**Standing Air Waves**

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**Abstract**

The theories surrounding resonance, wavelength and the speed at which a wave travels through a medium were tested. This was done using a pipe filled with water to measure significant fractions of sound wavelengths (¼ , ¾, etc.), marked by the occurrence of resonance. Tuning forks were used to drive these compression waves, and experimental values for the difference between resonance lengths (½ wavelengths) were used to compute the speed of the sound produced by the tuning fork, and this computed value was compared to the expected speed of sound for the ambient temperature of the room to test the efficacy of the results of the experiment.

The results of the experiment did support the theories in question, producing results within a predetermined 5% discrepancy threshold of difference from expected values, and were as follows: using a tuning fork rated for 512 Hz, a calculated value for the speed of sound of 346 m/s was found, resulting in a 0.723 % discrepancy when compared to the expected speed of sound (343 m/s); when a 288 Hz tuning fork was used, the experimental speed of sound came out to be 344 m/s, resulting in a 0.387% discrepancy.

**Theory**

The experiment allowed us to test the wavelengths of sound for different frequencies, using resonance states to help identify certain fractions of the wavelength (multiples of ¼), and the expected speed of sound was used to verify the results.

In accordance with wave theory, the wavelength of a wave is equal to the velocity with which that wave travels through its medium divided by the frequency with which that wave oscillates:

[ units: wavelength in m, Velocity in m/s, frequency in Hz ]

*Resonance* can is achieved when the *node* of a compression wave is at the center of the surface of the water column, and *anti-nodes* occur at the mouth, or slightly beyond, the mouth of the pipe (nodes are seen in the figure below in the center of the pipe where the amplitude of the wave is zero and minimal vibration is occurring, and anti-nodes are at the sides of the pipe, where the amplitudes are at their maximum, and maximum vibration is occurring). The surface of the water column acts as a wall, reflecting the sound wave that travels down the pipe. When resonance is achieved, the sound generated by the tuning fork is amplified, and a markedly louder, richer sound can be heard. This occurs because the lengths of the air column the wave is traveling through is such that the waves fit symmetrically, allowing for their nodes and antinodes to be in sync, and the antinodes just outside the mouth of the pipe work synergistically, creating even larger amplitude waves.

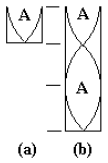


Figure 1: Illustrations of resonance in the pipe when the water column allows for (a) ¼ of a wavelength and (b) ¾ of a wavelength. The ‘A’s indicate the height in the tube at which the antinodes occur. As can be seen, as the medium vibrates, the antinodes alternate between crests and troughs. Image courtesy of Lab Instructions.

It should be noted that in this experiment, an *end correction* could have been applied. This end correction was the distance between the pulse generator (in this experiment, the tuning fork) and the mouth of the pipe, because the pulse generator could not be held perfectly at the mouth of the mouth of the pipe. This was actually where the first/last antinodes occurred as well.

In this experiment, the measurements of wavelengths were actually verified by using the calculated speed of the wave, or the speed of sound, and comparing it to an accepted value. Because the measured resonance length differentials represented intervals of half of the wavelength, the resonance length differentials were doubled and multiplied by the frequency to produce the speed of sound:

[ units: m/s ]

Average resonance length differentials were used (when possible) to produce a result more representative of the measured difference between resonance lengths.

The speed of sound, which would be used as our accepted value, can be found using the following relation that utilizes the ambient temperature of the air the sound wave is traveling through (in ˚C):

[ units: m/s ]

Experimental values will be compared to the accepted or expected values computed for the speed of sound with a percent difference approach.

[unit: percent]

*Procedure*

The experiment was performed using a long, vertical pipe (approximately 1 meter in length) with an attached tank and hand pump filled with water and two tuning forks that would emanate different tones. The pipe (hereafter to be referred to as the water column) had a clear window running down it lengthwise with a distance gauge along the side of the window so that the experimenter could see how high the column of water was. The distance gauge measured the distance from the top of the pipe to the upper level of the water column.

With the water column at its full height, a tuning fork was struck to produce a sound and held over the water column, and the hand pump was used to slowly decrease the pressure holding the water elevated, allowing the water level to drop. Experimenters listened for a resonance state, marked by a sudden increase in the reverberation of the air, producing a notably louder and richer sound than the tuning fork produced on its own, and the height of the water column when this resonance occurred was recorded. The tuning fork was re-struck as needed to produce sufficient vibration, and the water column was lowered further in the same manner to detect additional resonance lengths until there was not enough room left in the pipe to allow for further resonance occurrences. The difference between each resonance length and its preceding one was calculated, and then these differences were averaged to give a good estimate of half of a wavelength for each tone. The process was then repeated again with a second tuning fork.

These half wavelength results were then used to estimate the speed of sound in the ambient air, and were compared to what was assumed to be the true value of the speed of sound, calculated using the aforementioned formula. The temperature measurement required for this was found using a simple thermometer that was kept in the room.

**Data**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | f  (Hz) | nth Observation of Resonance | Resonance Length  (m) | ΔL  = Lf - Li  (m) | Average ΔL  (m) | Vsound  = 2ΔL\*f  (m/s) | Temperature  (°C) | Accepted  Vsound  (m/s) | %  Discrepancy |
| 1st Tuning Fork | 512 | 1 | 0.151 | - | 0.338 | 346 | 20.2 | 343 | 0.723 |
| 2 | 0.489 | 0.338 |
| 3 | 0.826 | 0.337 |
| 2nd Tuning Fork | 288 | 1 | 0.284 | - | 0.598 | 344 | 20.2 | 343 | 0.387 |
| 2 | 0.882 | 0.598 |

Table 1: The results of the experiment.

**Computations**

Computations were performed through the use of Microsoft Excel. Sample calculations are as follows:

The following calculations use data from the results using the first tuning fork:

The experimental speed of sound found with the first tuning fork:

The accepted speed of sound found for the experiment conditions:

The percent discrepancy between the experimental and the accepted one:

*Uncertainty*

This week’s uncertainty assignment was to simply make a table displaying the quantity measured by and the precision assumed for each device.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Measuring Device | Quantity Measured | Smallest Increment Reported By Device | Sample Measurement | Claimed Precision |
| Tuning Fork | Frequency of Vibration  (Hz) | 1 Hz | 512 Hz | 1 Hz |
| Water Column Distance Gauge | Distance Between Top of Water Column and Tuning Fork  (m) | 0.001 m | 0.489 m | 0.001m\* |
| Room Thermometer | Temperature  (˚C) | 0.1 ˚C | 20.2 ˚C | 0.1 ˚C |

Table 2: The measuring devices utilized in the experiment and the characterization of their measurement properties. Note: while the water column did measure to the stated precision, it did not measure the distance between the top of the pipe and the tuning fork, known as the *end correction*. While this would not affect the precision of the measurement, it would decrease the accuracy of the measurement for the first resonance length (but none of the others). However, this was not a problem for the experiment in that only the distance between resonance points was measured, and not the first ¼ wavelength.

**Results**

The experiment proceeded as expected and did successfully test the wavelengths of different sound frequencies when those wavelengths were used to calculate the speed of sound. Before conducting the experiment, it was decided that a percent discrepancy of no more than 5% would be tolerated, and the results of the experiment were well within this specification. Results of interest can be seen in Table 3.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | f  (Hz) | Average ΔL  (m) | Vsound  = 2ΔL\*f  (m/s) | Accepted  Vsound  (m/s) | %  Discrepancy |
| 1st Tuning Fork | 512 | 0.338 | 346 | 343 | 0.723 |
|
|
| 2nd Tuning Fork | 288 | 0.598 | 344 | 343 | 0.387 |
|

Table 3: A display of the results of interest for the experiment.

The results of the experiment were as follows: using a tuning fork rated for 512 Hz, a calculated value for the speed of sound of 346 m/s was found, resulting in a 0.723 % discrepancy when compared to the expected speed of sound, which was 346 m/s; when a 288 Hz tuning fork was used, the experimental speed of sound came out to be 344 m/s, resulting in a 0.387% discrepancy.

*Questions*

1. Are the airwaves in the pipe “longitudinal” or “Transverse”? Do the air molecules vibrate parallel or perpendicular to the pipe length? Are these vibrations of constant amplitude along the pipe length? (Briefly describe)

The airwaves in the pipe were longitudinal, they vibrated perpendicular to the length of the pipe. The vibrations were not of constant amplitude within the pipe, and it was this property that allowed us to find resonance points, which occurred when nodes of these waves were at the center of the surface of the water column, allowing the wave to be reflected back but with an amplitude opposite that of the incoming wave, resulting in effect in two waves of opposite amplitudes exiting the pipe, creating resonance.

1. Explain the physical significance of the “end correction.” Did the experimental value for the wavelength depend on the end correction? Why?

The end correction, although not used in performing this experiment, is significant because it represents the length beyond the pipe that should be added to the measurement obtained for the first length of resonance to accurately report the first ¼ wavelength of the tone. The experiment’s success did not depend on accurately measuring the end correction because only distances between resonance points were considered, and for that a measurement of the first resonance length (or ¼ wavelength) was not necessary.

1. Will the speed of sound change with barometric pressure (P0), if the temperature remains constant?

Explain with reference to the equation:

Where ρ0 is density and η is the ratio of specific heat.

Yes, the speed of sound will remain constant. In the above expression, it can be seen that because the specific heat term is a constant, variation of the speed of sound will only arise though variation of the ratio of the barometric pressure and the density of the air. Using the gas law expression , where R is the universal gas constant and T is the temperature of the gas. Then rearranging the expression to give us an expression defining the ratio of pressure and density gives: . Because R is a constant, and T is to be held constant according to the problem statement, we can see that the ratio of pressure and density will not change, meaning that the speed of sound will not vary if temperature remains constant, even if barometric pressure changes. This is because as the barometric pressure varies, the density of the air will also vary relative to the pressure, maintaining the ratio of pressure to density that has been key to answering this question.

1. The velocity of sound as computed in step 6 above appears to be independent of the diameter of the tube used. Would you expect this to be true if you had thought about it previously? Under what conditions would you expect the velocity of sound in a pipe to depend upon the diameter of the pipe?

Yes, I would have thought that the speed of sound would not vary depending on the diameter of the pipe, because waves travel at the same speed regardless of their amplitudes. I would not expect there to be a case such that the speed of sound would vary due to variations in diameter of the pipe. If the pipe were wide enough that the tuning fork was unable to compress the entire column of air, then I would expect that resonance would not occur, in which case we would not be able to evaluate the speed of sound. But still, the speed of sound would remain unchanged. The speed of sound would be more apt to change depending on the medium that the pipe was filled with.

*Discussion*

The experiment was conducted using a pipe filled with a column of water to reflect a sound wave (compression wave) generated by a tuning fork, and the height of the column of water was adjusted to allow for resonance to be achieved at varying heights. The distance between the tuning fork and the water column was used to estimate different fractions of the wavelength of the sound wave. These results were used to compute an estimate for the speed of sound, which was then compared to the expected value of the speed of sound (based on the ambient temperature of the room) to test the efficacy of the results of the experiment.

The results of the experiment did support the wave theories they were intended to test. To re-iterate: using a tuning fork rated for 512 Hz, a calculated value for the speed of sound of 346 m/s was found, resulting in a 0.723 % discrepancy when compared to the expected speed of sound of 343 m/s; when a 288 Hz tuning fork was used, the experimental speed of sound came out to be 344 m/s, resulting in a 0.387% discrepancy. Both of these results were well within the aforementioned 5% specification that was set to evaluate the success of the experiment.

Sources of error in this experiment were minimal. While the *end correction* might seem to be a source of error, in fact, as long as the end correction was small enough so that resonance could still occur, the design of the experiment was such that the end correction really didn’t play any significant role in the computations. A true source of error might have stemmed from the reading of the distance gauge. Because the distance reading had to be read on the fly, so to speak, error may have arisen, however it is doubtful excessive error was present given the high level of the correlation of the results with the expected value. Finally, error could have been reduced through the use of finer, more precise instruments, but, again, the results were such that it probably would not be cost effective to acquire such instrumentation to achieve better results.