Waves

Purpose:

Part 1. Determine the mass per unit length of the string used to transmit transverse waves.

Part 2. Determine the speed of sound.

Discussion: mechanical waves are disturbances that propagate through a medium. In today’s lab, we will investigate the behavior of both transverse and longitudinal waves. In part 1, a small vibrator is used to set up transverse waves on a taut string. The greater the tension on the string, the faster the wave travels, \( v = f \lambda \). You will collect data on tension, \( T = mg \), and wavelength of the resulting standing wave.

By increasing the tension in the string, the wave speed increases and the resulting standing wavelength will increase. Frequency is set at 120Hz.

In part 2, a standing wave is produced in a hollow tube closed at one end. The length of the tube is changed by changing the water level. The standing wavelength is determined by both its frequency and the length of the air column.

The length of the wave, \( L \), is slightly longer than the air column, \( L_0 \), and must be adjusted as follows:

\[
L = L_0 + 0.3d \quad d = \text{inside tube diameter}
\]

\[
L = \frac{1}{4} \lambda \quad \text{(column on the left)}
\]

\[
L = \frac{3}{4} \lambda \quad \text{(column on the right)}
\]

In part 2, you will collect data on length of air column and tube diameter. The frequency is fixed by the tuning fork used to set up the resonance condition.
Procedure Part 1

After plugging in the 120Hz wiggle-o-matic, begin adding mass to the hanger. Add 10-20g at a time until you begin to see a pattern of standing waves. Once you begin to see a pattern, adjust the mass on the hanger until the pattern becomes strong and steady. Measure and record one wavelength, two loops or antinodes, and the mass including the 50g hanger. For best accuracy, measure the length of all loops, L, divided by the number of loops, n, and multiply by 2 to find the wavelength, \( \lambda \). Repeat by increasing the hanging mass until the next pattern appears which should have one less antinode. Repeat until you have recorded a minimum of 5 data points. Each trial has a different value of “n.”

The relationship between tension, T, and wave speed, v, is: \( v = \sqrt{\frac{T}{\mu}} \) or \( \sqrt{T} = \sqrt{\mu} \cdot v \)

Plot \( \sqrt{T} \) as a function of v to find the value of \( \mu \), the mass per unit length of the string in units of kg/m.

\( L = \underline{\text{__________}} \) (length of vibrating string)
\( f = 120\text{Hz} \)

<table>
<thead>
<tr>
<th>trial</th>
<th>n</th>
<th>( \lambda ) (m)</th>
<th>v (m/s)</th>
<th>m (kg)</th>
<th>T (N)</th>
<th>( \sqrt{T} ) (( \sqrt{N} ))</th>
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(conduct a minimum of 5 trials to complete the above table)

Use the balance to measure the actual value of \( \mu \) by dividing the mass by the length of a similar piece of string, or the one used in the experiment.

**Results for part 1 is the experimental value of \( \mu \), the mass per unit length and error.**

**Procedure Part 2**

Record the frequency of the tuning fork. Give the tuning fork a substantial whack with the rubber mallet and hold it just above the tube. Listen for and adjust the length of the air column by raising or lowering the cup until the sound is loudest. This should occur at several positions along the length of the tube. The shortest length represents the 1/4\( \lambda \) position and the next shortest, approx 3 times the length of the 1/4\( \lambda \), represents the 3/4\( \lambda \) resonance. Make the adjustment to the tube length to calculate the actual wavelength.

\( L = L_0 + .3d \) (refer to the figure above)

Calculate the wavelength for each resonance point and find the average. Using the frequency and average wavelength, determine the speed of sound.

Calculate the theoretical value for the speed of sound: \( v = \sqrt{\frac{\gamma P_0}{\rho}} \)

\( \gamma = 1.402 \) (ratio of specific heat at constant pressure to specific heat at constant volume)

\( P_0 = \) static pressure in units of Pascals(N/m\(^2\)) use 101,000Pa = 76mmHg to convert.
\( \rho = \text{air density in kg/m}^3; \ \rho = 1.2929 \left( \frac{273.23K}{T} \right) \)

The result for Part 2 is your experimental speed of sound, the theoretical speed of sound and relative error.

Supplemental Questions: (write the questions and show your work)

1. Using the theoretical equation for wave speed, determine by what factor the wave speed would change if the linear mass density of the string were doubled.

2. Do a rough estimate of the total force on the neck of a guitar. Show your estimated values for: length of strings, frequency, wavelength, and string linear density. (no actual measuring allowed!)

3. You are at a track meet and measure the time for the sound of the starter gun to reach you as 2.8s. Use the above equations for part 2 to determine first, the air density and then the temperature.
Supplemental Questions: write questions and show all work.

1. Discuss an experiment to find the air temperature using the principles in part 2 of this lab.

2. Using the principles of part 1, discuss guitar design in context of string diameter and placement. Why not use strings of the same diameter and just vary the tension to produce different pitches?

3. What is the Doppler effect and discuss two practical applications.