Standing Waves on a String

I. EQUIPMENT LIST

String Oscillator	String
Function Generator	Banana – BNC cables
Table clamp w/rod	Meter stick
Table clamp w/pulley	Electronic scale
Slotted mass set and hanger	

II. BACKGROUND INFORMATION

Stringed musical instruments, such as a guitar, violin or harp, have strings that are u nder tension between two fixed end points. When the string is excited by plucking, striking or bowing, waves of different frequencies will travel back and forth on the string. The waves will reflect from the fixed ends. For a few of the waves, their wavelengths match the conditions of the string and they will produce a standing wave pattern. This is because the waves moving on the string interfere with each other as the travel along the string. At some points the interference is always destructive and creates nodes and at other points the interference is constructive and an antinode appears. A set of frequencies will produce different standing wave patterns. As the frequency increases, the number of nodes and antinodes on the string increases. A standing wave pattern where the length of the string is one wavelength will have three nodes (one at each end and one in the middle) and two antinodes. The frequencies that produce the standing waves are the resonant frequencies of the string.

The standing waves are produced when the frequencies have wavelengths λ such that the following condition is met: $L = n\,\frac{\lambda}{2}$

…where L is the length of the string and n is an integer. The frequency f and wavelength λ are related by; $v = \lambda f$

…and the speed of the traveling wave on the string is given by;

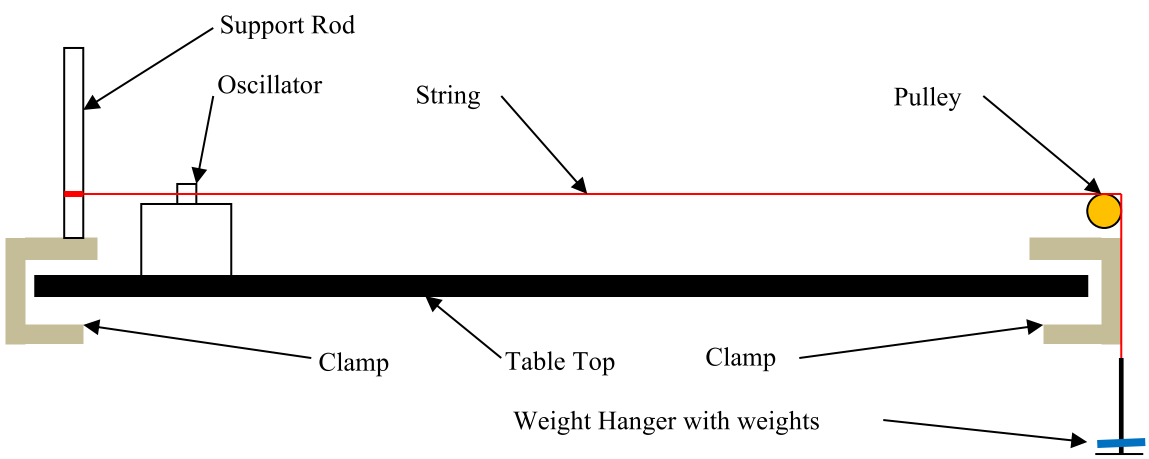
$$v = \sqrt{T/\mu}$$

…where T is the tension in the string and μ is the linear density of the string in kg/m.

Changing the tension or the frequency will change the standing wave pattern. In this lab the standing wave will be set up in the lightweight line. The vibrator will produce the frequency in the string. The tension in the string is provided by masses ($T = mg$) at one end and the vibrator at the other.

III. EXPERIMENTAL PROCEDURE

1. Initially slide the drive arm of oscillator to <u>lock position</u> (This protects the speaker as you connect the drive arm to a string or other apparatus).



Set up Diagram

2. Attach a clamp on each side of the table. One clamp has a support rod while the other clamp holds a pulley.
3. Fasten one end of the oscillator string to the Support Rod. Place the oscillator at this end as close to the clamp as possible. Pass the string through the oscillator's string holder and the other end over the pulley on the other side of the table.
4. Fasten a mass hanger to the end over the pulley as shown in the figure above. Measure the length of the string between the Pulley and the Oscillator.
5. Connect the Function Generator to the Oscillator using the Banana – Banana/BNC cable and plug in the Function Generator .
6. **Slide the drive arm of oscillator to unlock position.**
7. Turn on the Function Generator and set it for approx. 50 Hz.
8. Add a 500 gram mass.
9. Use the Function Generator to adjust the frequency and the amplitude of the wave until the string exhibits a standing wave with one or two antinodes. If necessary, adjust the tension by adding or removing small masses, or adjusting the length of the string slightly by sliding the Oscillator closer to the Pulley end of the string.
10. Measure the distance from the vibrator to the first node. Repeat measurements between other nodes. The distance between successive nodes is equal to one-half wavelength. Record the distances in meters and the tension in Newtons for this situation.
11. Adjust the frequency (or tension) to achieve a standing wave of 3, 4, 5, and 6 segments for four separate trials. In each trial measure the distance between successive nodes and record the wavelength and corresponding tension.
12. After the experiment is done, slide the drive arm of oscillator to lock position.

IV. DATA

1. Measure the length of the sample string (approximately 1.2 m), measure its mass on the digital scale, and compute the linear density. 149.5 cm / 2.33 g = 64.163 cm/g
2. Record the length L of the string between stationary supports.

112 cm (length of string)

3. Perform **constant tension** measurements and record data in **Table 1** of the data sheet.
a. Adjust and record the frequency to achieve a standing wave of 1-6 antinode segments. Also record the range in frequency for which the same standing wave pattern is produced.
b. In each trial determine the distance between successive nodes by dividing the length of the string between the stationary supports by the number of antinodes.

4. Perform **constant frequency** measurements and record data in **Table 2** of the data sheet.
a. Lower the frequency of the function generator to about 50-100 Hz.
b. Adjust the mass on the hanger to obtain a standing wave of with 2-6 antinode segments, starting with about 600 g and going down.
<u>Do not overload the weight hanger. If there is too much mass, the Oscillator may have trouble vibrating the string.</u>
c. Determine the distance between successive nodes as in the previous set of measurements.

V. DATA ANALYSIS

1. Calculate the quantities in Tables 1 and 2:
   a. Calculate the wavelength for each standing wave situation.
   b. Compute the speed of the wave by using the wavelength and frequency.
   c. Compute the speed of the wave using the tension and mass density.
   d. Compare the values computed in steps 3 and 4 by calculating the percent difference. This will be an extra column in your analysis tables.

2. Use the data in Table 1. to graph the frequency (on y) versus the inverse wavelength (on x).
   a. What is the shape of the curve?
   b. Perform a linear fit.
   c. Express the slope in terms of tension T and density μ.
   d. Compare the slope of the fit to the value of the wave speed calculated using the tension and the linear mass density, i.e. calculate the percent difference.

3. Use the data in Table 2. to graph $\ln(v)$ – on y, versus $\ln(T)$ – on x, using the speed calculated from wavelength and frequency.
   a. Perform a linear fit.
   b. Find the analytical expression of the line and clearly indicate the slope and the intercept.
   c. Compare the slope of your fit to the theoretical value, i.e. calculate the percent difference.

4. What conclusions – if any - can you reach about the relationship between the speed of the traveling wave on the string and the number of antinodes in the standing wave pattern? Make sure to comment separately on the data from Table 1 and Table 2 and to back up your statements with known theory.

DATA SHEET

Sample string: $L \pm \Delta L =$ 149.5 ± .2 cm $\mu = \frac{m}{L}$

$m \pm \Delta m =$ 2.33 ± .005g $\mu \pm \Delta\mu =$ 0.0156 ± g/cm

String length: $L \pm \Delta L =$ 112 cm ± .2cm

Table 1. Constant tension measurements

Hanging mass: $m \pm \Delta m =$ 551 ± 2g

f (Hz)	Δf (Hz)	n	$\lambda = \frac{2L}{n}$ (m)	$\frac{1}{\lambda}$ (m^{-1})	$v_{meas} = \lambda f$ (m/s)	$v_{calc} = \sqrt{T/\mu}$ (m/s)	$\frac{\Delta v}{v}$ (%)
26.5	1	1					
53	1	2					
80	1	3	99.$\overline{6}$	.010	7973.$\overline{3}$		
107	1	4					
134.5	1	5					
161	1	6					

Table 1. Constant frequency measurements

Frequency: $f \pm \Delta f =$ 58 ± .05

m (kg)	T (N)	$\ln(T)$	n	$\lambda = \frac{2L}{n}$ (m)	$v_{meas} = \lambda f$ (m/s)	$ln(v_{meas})$	$v_{calc} = \sqrt{T/\mu}$ (m/s)	$\frac{\Delta v}{v}$ (%)
.662			2					
.285			3					
.160			4					
.100			5					
.066			6					