WAVES ON A STRING

Objectives: • Measure the frequency, wavelength, and speed of waves on a string
• Examine how string mass, tension, and length affect the resonant frequency

To Do Before Lab: • Read this lab
• Review Taylor Ch. 3 and think about how the error propagation formulas will be applied in this lab

Apparatus: Strings, masses, loudspeaker, function generator, oscilloscope, meter sticks, strobe light, tuning fork. Begin with 1kg on the string.

Introduction:
Vibrating strings have been used throughout the world, for thousands of years, to produce musical sounds. Familiar examples include the violin, piano, ukulele, zither, and harp. In this lab you will investigate some of the basic phenomena common to all stringed instruments.

When a stretched string is disturbed by a source (usually plucking near an end of the string or stroking with a bow), a wave train is produced which travels along the string away from the source. When the wave reaches the end of the string it reflects and travels back toward the source end where it reflects again, and so forth. In general, the waves travelling along the string in opposite directions will interfere with each other in a complicated way and no regular wave pattern will appear on the string. However, for the right combination of frequency, wave speed, and string length, a *standing wave* or *resonance* will occur.

Standing waves are produced when two sinusoidal waves of equal amplitude and frequency travel through a medium in opposite directions. In this case, the waves traveling in opposite directions always interfere constructively at certain places on the string (called *antinodes*), and destructively at other places on the string (called *nodes*). At the antinodes the string vibrates transversely about its equilibrium position and at the nodes the string does not show any displacement at all. The resulting pattern on the string looks like a wave, but no motion along the length of the string is apparent, hence the name standing waves. The nodes and antinodes of a standing wave are evenly spaced along the string. An analysis of the interference of two waves travelling in opposite directions shows that the distance between a node and an adjacent antinode is 1/4 of a wavelength.

To produce standing waves in this experiment you will use a string clamped at one end and pulled over a pulley by some hanging masses at the other end. In this case, both ends of the string are fixed so nodes must exist at the ends. The wave source consists of a modified loudspeaker connected to a function generator. The loudspeaker is pressing against the string, and as the speaker moves back and forth it produces a continuous wave disturbance on the string.

The function generator has a frequency dial, but the scale is not very accurate. To get accurate frequency measurements the function generator is simultaneously connected to the input of the oscilloscope.

Part I:

(1) Qualitative observations of standing waves: Turn on the function generator and set the amplitude to about half maximum. At low frequencies you may not hear any sound coming from the loudspeaker, but if you look at the string or gently touch it near the speaker you should be able to tell that it is vibrating. Vary the frequency of the signal generator over a range of frequencies from 20 Hz to 200 Hz. Observe the behavior of the string, but do not make any measurements at this time.

Part II:

(1) Quantitative observations-the harmonic series: Tune the function generator to produce the *fundamental* or simplest mode with as large an amplitude as possible (this mode is also called the *first harmonic*). Sketch the vibration pattern of the string. Measure the distance between the two nodes of the standing wave. Estimate the uncertainty. Determine the wavelength of this mode with uncertainty.

(2) Use the oscilloscope to determine the period of the wave and uncertainty. Determine the frequency and uncertainty.

(3) Calculate the wave speed and the uncertainty.

(4) Tune the function generator to produce the second harmonic (or first overtone) and follow the same procedure as in steps 1, 2, and 3, but without the uncertainties. Continue the above procedure until you have measured the first 6 harmonics.

(5) Describe any patterns you are able to infer about the frequency, wavelength and speed of the standing waves in this harmonic series.

(6) Find your best estimate of the wave speed. How does the variation in your speeds compare with your estimated uncertainty?

(7) The speed of a wave on a string (any wave, not just a standing wave) is given by the theoretical formula $v = (T/\mu)^{1/2}$ where T is the tension in the string and μ is the mass per unit length of the string. A 10.00 +/- 0.01 m length of the string you are using has a mass of 12.5 +/- 0.2 g. Assume that the labels on the weights are accurate to 0.1g. Determine the mass per unit length and tension for your string and then calculate the wave speed. Calculate the uncertainty in the wave speed being sure to explicitly write out each step.

(8) Think about which uncertainties are the most important. These are called the "dominant errors". Any uncertainty that will not significantly contribute to the final uncertainty can be

ignored saving you a lot of work. Repeat your error analysis using only the dominant errors. Look at the intermediate steps in your calculations from (7) to justify this approximation.

Part III:
Examining a standing wave: For this section a strobe light is required. If the strobes are in use by other groups, work on another part and come back to this section later.

(1) Tune the function generator to produce the third harmonic.

(2) Measure the frequency of the third harmonic, then convert this frequency to cycles/minute. Set the frequency of the strobe light to match that of the function generator. Make slight adjustments to the frequency until the string appears to stand as completely still as possible. Sketch what you observe, paying particular attention to how the string in one section of the standing wave is related to the string in an adjacent section. Explain why the strobe light makes it look like the string is standing still.

(3) Adjust the strobe light to half and twice the frequency of the standing wave. Describe and explain your observations.