resonance #	Resonance Position L (cm)	Wavelength λ (cm)
1		
2		
3		
Average Wavelength $\bar{\lambda}_2 =$		
Speed of Sound $v_2 = \bar{\lambda}_2 f_2 =$		

Tuning Fork Frequency $f_3 =$ hz		
Resonance #	Resonance Position L (cm)	Wavelength λ (cm)
1		
2		
3		
Average Wavelength $\bar{\lambda}_3 =$		
Speed of Sound $v_3 = \bar{\lambda}_3 f_3 =$		

Tuning Fork Frequency $f_4 =$ hz		
Resonance #	Resonance Position L (cm)	Wavelength λ (cm)
1		
2		
3		
Average Wavelength $\bar{\lambda}_4 =$		
Speed of Sound $v_4 = \bar{\lambda}_4 f_4 =$		

3. Questions:

1. Find the overall average value of the speed of sound from your four measurements. Compare to the known value of $v = 343$ m/s and find the % error. Does the velocity of sound in air depend upon the frequency of the tuning fork?

2. Sketch the air column vibrations for the third resonance. Label the positions of the nodes with an **N**, and the anti-nodes with an **A**. What is the difference between the positions of the third and the first resonance in terms of wavelength?

3. Are there anti-resonances where the sound coming out of the air column reaches a minimum? What is the length of air columns for these anti-resonances?

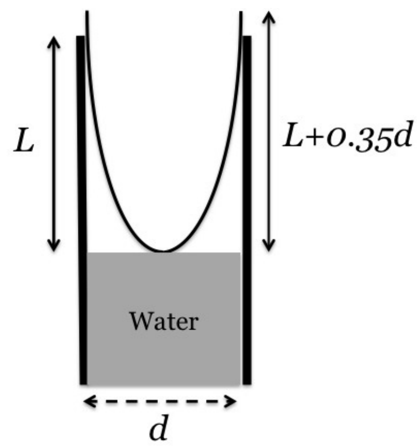
4. Why does the resonance position correspond to the loudest sound?

5. **END CORRECTIONS:** You may have found that all of your values for the speed of sound are close to, but somewhat below, the known value $v = 343$m/s. It turns out that a number of very careful experiments have shown that the idealized pictures shown in Fig. 1 are not the whole story for tube resonance. The figure next to Table 2 shows a more realistic picture of the sound waves at first resonance for a tube of diameter d. Here we see that the position of the anti-node is not *exactly* at the tube entrance, as we assumed in Fig. 1, but is in fact slightly above it. This affect is also seen for all order resonances. It's clear from this more realistic picture that the distance from the node (water surface) to the antinode is slightly longer than the measured distance L. The extra length depends on the tube diameter d, and has been found to be approximately equal to $0.35d$.

   You can test whether this more exact model can improve your values for the speed of sound v. Specifically, you are to re-analyze the data for the first harmonic resonances. To do this, record the inner tube diameter d in Table 2, then, as shown, redo the calculations for λ that includes the end affects, $\lambda = 4(L + 0.35d)$. Does this improve your data for the speed of sound?

Table 2: **End Effect Corrections:** Experiments have shown that in real tubes, of diameter d, the position of the anti-node during resonance is actually very slightly above the top of the tube. The extra length depends on the tube diameter d, and has been found to be equal to $0.35d$.

First Resonances Tube diameter $d =$ cm $\lambda = 4(L + 0.35d)$			
Frequency f (hz)	First Resonance L (cm)	Wavelength λ (cm)	Speed of Sound v (m/s)
$f_1 =$			
$f_2 =$			
$f_3 =$			
$f_4 =$			
Average Speed of Sound $\bar{v} =$ % Error =			



4. References

[1] http://www.physicsclassroom.com/class/sound/u11l5a.cfm
[2] http://www2.cose.isu.edu/∼hackmart/spl1ssar.pdf
[3] http://galileo.phys.virginia.edu/classes/152.mf1i.spring02/Particle%20Wave.swf

END LAB #10

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