S3c: Standing Waves on a String

Introduction:

Waves lapping up on the beautiful beach shore, the ripples in a pond, the sound of a physics instructor's voice, and even the music that emerges from the radio; all of these phenomena have one major thing in common: waves. A wave is a disturbance in a medium, through which the disturbance can travel, or propagate, from one area in the medium to another. This commonly accepted definition is by no means a concrete standard, and due to the complexity of what a wave is and how it behaves Wave Theory in physics is one of the more complex branches of study.

In an effort to provide familiarity with waves and their behavior, this experiment is designed to examine the relationship between wavelength, linear density, frequency, and tension of a vibrating string. Two strings with different density will be analyzed. Changing the frequency of the oscillations it will be possible to find different harmonics, calculate the wavelength, and finally determine the tension for each string.

Apparatus:

- Mechanical Wave Driver
- Pulley with clamp
- Mounting hardware
- 2 Strings with different density
- Mass set with hangers
- Precision mass scale
- Meter stick
- Computer with interface and software

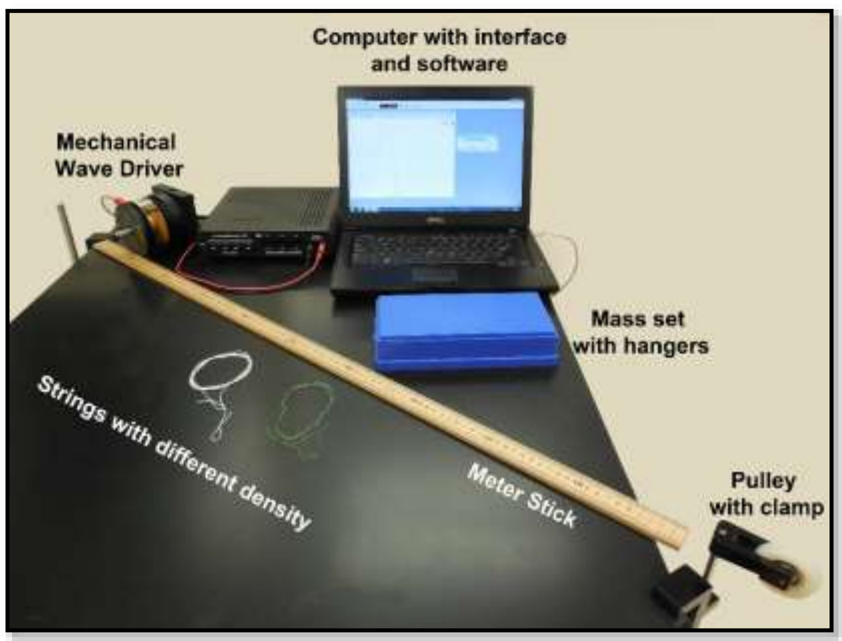

Figure 1

Discussion:

Rather than try to establish a universal definition for what it means to be characterized as a wave, instead the focus will center on the behavior of waves as they travel down a vibrating string, also known as a transverse wave. In a transverse wave the displacement of the medium (in this case the displacement of the string) is perpendicular, or *transverse*, to the direction of travel of the wave. The form of a wave can be represented graphically as either a sine or cosine function, or even a sum of the two. The amplitude of a wave is the maximum displacement of a particle from the equilibrium position; for this experiment, the equilibrium position will be when no wave is travelling through the string. The wavelength, λ, is the distance between successive corresponding points on a wave, e.g., between successive crests or valleys. Consider the representation offered in **Figure 2**.

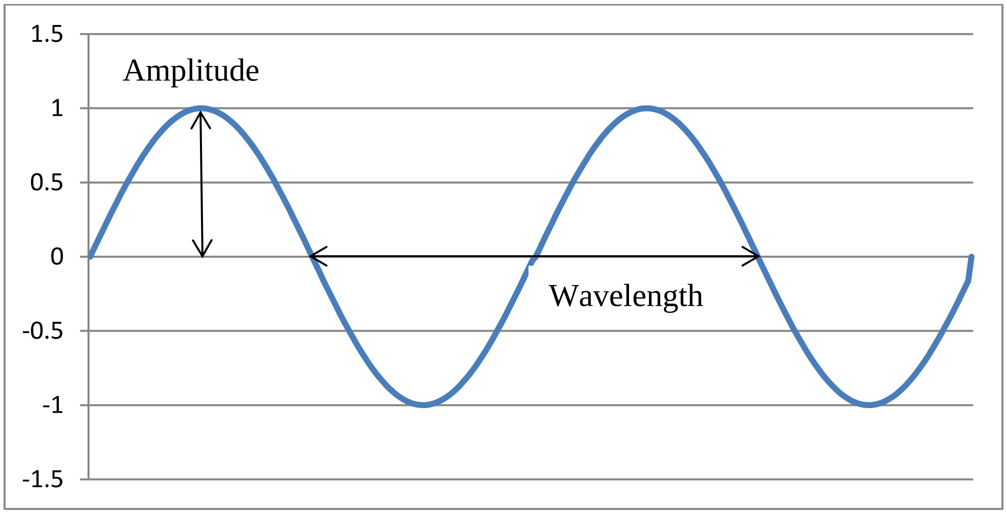

Figure 2

The frequency, f, of a wave is the number of waves generated per unit time, and is usually expressed in vibrations (cycles) per second. The period, T, the time required for the generation of a single wave, is the reciprocal of the frequency.

$$T = \frac{1}{f} \qquad (1)$$

A simple relationship exists between frequency and wavelength. The wave pattern travels a distance λ over a time of one period T, that is, the speed of the wave v is given by $v = \lambda/T$. Noting that $f = 1/T$, we get:

$$v = f\lambda \qquad (2)$$

For Part I of the experiment the waves on the string will have a constant velocity, C. We can then solve equation (2) for frequency, representing the frequency as a function of wavelength:

$$f = C\lambda^{-1} \qquad (3)$$

where C is the constant velocity. When the frequency is graphed as a function of wavelength, equation (3) may be used to determine the velocity from the graph.

In the set up for this lab, waves reach the end of the string fairly soon, where they are reflected. Hence two wave “trains” traveling in opposite directions are present simultaneously. See **Figure 3**. If the proper relationship exists between the frequency, the string length and the string tension, a standing wave is produced. When conditions are such as to make the amplitude of the standing wave a maximum, the system is said to be in resonance.

Along a standing wave there are points that do not move at all, known as nodes. Midway between two consecutive nodes are points called antinodes, where the amplitude is greatest. See **Figure 3**. In this lab you will measure the distance between two nodes, also called the internodal distance, in order to calculate the wavelength of the wave.

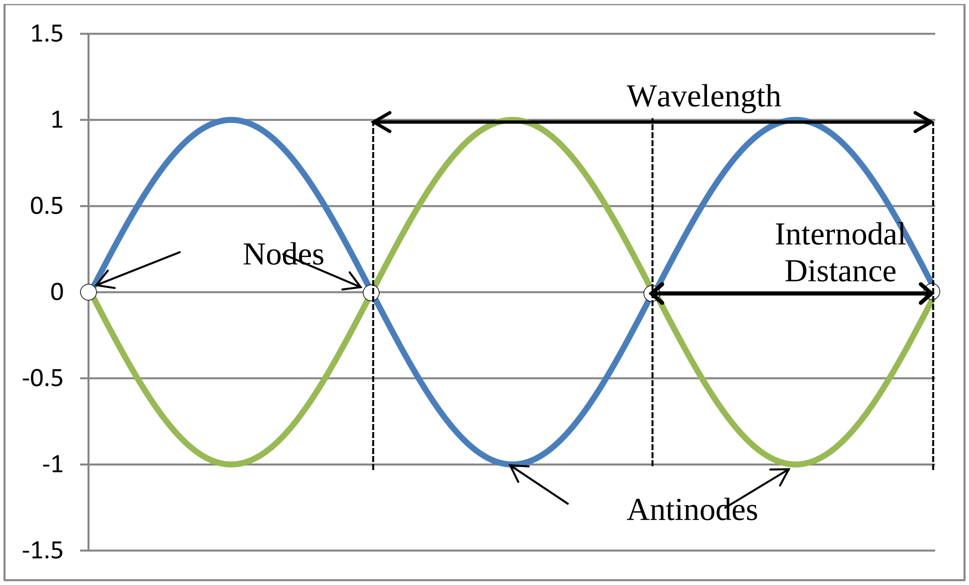

Figure 3

We have seen that the velocity of the transverse wave has a simple relationship to the frequency and wavelength of the wave. As we will see, there is also a simple relationship between the physical properties of the wave and the velocity. These physical properties turn out to be the tension, F, in the string, and the mass, m, per unit length, l, also called linear density, ρ, of the string, where

$$\rho = \frac{m}{l} \qquad (4)$$

We might guess that increasing the tension in the string would also increase the velocity of the wave, and that increasing the mass (and thus the linear density) would make the string heavy and slow, thereby decreasing the velocity. Both of these guesses turn out to be correct, and the equation relating them is:

$$v = \sqrt{\frac{F}{\rho}} \qquad (5)$$

Procedures:

Part I: Constant Wave Velocity

1. Beginning with the thinnest string of the two, measure its mass and length. Note the strings in this experiment are very light so measure the mass with precision to a ten-thousandth of a gram. Measure the string lengths with precision to a millimeter. Record the measurements on Table 1. Mass should be reported in Kilograms and length in meters.
2. Tie one side of the first string to the post attached to the table and place the other side over the pulley.
3. Suspend the mass hanger with a 20 gram mass added on the loose end of the string over the pulley.
4. Open the corresponding data collection program and have a lab instructor give you instructions about the oscillator and the function generator.
5. Adjust the frequency of the function generator until the string oscillates with a standing wave of one loop. Record the oscillation frequency, the number of loops, and the internodal distance.
6. Repeat step 5 for standing waves of 2, 3, 4 and 5 loops. Record all of the information on Table 1.
7. Remove the string.
8. Repeat steps 1 thru 7 for the second string recording the information on Table 2.

Part IIa: Constant Wavelength

9. Use Second string, the thickest one, for the remaining experimental trials. Begin with 20 grams on the mass hanger and the oscillation frequency set at 50Hz.
10. Adjust the oscillation frequency until the string oscillates with a standing wave of three loops having the maximum amplitude.
11. Determine the internodal distance for this standing wave.
12. Record the total hanging mass, the number of loops, the frequency and the internodal distance in Table 3.
13. Add 10 grams to the mass hanger and measure. Repeat steps 10 thru 12.
14. Add another 10 grams to the mass hanger and measure. Repeat steps 10 thru 12.

Part IIb: Constant Frequency

15. Keep the setup the same as the last trial you completed: use the same frequency and start with the same total mass.
16. Adjust the mass on the mass hanger until four loops are obtained having the maximum amplitude. This will require gradually reducing the mass.
17. Determine the internodal distance.
18. Measure the total mass hanging from the string, including the mass hanger as well.
19. Record the total hanging mass, the number of loops, the frequency and the internodal distance in Table 3.
20. Adjust the mass until five loops are obtained, repeating steps 16 thru 19.
21. Adjust the mass until six loops are obtained, repeating steps 16 thru 19.

Analysis:

Part I: Constant Wave Velocity

1. For Table 1.
2. Calculate the linear density of the string in units of (kg/m), Equation (4).
3. Calculate the wavelength of the standing wave using the internodal distance, Figure 3.
4. Graph the frequency of the wave as a function of the wavelength using Excel.
5. Choose the appropriate trendline fit in Excel for the data, Equation (3). Next use the equation of the fit to determine the experimental wave velocity.
6. Calculate the value of the velocity of the wave using Equation (5).
7. Calculate the percent difference between the wave velocities.
8. Repeat these steps 2 thru 7 for data collected in Table 2.

Part II: Constant Wavelength and Constant Frequency
(Use measurements from table 3 and register the calculations on table 4)

1. Calculate the wavelength for each trial using the internodal distance, Figure 3.
2. Calculate the wave velocity for each trial using Equation (2).
3. Calculate the tension in the string for each trial due to the hanging mass.
4. Calculate the linear density for each trial, Equation (5).
5. Calculate the mean and standard deviation for the linear density.
6. Calculate the percent difference between the linear density found in Table 2 for string #2, and the mean linear density found in Table 4.

Experiment S3c: Standing Waves on a String

Student Name______________________________________

*Lab Partner Name*_______________________________________

*Lab Partner Name*_______________________________________

Physics Course____________________________________

Physics Professor__________________________________

Experiment Start Date______________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: Part I: S3c: Standing Waves on a String

NAME: ____________________________   DATE: _________________

Table 1: String #1

Hanging Mass: **Tension:**

String Mass: **String Length:**

Linear Density:

Frequency	# Loops	Internodal Distance	Wavelength
	1		
	2		
	3		
	4		
	5		

Wave Velocity from graph =__________

Wave Velocity = $v = \sqrt{\frac{F}{\rho}}$ = ___________

% Difference:___________

Data Sheets: Part I: S3c: Standing Waves on a String

NAME: _____________________________ DATE: _________________

Table 2: String #2

Hanging Mass: **Tension:**

String Mass: **String Length:**

Linear Density:

Frequency (Hz)	# Loops	Internodal Distance	Wavelength
	1		
	2		
	3		
	4		
	5		

Wave Velocity from graph =_________

Wave Velocity = $v = \sqrt{\frac{F}{\rho}} =$ ___________

% Difference:___________

Data Sheet: Part II: S3c: Standing Waves on a String

NAME: ____________________________ DATE: _________________

Table 3: String #2 - Constant Wavelength and Constant Frequency

# of loops	Internodal Distance (m)	Frequency (Hz)	Mass (kg)

Data Sheet 4: Part II: S3c: Standing Waves on a String

NAME: ____________________________ DATE: _________________

Table 4: CALCULATIONS FROM TABLE 3

Wavelength (m)	Velocity (m/s)	Tension (N)	Linear Density (kg/m)

Mean Linear Density: ___________________

Standard Deviation: ___________________

Percent Difference: ___________________