

Measuring the Speed of Sound in Air

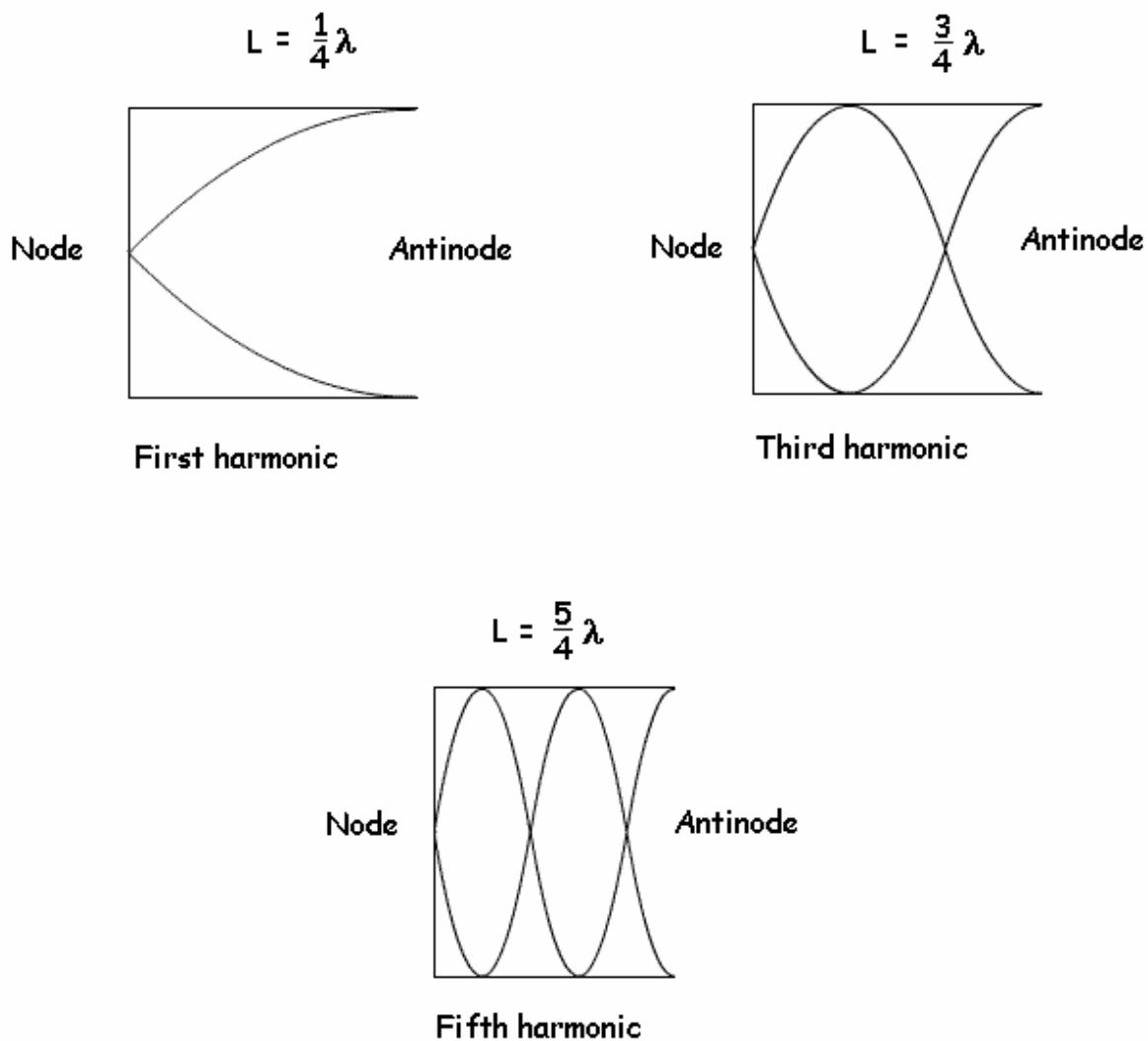
Key Terms: Transverse waves, longitudinal waves, wavelength, frequency, harmonic, node, antinode.

Objective: The purpose of this experiment is to measure the speed of sound in air by exploiting standing wave and resonance effects in *longitudinal waves*.

Equipment: Tuning forks (512 Hz, 1024 Hz, 2048 Hz), rubber mallet, resonance apparatus, water.

Physics Theory: In transverse waves the *displacement* of the medium through which the wave propagates is perpendicular to the *direction* of wave travel. Electromagnetic waves and waves on strings are examples of transverse waves. In longitudinal waves the displacement of the medium through which the wave propagates is parallel to the direction of wave travel. Sound waves are a prominent example of longitudinal waves.

In this experiment we will create longitudinal standing waves in a tube containing air. A standing wave is a stable wave pattern consisting of an incident and a reflected wave in which the *crests* and *troughs* of both waves maintain fixed positions. The tube is open at the top, and 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. The end of the tube containing water constitutes a "closed" end. In tubes, pipes or columns open at one end and closed at the other a stable standing wave pattern 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 of such a tube occurs when the column of air is of length $\frac{\lambda}{4}$. 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).



Experimental: In this experiment the resonant frequencies, f , are determined by the tuning forks that you will use to produce standing waves in a column of air in a tube open at one end. These are of known value. By adjusting the level of water at the other end of the tube you will be able to adjust ℓ , the effective length of the tube. In doing so, you will be able to adjust the length of the column of air so as to form standing waves in the tube. Once a standing wave of a given frequency has been established by adjusting the tube to the appropriate value of ℓ for the fundamental of that particular frequency it will be possible to locate the position of each successive antinode along the wave by lengthening the tube. By

measuring the difference between successive nodes you will be able to compute the wavelength of the standing wave and from that the speed of sound in the column of air by:

$$v = \lambda f$$

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. Begin with the 512 Hz tuning fork. Strike the fork on its tines (a great deal of force is not necessary) with the rubber mallet. It will produce a 512 Hz tone audible to the ear. Hold the tuning fork over the mouth of the tube with the end of the tines vibrating perpendicularly to the mouth of the tube (Why is this necessary?) and adjust the level of water in the tube by moving the reservoir up. You will notice that the tube will emit loud tones of the same frequency as the tuning fork for certain water levels. This indicates resonance and the presence of an antinode at the mouth of the tube. The first resonance will occur when the water level is $\frac{\lambda}{4}$ beneath the mouth of the tube, the second when the water level is $\frac{3\lambda}{4}$ beneath the mouth of the tube, the third at $\frac{5\lambda}{4}$, etc. Note that the distance between successive antinodes is $\frac{\lambda}{2}$. Note, as well, that the number of resonances will increase with increasing frequency. *Can you explain why?*

Once you have located the approximate position of each resonance for a given tuning fork repeat the procedure again but this time measuring the position of each resonance as carefully as you can. Record each measurement below along with a sketch of the standing wave in the tube at the position that you are measuring. Once you have measured the position of each resonance, repeat the experiment at least three times and compute the mean \bar{x} and standard deviation σ for the position of each resonance. Record each of these values in the table below. When you are finished with this procedure for a particular frequency, repeat the procedure with tuning fork with the next highest frequency.

Frequency (Hz)	Resonance	Position (cm)	Average (cm)	Standard Deviation (cm)
512	1		$X_1=$	
	2		$X_2=$	
	3		$X_3=$	
1024	1		$X_1=$	
	2		$X_2=$	
	3		$X_3=$	
	4		$X_4=$	
	5		$X_5=$	
	6		$X_6=$	
2048	1		$X_1=$	
	2		$X_2=$	
	3		$X_3=$	
	4		$X_4=$	
	5		$X_5=$	
	6		$X_6=$	
	7		$X_7=$	
	8		$X_8=$	
	9		$X_9=$	
	10		$X_{10}=$	

Data Analysis: The distance between adjacent resonances (antinodes) is $\frac{\lambda}{2}$. We seek λ since $v = \lambda f$. The calculations involving mean values are elementary. But in order to insure good statistics we must take care to carry the correct standard deviations from our measurements through our calculations. To do so, use the following procedure.

1. Using mean values (\bar{x}_1, \bar{x}_2), determine the mean distance between each resonance for a given frequency, e.g., $|\bar{x}_1 - \bar{x}_2| = \frac{\lambda}{2}_{ave}$. Compute the standard deviation of this data.

512 Hz

$\frac{\lambda}{2} =$	$x_2 - x_1 =$ _____	$\frac{\lambda}{2}$ Average _____
	$x_3 - x_2 =$ _____	

1024 Hz

$\frac{\lambda}{2} =$	$x_2 - x_1 =$ _____	$\frac{\lambda}{2}$ Average _____	
	$x_3 - x_2 =$ _____		Standard Deviation _____
	$x_4 - x_3 =$ _____		
	$x_5 - x_4 =$ _____		
	$x_6 - x_5 =$ _____		

2048 Hz

$\frac{\lambda}{2} =$	$x_2 - x_1 =$ _____	$\frac{\lambda}{2}$ Average _____	
	$x_3 - x_2 =$ _____		Standard Deviation _____
	$x_4 - x_3 =$ _____		
	$x_5 - x_4 =$ _____		
	$x_6 - x_5 =$ _____		
	$x_7 - x_6 =$ _____		
	$x_8 - x_7 =$ _____		
	$x_9 - x_8 =$ _____		
	$x_{10} - x_9 =$ _____		

2. Now to compute the mean and standard deviation of λ , multiply your results from step 1 by 2. Do this for each frequency.

512 Hz

_____ * 2 = λ
 _____ * 2 = standard deviation of λ

1024 Hz

_____ * 2 = λ
_____ * 2 = standard deviation of λ

2048 Hz

_____ * 2 = λ
_____ * 2 = standard deviation of λ

3. Calculate the velocity of sound and its standard deviation for each frequency by multiplying the values from 2 by the frequency of the tuning fork.

512 Hz

_____ * 512 Hz = v
_____ * 512 Hz = standard deviation of v

1024 Hz

_____ * 1024 Hz = v
_____ * 1024 Hz = standard deviation of v

2048 Hz

_____ * 2048 Hz = v
_____ * 2048 Hz = standard deviation of v

4. The speed of sound in air in eastern Idaho at STP (standard temperature and pressure) is about 331 m/s. Statistically speaking, how do your results compare with this?

Questions for thought

1. Is the speed of sound independent of frequency?
2. Does the speed of sound depend on anything that could be easily varied in this experiment?
3. Compare and contrast transverse and longitudinal waves.
4. What limited the number of resonances you found in the tube in this experiment for a given frequency?