

Lab 3: Resonance

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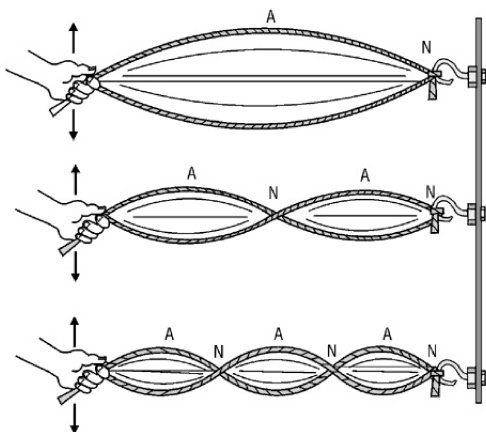
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1 Introduction

It is possible to increase the amplitude of an oscillating medium to very large levels, with a seemingly small amount of energy, by shaking the system at a particular frequency. Loosely speaking, this phenomenon is called “resonance.” One example of resonance is the famous case of a crystal champagne glass and an opera singer. If you tap a champagne glass lightly with a spoon, it produces a musical note. This oscillation frequency of the glass when it is allowed to vibrate freely is its natural frequency. When a singer sings at this frequency, the glass absorbs the sound energy, oscillates with ever increasing amplitude and then breaks when the glass vibrates too much. In this lab you will observe the phenomenon of resonance in a vibrating column of air and measure the speed of sound in air.

1.1 Simplified Theory

If two waves of the same frequency travel in opposite directions in a medium and meet, the disturbance they produce will look like a wave that is neither moving one way or another. We say that a **standing wave** is produced. It is a result of the **interference** of the two waves. At some points, called **nodes**, the interference causes the amplitude of the oscillating medium to be zero and the interference is said to be completely destructive. At other points, called **anti-nodes**, the waves reinforce one another so that the amplitude is largest here and the interference is said to be constructive. The following diagram represents a standing wave for a vibrating string.

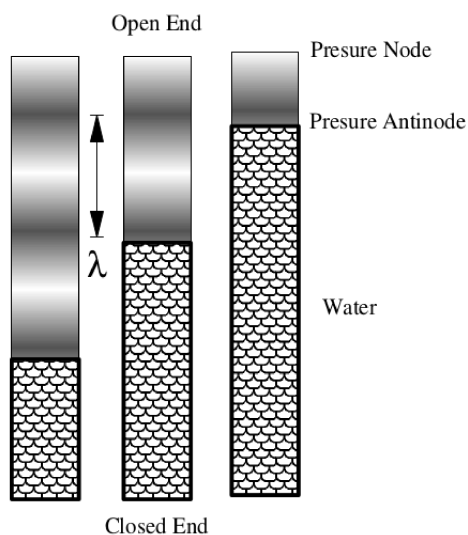


The standing wave is on a string that is fixed at one end. The three different diagrams show the string vibrating at three different frequencies. The nodes, labeled “N” occur at the end (where the string is stationary) and in the middle of the rope. The anti-nodes occur at “A” where the amplitude of the wave is maximal. The distance between nodes (or anti-nodes) is half the wavelength. Such a standing wave can also occur in a resonant cavity for sound waves. An example is the all familiar organ pipe. In the case of the sound wave, the pressure varies as the air molecules vibrate and are displaced from their equilibrium positions.

Any medium (i.e. water or a stretched wire) that can support traveling waves can be made to resonate. When a medium is made to resonate, energy is efficiently exchanged between whatever is vibrating the medium (the source), and the medium itself. The standing-wave concept can be used to determine the resonant frequency of air columns.

Imagine a column of air that is open at the top but closed at the bottom. Suppose a tuning fork or other suitable single-frequency sound source excites this column of air. The column will resonate (you will hear a loud sound) when the tuning fork source excites the air column at one of its natural (resonant) frequencies. The resonant frequency of the column occurs when its length L is such that a displacement anti-node¹ occurs at the open end where air molecules are free to vibrate, and a node occurs at the closed end where the air molecules are not allowed to vibrate.

In general, the condition for an anti-node at the open end and node at the closed end is $L = \frac{n\lambda}{4}$, where $n = 1, 3, 5, 7, \dots$. In this case, the wavelength λ of the standing wave is defined by $\lambda = \frac{4L}{n}$. Varying the amount of water in a tube changes the length of an air column. The following diagram illustrates this.



The pressure nodes in the diagram correspond to those places where the pressure does not change at all, while the pressure anti-nodes are the places where the variation in the pressure is a maximum. We can tune the air column length to resonate with a tuning fork of known frequency. From the above condition for resonance, you can determine the wavelength of the resonant standing waves and if the frequency of the tuning fork is given, you can use the following relationship to calculate the velocity of sound:

$$v = f\lambda$$

where v is the speed of either one of the traveling waves that make up the standing wave, f is the frequency of the standing wave, and λ is the wavelength of the standing wave. Note that the standing wave and both of the traveling waves that compose it have *identical* frequencies and wavelengths.

This lab will familiarize you with the phenomenon of resonance and allow you to measure the speed of sound in air. You will then compare your experimental value to the accepted value. The speed of sound in air depends on the temperature. The "accepted speed" (v_{theory}) for sound in air is given by the formula,

$$v = 332 \left(\frac{\text{m}}{\text{s}} \right) + 0.6 \left(\frac{\text{m}}{\text{s}^\circ\text{C}} \right) T$$

where v is the speed of sound in meters per second and T is the temperature in $^\circ\text{C}$.

2 Procedure

2.1 Fill the metal can reservoir with water when it is in a relatively low position

Once there is water in the reservoir, move it up and down a bit. Try and get a sense of the way the water level reacts to your movements. *Caution:* Move the reservoir slowly and wait for the water to react.

2.2 Hold a vibrating tuning fork over the open end of the tube while changing the water level

Activate the tuning fork by striking the green rubber block on your lab table. **Do not strike the tuning fork on the table or any other hard surface.** This can damage the tuning fork and ruin your results.

¹The discussion here is for the displacement wave. The pressure wave discussed later and referenced in the figure is ninety degrees out of phase with the displacement wave. This corresponds to a exchange of the nodes and anti-nodes.

Locate a fundamental resonance (loudest sound) by manipulating the water level and reactivating the tuning fork. *Slowly* move the water level up and down until you hear the sound reach a maximum volume. **Be careful** and make sure that you have found the resonance. Remember: you want to minimize the error in your measurement so you will need to get as close to the actual resonance as possible.

2.3 Read the water levels x_1 and x_2 at two successive resonance points

Record these measurements on your data table. Calculate the wavelength from the formula

$$\lambda = 2|x_1 - x_2|,$$

where $|x_1 - x_2|$ is the absolute value of $x_1 - x_2$, that is a positive quantity. A sample data table appears below but the actual data table should be drawn and recorded in your lab notebook. This is just a guide.

Trial	1	2	3
f_{fork}			
x_1			
x_2			
λ			
v_{measured}			
% error			

T_{room}	
v_{theory}	

2.4 Record the frequency of the tuning fork used

Calculate the velocity of sound (v_{measured}) using the relation, $v = f\lambda$, and record it.

2.5 Repeat

Repeat the above steps for three different frequencies of tuning forks. By averaging the three measurements you can reduce the statistical error on your measured speed of sound.

2.6 Calculate the theoretical speed of sound

Using the measurement of the room's temperature provided by the TA, compute a theoretical value for the speed of sound (v_{theory}) as given by the formula above.

3 Results

- Describe your results for this experiment.
- Name the different factors necessary for resonance and for producing a standing wave in this apparatus. You may want to draw a sketch.
- If both the ends of the tube were closed (i.e. fixed and rigid), sketch the standing wave and identify the nodes and anti-nodes.
- Do you think that the diameter of the tube has an effect on the resonance? (Think about the speakers on your stereo.) Explain.
- **As always, do not forget to include an Abstract and Conclusion in your lab write-up.**

4 Error Analysis

- How well do you think you could measure the water level positions that correspond to resonant conditions? Explain your error estimate.
- Calculate the percentage error for your averaged value of the speed of sound. Explain what you think caused a difference from the accepted value.