PHY 157
Standing Waves on a String
(Experiment 5)

Name: _____

1 Introduction

In this lab you will observe standing waves on a string. You will also investigate the relationship between wave speed and tension in the string and verify the theoretical formula for wave speed.

The speed v of waves on a stretched string will be determined using the basic wave relationship $v = f\lambda$, where f is the frequency of the waves and λ is their wavelength. A sketch of the experimental apparatus is shown in Figure 1. One end of a string is attached to a vibrator of *fixed* frequency f and the other end is passed over a pulley and attached to hanging mass M. The *weight* of the hanging mass produces a tension in the string which determines the speed of the waves that travel on the string. The frequency of the electric current that drives the vibrator is 60 Hz, but since the vibrator vibrates twice for each cycle of electric current, its *frequency* (and thus the wave frequency f) is 120 Hz. The wavelength of a wave can be determined by setting up a setting up standing waves of known length in the string. Since you want to collect wave speed data as a function of string tension, you will have to adjust the string tension to values that will allow standing waves to occur on the string. The *wavelength* of the waves is then determined from length L (the vibrating length of the string) and the number of vibrating segments on this length. Once frequency and wavelength are known, the *speed of the waves* is determined using the frequency/wavelength formula given above. Recall that a standing-wave pattern will vibrate on a string of length L when an *integer number of half-wavelengths* of the wave

fit into length L. The wave speed vs. string tension data will be analyzed using a curve-fit program to determine the relationship between them.

2 Apparatus

- 60 Hz string vibrator
- String
- Mass set and hanger
- Metric tape
- Table support rod
- Rod clamp
- Table pulley
- Milligram balance

3 Procedure

1. Measure and record the *entire* length of the string. Don't untie knots, just *estimate* the length of the string in each knot and add it to the measured length.

   Measure the mass of the string on a milligram balance and record.

   Use the measured mass and length to determine the linear mass density of the string in units of *kg/m*.

2. Attach the string to the vibrator, run it over the table pulley, and attach the other end to a mass hanger. The mass of the hanger is 5 g. Adjust the vibrator so that the wave amplitudes will be horizontal to the top of the table.

   (a) Record the frequency of the vibrator.

   (b) To become familiar with the effect of changing the string tension, turn on the vibrator and gently pull down on the mass hanger until a standing wave pattern is obtained. Try to obtain a number of different patterns. As string tension is increased, does the number of standing wave segments increase or decrease?

(c) Carefully measure and record the vibrating length L of the string from the end of the vibrator to the top of the pulley. This distance is the length of string into which the standing wave segments must fit.

3. Use the following table to record your data.

# Vibrating segments	Hanging mass (g)

(a) Place masses on the hanger until a standing wave pattern of 6 vibrating segments is set up on the string. The standing wave pattern is often sensitive to changes in tension due to mass changes as small as ± 2 g. Adjust the amount of mass so that you obtain a standing wave pattern with *maximum amplitude* at the antinodes. Record the total mass that produces this standing-wave pattern.

(b) Repeat for 5, 4, 3, and 2 vibrating segments.

4   Analysis

1. Use the following analysis table for your analysis.

# Vibrating segments	Wavelength (m)	Wave speed (m/s)	Tension (N)

For each experimental standing wave pattern, determine the wavelength of the waves and use the frequency/wavelength formula to determine *wave speed*. Then use the hanging mass for each case to determine the *tension* in the string. (Then tension will be mg, where m is the total mass (including hanger) and g is the acceleration due to gravity, 9.8 m/s^2.)

2. **Theory.** The theoretical formula for wave speed v on a stretched string is

$$v = \sqrt{\frac{F}{m/L}}. \tag{1}$$

Here F is the tension (in newtons) in the string and m/L is the linear mass density (in kg/m) of the string. Thus the theoretical formula for wave speed is not a linear function. However, if this equation is *squared*, it predicts that the speed squared, v^2, is a *linear function* of string tension, F, with a slope equal to the reciprocal of the linear density of the string. This formula can be verified using your experimental data for wave speed by finding the square of your measured speeds and making a plot of v^2 vs. F.

3. **Analysis of the v^2 vs. tension data.** Plot the square of the speed (v^2) vs. tension. Draw a sketch of the resulting graph. Is this relationship linear? (It should be.)

If you obtain a linear relationship, then you have verified the form of the theoretical formula.

(a) Do a linear regression analysis of your transformed data (v^2 vs F) and report the slope and y-intercept with the proper units.

(b) You have verified the form of the theoretical formula for wave speed, but not the explicit formula. In order to completely verify the theoretical speed formula for transverse waves, your data must also correctly predict the slope of the theoretical formula. Determine and report the reciprocal of your measured linear mass density of the string. This is the theoretical value for the slope of your linear graph.

(c) Compare the experimental slope to the theoretical slope. Does your data tend to verifty the theoretical formula for wave speed, equation (1)?
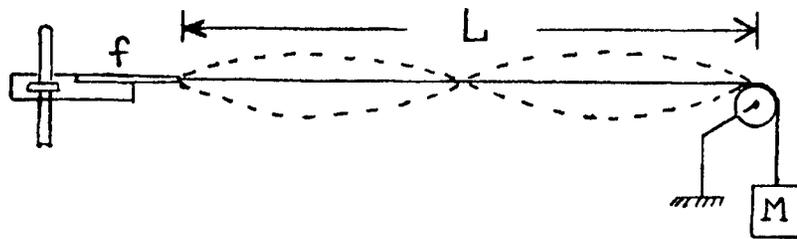
Figure 1.