Standing Waves on a String (Remote)

Equipment:

- No special safety equipment is required for this lab
- Computer with modern HTML5 web browser
- http://thephysicsaviary.com/Physics/Programs/Labs/StandingWaves/

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. Open the Physics Aviary simulation for standing waves and click begin.
   http://thephysicsaviary.com/Physics/Programs/Labs/StandingWaves/
2. Set the String Tension to 3 N. All other parameters will remain the same throughout lab:
   - Frequency = 2 Hz
   - Amplitude = 12 cm
   - Linear Density = 0.1 kg/m
3. Click the Power button to form a standing wave.
4. Click Activate Grid to show a ruler behind the standing wave. (units are in meters)
5. Select "(Node/Node) Show Fundamental" option to establish boundary points for the string. The boundaries are shown as two gray poles with the string oscillating up and down as a single large wave segment. This is the fundamental harmonic of the string (n=1) based on the selected parameters.
6. Measure the length of the string between the poles.
7. Calculate the wavelength of the fundamental harmonic using the measured string length and the first equation in the Introduction.
8. Calculate wave speed using the displayed frequency, the calculated wavelength, and the wave speed equation in the Introduction.
9. Select "Show 2nd Harmonic" option directly below the "(Node/Node) Show Fundamental" option. This is the 2nd harmonic of the string (n=2) based on the selected parameters. The wave oscillates up and down between the poles as two wave segments.
10. Measure the length of the string between the poles. It will be longer than the fundamental.
11. Calculate the wavelength of the 2nd harmonic, and calculate the corresponding wave speed.
12. Average the wave speeds of the 1st and 2nd harmonics, then square the average.
13. Click the Power button to stop the oscillating wave.
14. Repeat steps 3-13 four more times while increasing String Tension in increments of 2 N up to 11 N.

Tension (*N*)	Harmonic Number *n*	String Length (*m*)	Wavelength (*m*)	Frequency (*Hz*)	Wave Speed (*m/s*)	Avg. Wave Speed Squared (m^2/s^2)
3						
5						
7						
9						
11						

Table 1. Wavelength and wave speed for varying amounts of tension.

Data Analysis:

1. Make a scatterplot of average wave speed squared vs tension. Find the slope of the best fit line using the Excel trendline feature.
2. Calculate the experimental value of linear mass, $\mu_{calculated}$, from the slope. Hint: $v = \sqrt{\frac{F_T}{\mu}}$
3. Compare the calculated linear mass with the linear mass established by the simulation ($\mu_{displayed}$). Calculate the % error of linear density assuming $\mu_{displayed}$ is the accepted value.

Trendline Equation:	
Slope =	
$\mu_{calculated}$ =	
$\mu_{displayed}$ =	
% Error	

Table 2. Values of linear mass of the string obtained through the experiment and displayed in the simulation.

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 string length, wavelength, wave speed, $\mu_{calculated}$, and $\mu_{displayed}$ were determined in the experiment. Use equations to support your statements.
- Data Summary including quantities worked into sentences.
  - Does wavelength change as you increase the harmonic number? Why or why not?
  - What does the data show about the relationship between frequency and wave speed?
  - What does the data show about the relationship between wave speed and tension force?
  - How does calculated μ compare to displayed 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