Lab 5: Standing Waves on a String

Pre-lab Exercise: As you have seen in class, the phase velocity of a wave on a string is given by the theoretical formula $v = \sqrt{\frac{F_T}{\mu}}$, where F_T is the tension in the string and μ is the mass per unit length, or linear density of the string.

1) A string is secured at one end while the other end runs over a pulley to a 550 g hanging mass. Assuming a frictionless pulley, what is the tension in the string?

2) A 940 cm length of the string is found to have a mass of 11.7 g. Determine the linear density of the string in kg/m.

3) Determine the speed of a wave on the string.

4) Suppose the uncertainty in the hanging mass is ± 1 g, the uncertainty in the length of the string is ± 2 cm, and the uncertainty in the string mass is ± 0.1 g. Propagate error to determine the uncertainty in the wave speed. Use the lab 3 class average for g: $g = 9.818 \pm 0.005$ m/s^2.

5) Express the speed with uncertainty in standard form, with both given to the correct precision.

Objectives

Measure the frequency, wavelength, and speed of standing waves on a string. Examine how string mass, tension, and length affect the resonant frequency.

Apparatus

Light and heavy strings, masses, pulley, function generator, amplifier, loudspeaker, 2-meter stick, strobe light.

Introduction

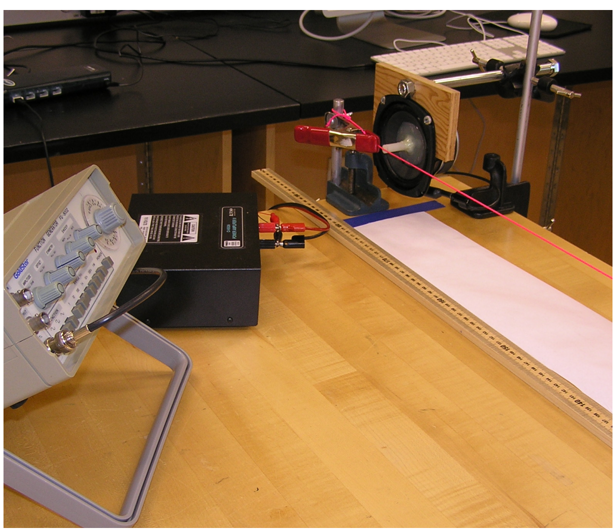
Vibrating strings have been used throughout the world, for thousands of years, to produce sound waves, or music. Familiar examples include the violin, piano, ukulele, zither, and harp. In this lab you will investigate some of the basic phenomena common to all stringed instruments.

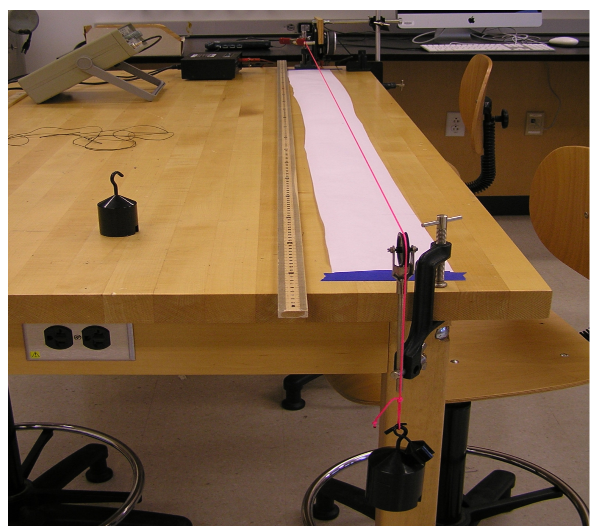
When a string under tension is disturbed by a source (for example plucking the string, or stroking it with a bow), a complicated wave train is produced which travels along the string away from the source. When the wave reaches the end of the string it is reflected and travels toward the other end of the string where it can be reflected again, and so on. The reflected waves can interfere with new waves coming from the source in a complicated way and in general, no regular wave pattern appears on the string. However, for certain frequencies, which depend on the wave speed and string length, the reflected wave will be *in phase* with new waves from the source. In this case we get a *resonance* known as a *standing wave*. When we are at a resonant frequency, the wave amplitude grows much larger than it would be for just a single wave, and the pattern seen on the string is very regular.

Standing waves are produced any time two sinusoidal waves of the same amplitude and frequency travel through a medium in opposite directions. The waves traveling in opposite directions always interfere constructively at certain places (called *antinodes*), and destructively at other places (called *nodes*). If we are dealing with *transverse* waves on a string, then at the antinodes the string moves back and forth at right angles to the direction of wave propagation. At the nodes the string does not move. 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 traveling in opposite directions shows that the distance between a node and an adjacent antinode is 1/4 of a wavelength.

Equipment

In this experiment we will produce standing waves on a string clamped at one end and pulled over a pulley and attached to a hanging mass at the other end, as shown in the photos below. The wave source consists of a modified loudspeaker connected to a function generator and power amplifier, similar to the equipment you used last week in the Resonance lab. The output of the frequency generator is connected to an oscilloscope as well as to the amplifier. A rod attached to the loudspeaker presses against the string, and as the speaker moves back and forth it produces a periodic wave disturbance on the string.





<u>Instructions</u>

The function generator has a frequency dial, but the scale is not very precise. To get better frequency measurements the voltage signal sent to the loudspeaker is simultaneously sent to the oscilloscope on your desk. Scale the sin wave appropriately and then use the "measure" button to find the frequency of your wave.

Part I:

You instructor will introduce you to the trigger capabilities of the oscilloscope. Explore the properties of these modes and write down your observations. What are the distinguishing features of each of these modes?

Part II:

Qualitative observations of standing waves: Turn on the function generator and set the amplitude such that the wave vibrates with a large amplitude, but the red light on the amplifier does not turn on. 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 and record general observations. You do not have to make quantitative measurements at this time.

Part III:

Create an experiment to determine if/how the velocity of the wave changes as the harmonic number changes. Make independent measurements of the wavelength and frequency of multiple standing waves to calculate this velocity. The uncertainty for each velocity measurement will likely be different! For each velocity data point, be sure to include a description of each measurement taken, the uncertainty of each measured quantity, a justification of that uncertainty, and the uncertainty propagation calculations. Use any and all techniques to minimize uncertainty in your measurements. Create a graph that summarizes your results and pose a conclusion based on your data. Print a copy of this graph for each group member, so that everyone can submit on copy for the post-lab. You will have to justify your conclusion to the class, so include all headings, axis titles, and error bars in your graph.

Part IV:

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.

Tune the function generator to produce the third harmonic. 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. Adjust the strobe light to half and twice the frequency of the standing wave. Describe and explain your observations.