Standing Waves on a String

Equipment:

- Function Generator
- Mechanical Driver aka String Oscillator (It is a speaker with a string is tied to the post.)
- Table Clamp with a pulley on a post
- BNC to alligator clips cable
- Mass hanger
- Set of masses

Objectives:

- *To find the linear mass density of the string using the relationship between the number of segments in the standing wave and the tension in the string along with the frequency of oscillation of the string.*

Introduction:

When a stretched string is plucked, it will vibrate in its fundamental mode in a single segment with nodes on each end. If the string is driven at this fundamental frequency, a standing wave is formed. Standing waves also form if the string is driven at any integer multiple of the fundamental frequency. These higher frequencies are called the harmonics.

Each segment is equal to half a wavelength. In general, for a given harmonic, the wavelength is given by:

$$n(\lambda/2) = L$$

where L is the length of the stretched string and n is the number of vibrating segments in the string.

The linear mass density of the string can be directly measured by weighing a known length of the string. The density is the mass of the string per unit length.

$$\mu = m/L$$

The linear mass density of the string can also be found by studying the relationship between the tension, frequency, length of the string, and the number of segments in the standing wave. To derive this relationship, the velocity of the wave is expressed in two ways.

The velocity of any wave is given by $\boldsymbol{v = \lambda f}$**,** where $\boldsymbol{f}$ is the frequency of the wave.

The velocity of a wave traveling in a string is also dependent on the tension, F_T, in the string and the linear mass density, $\boldsymbol{\mu}$**,** of the string:

$$v = \sqrt{F_T/\mu}$$

In this experiment we need to set conditions that will lead to standing waves in a stretched string. Unlike a spring-mass system, a string has many different resonant frequencies. There are two waves moving in opposite directions in the string, getting reflected at the end points and interfering with each other, following the principle of superposition. For some combinations of tension, string length, and string linear mass density, the resulting pattern due to the two interfering waves is a vibration of the string in loops whose crests are stationary unlike those of a traveling wave. If this string is driven by an oscillator and the oscillator's frequency matches one of the resonant frequencies of the string, large amplitude standing waves will be observed.

Data Recording:

1. Pass the string from the String Oscillator (i.e. the Speaker) over a pulley and hang the mass hanger on the loop at the loose end. Add mass as needed.
2. Adjust the pulley, so that the string is parallel to the tabletop
3. Measure the vibrating length of the string, *L*.
    - The length *L* of the string is the length ***only*** from the string post to the pulley. The vertical part of the string isn't vibrating, so it doesn't count as part of the length.
4. Connect the String Oscillator to the signal generator with a BNC cable. Ground the circuit by connecting the Output of PASCO (⏚) to one of the speaker terminals with a banana cable.
5. Set the Function Generator as follows:
    - Frequency (FREQ) = 10 Hz
    - Amplitude (AMPL) = 20 V.
6. Adjust the frequency gradually so that a single segment of the standing wave forms on the string.
7. Optimize the frequency (to nearest tenth of Hz) to make largest amplitude standing waves on the string.
8. Record both the number of segments (n) and the frequency (f_n).
9. Repeat the procedure with this mass for higher harmonic numbers. (See Table 1.)
10. Repeat the procedure with various masses (in 10 g increments) for a series of data.

Suspended mass (kg)	**Tension (N)**	**Harmonic Number *n***	**Resonant frequency (Hz)**	**Wave speed (m/s)**	**Average wave speed, squared**
0.050					
0.060					
0.070					
0.080					

Table 1. Standing wave frequencies for a string of length ____________________.

Data Analysis:

1. Calculate the wave speed for each obtained frequency.
2. Average the wave speeds for each tension and then square the average.
3. Make a scatterplot of Average wave speed squared vs tension. Find the slope of the best fit line using the Excel trendline feature.
4. Calculate experimental value of linear mass, μ_{exp}, from the slope. Hint: $v = \sqrt{\frac{F_T}{\mu}}$
5. Directly calculate the value of linear mass, μ_{direct}, from the length and mass of the sample segment of the string provided separately from the oscillating string. DO NOT weigh or cut your string.
6. Compare the two values of μ.

Experiment	**Direct Measurements**
Trendline equation:	Mass of a string segment (kg) =
Slope =	Length of a string segment (m) =
μ_{exp} (kg/m) =	μ_{direct} (kg/m) =
% Difference =	

Table 2. Values of linear mass of the string obtained through the experiment and direct measurements.

Requirements for the Report:

The report must contain a **Header** at the top (Title of Lab, Authors, and Date)

Abstract Section must contain the following in paragraph form:

- Brief Introduction that includes objectives and basic theory of the lab.
- Methodology describing broadly what was done, using what tools, and what was measured/recorded. Make sure you explain how wave speed, tension, μ_{direct}, and μ_{exp} were determined in the experiment. Use equations to support your statements.
- Data Summary including quantities worked into sentences.
  - What does the data show about the relationship between resonant frequency and wave speed?
  - What does the data show about the relationship between wave speed and tension force?
  - How does experimental μ compare to direct μ? What potential errors could have led to the observed % difference?
- Conclusions based on the quantitative results and possible sources of Error. DO NOT use "human error".

Data Section must contain the following:
[Each table and graph should be labeled and descriptively captioned.]
- 2 Tables
- 1 Graph