Labs: Trigonometry Based Physics Part I

EXP 13 – Lab

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by J. T. Sizemore, P. Johnson, M. Brooks, G. Sherman, M. Broyles, A. Kumar

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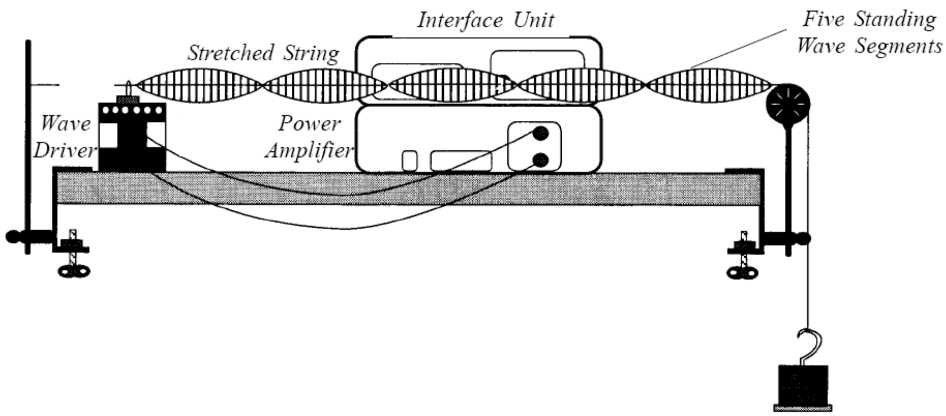
Standing Waves on a String



Purpose

In this experiment, you will explore the relationship between string length, wavelength, frequency, linear density, and string tension in a standing wave, thus gaining an empirical understanding of the normal modes of vibration in a stretched string.

Equipment

- Frequency generator
- Meter stick
- Pulley
- Banana plug patch cords (multiple)
- Mechanical wave driver
- Clamps (C clamps, table clamps)
- Amplifier (may not be necessary – output of frequency generator may provide sufficient power
- String
- Mass set with hanger (up to 2 kg total)
- Support rod

Introduction

A wave moving within any material is evidence that energy is being transported as the result of a disturbance. There are two distinct categories of waves: mechanical and electromagnetic. Mechanical waves require some kind of material to travel in, but electromagnetic waves, including light, do not.

The speed of both categories of waves depends on two properties of the material they are moving through. For mechanical waves they are an inertial property and an elastic property. For electromagnetic waves they are the permittivity and permeability of the material. For a mechanical wave in a stretched string, the inertial property is its linear density (its mass per unit length), and the elastic property is the tension force in it.

A wave will propagate along the string if you disturb its equilibrium state at any position. When the wave reaches either end, it will reflect and propagate back toward the disturbance.

If you make the disturbance repetitive by using, say, an electric vibrator at one end, the waves propagating away from the vibrator interfere with those that are reflected back from the other end. If the length of the string is an integral multiple of the half-wavelength of the interfering waves, the interference pattern (blur, wave envelope) will be stationary in the string. Such a stationary wave pattern is called a *standing wave*. Using a high speed camera we show actual motion vs. what the eye sees on this YouTube video: http://www.youtube.com/user/SizemoresScience#p/a/u/0/VmGWvuqFqxQ.

In this experiment, you will create standing waves in a stretched string and then measure their wavelength. You will explore the relationship between string length, wavelength, frequency, linear density, and string tension in a standing wave, thus gaining an empirical understanding of the normal modes of vibration in a stretched string.

You will compare your measurements of standing waves to the theory that relates these properties. When you are finished, you will be able to

1. Explain how standing waves are created.
2. Identify the nodes and antinodes and the number of segments in a standing wave.
3. Discuss the factors that determine the natural frequencies of a vibrating string.

Theory

The properties that characterize a wave are its wavelength λ, its frequency of oscillation f (measured in hertz, or $1/s = s^{-1}$), and its speed v. These properties are related by the equation:

$\lambda f = v$ **_Equation 13.1_**

Mechanical waves propagate through a medium in either a longitudinal or a transverse mode. In a longitudinal wave, each particle in the medium oscillates in the same direction as the wave propagation. Sound waves in any material travel in this manner. In transverse waves, each particle oscillates perpendicular to the direction of wave propagation. The waves in a stretched string vibrate in a traverse mode.

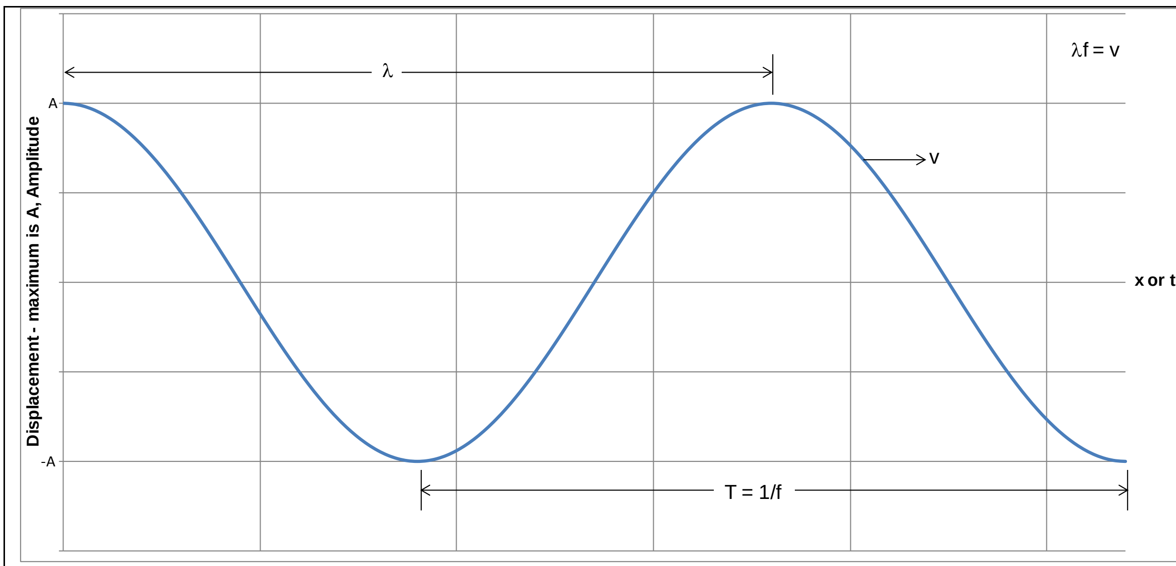


Figure 13.1 – Plot of wave height (displacement) vs. distance, x, or time, t. Interpreting this as a plot vs. x, this would be a snapshot of the wave at an instant of time. Interpreting this as a plot vs. t, then one would stay at a particular location and record the wave height as it progresses over time.

As each particle oscillates, its maximum displacement up and down is called the wave's *amplitude*, designated as $+A$ or $-A$. Figure 13.1 is a plot of displacement vs. either position or time. The energy being carried by the wave is related to its amplitude. The period of oscillation is inversely related to the frequency:

$T = 1/f$ **_Equation 13.2_**

Let's think about why Equation 13.1 and 13.2 are true. A period is the time required for a wave to go from its peak, down to the valley, and back up to the peak again when the observer is standing in one position. To understand this, go to the phet simulation (http://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html). Select "no end", "oscillate", zero damping, low frequency, and low tension. Position the computer mouse pointer where one of the green dots is at a maximized and observe the time required for the green dot to go down and back to your mouse pointer. This time is the period, *T*.

Frequency is related to the number of cycles, *n*, (up, down, and back up) observed in a given time, *t*, and is defined as:

$f = n/t$ **_Equatioon 13.3_**

The faster the wave goes up and down the higher the frequency. The time required for one cycle has the special name of period – the same period as above. When we observe only a single cycle, frequency equals one cycle per the period, or:

$f = 1/T$ **_Equation 13.4_**

It is easy to observe that rearrangement of Equation 13.4 leads to Equations 13.2.

The wavelength is the distance a wave travels in one period and has a special Greek letter for it, λ. λ is Greek for l and stands for length as in wavelength. Look at the phet simulation again. You will observe (if it is slowed down sufficiently for your eye to see) that the distance a wave travels in one period is the distance from one peak to the next peak. Wave speed is, therefore:

$v = \lambda/T$ **_Equation 13.5_**

Substituting Equation 13.2 for *T*, one obtains Equation 13.1 presented previously.

Two waves meeting each other will interfere. The combined wave they produce is a simple superposition of the two waves. If two waves moving in opposite directions have the same amplitude and frequency, their interference produces a standing wave as shown in Fig. 13.2. The positions of minimum displacement (destructive interference) are called *nodes*, and the positions of maximum displacement (constructive interference) are called *antinodes*. The length of one segment of the standing wave is equal to one-half its wavelength.

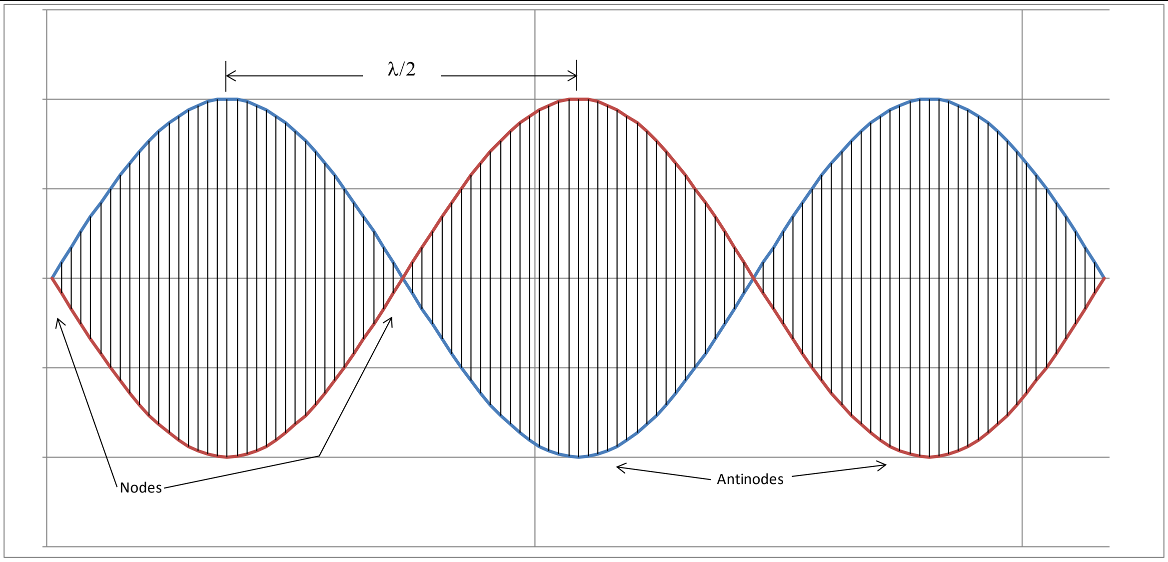


Figure 13.2 – Standing wave on a string at frequencies higher than the eye can see. The oscillating wave looks like a blur (the vertical lines). At any given point in time the wave can be at the bottom red line, or top blue line, or somewhere in between. See the High Speed Video of a standing wave to observe blurring using ordinary vision, but slow motion from a high speed camera.

When a string is vibrated at one end, waves traveling from the vibrator interfere with waves reflected from the opposite fixed end. This interference produces a standing wave in the string at specific frequencies that depend on the string's density, tension, and length. If the string is vibrated at multiples of this frequency, standing waves with multiple segments will appear. The lowest frequency (far left in Figure 13.3) is known as the *first harmonic* and higher frequencies are higher (second, third, etc.) *harmonics* (see Figure 13.3).

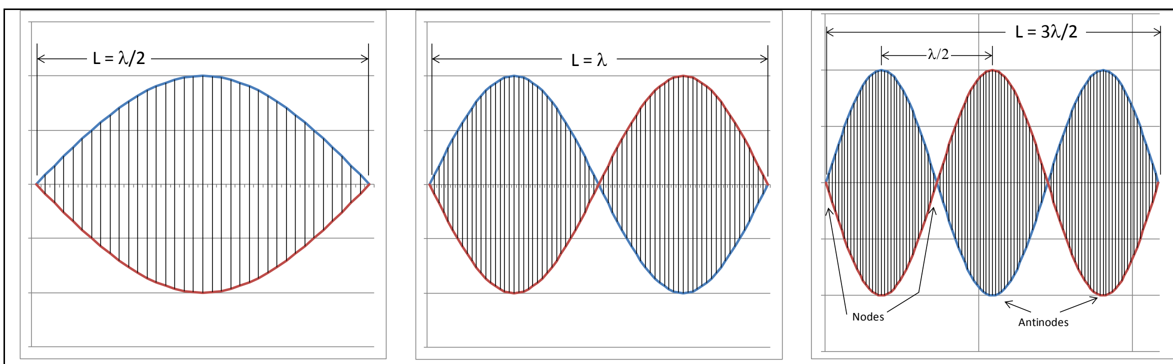


Figure 13.3 – Standing waves of three different wavelengths on the same string at resonance showing the relationship between resonant frequencies and the stringth length.

Note that each segment is equal to one-half of a wavelength. Our vision interprets the rapidly moving string as a blur, but if you video this in slow motion one can observe the entire string oscillating and, furthermore, clearly observe that a segment is one-half wavelength. Thus, for a given harmonic, the wave-length becomes:

$$\lambda = \frac{2L}{n}$$ ***Equation 13.6***

where L is the string length and n is the number of segments. You can therefore express the velocity of a wave in a stretched string as:

$$v = \frac{2Lf}{n}$$ ***Equation 13.7***

You can also find the velocity of a wave in a stretched string from the relationship:

$$v = \sqrt{\frac{F_T}{\mu}}$$ ***Equation 13.8***

where the tension force, F_T, is the force applied to stretch the string and the linear mass density, μ, is an inertial property equal to mass per unit length. You can find the value of μ by weighing a known length of string.

$$\mu = \frac{\text{mass}}{\text{length}}$$ ***Equation 13.9***

Procedure

You will apply tension to a length of string by hanging mass from it over a pulley, as shown in Figure 13.4. You will then create waves in the string with a computer-driven vibrator and adjust the frequency (Part A) and the tension (in Part B) to create standing waves having from 1 to 7 segments.

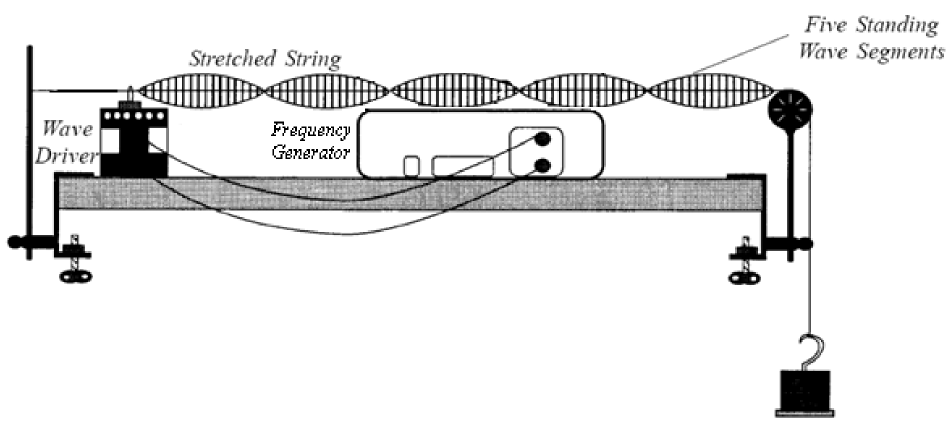


Figure 13.4 – Schematic of Experimental Apparatus

1. Cut a piece of string about 5 m long. Stretch it out on the table (doubling it if necessary) and measure its length l_s. Wad the string up and carefully measure its mass m_s. Record both values in Data Table 13.1.
2. Calculate the string's linear density μ and record its value in Table 13.1.
3. Cut about a 2-m piece of your string and tie a loop in each end. Slip one loop over a vertical support rod that is clamped to the table. Pass the string over a pulley that is clamped to the end of the lab table about 1.5 m away and hook a mass hanger in the other loop.
4. Place the wave driver under the string near the vertical support rod. Slide the loop down the support rod until the string rests in the slot on the top of the wave driver. Use banana-plug patch cords to connect the wave driver to the output of the power amplifier. With the power switched off, plug the Power Amplifier

into Analog Channel A. Note that in some experimental arrangements the Power Amplifier is not necessary.

5. Place 1 kg mass on the hanger, however more or less may be required depending on the experimental arrangement.
6. Measure the length of string *L* between the vibrator and the top of the pulley. Record this length in Table 13.1.
7. Turn everything on and set amplitude to 1 V (or as near as possible). Vary the frequency until the string vibrates (resonates) at its fundamental frequency (one segment). Adjust the frequency only to obtain the greatest amplitude possible.
8. Vary frequency to get higher and higher harmonics (2, 3, etc. segments) and record resonance frequencies up to 7 segments in Table 13.1.
9. Add approximately 0.5 kg to the mass hanger and repeat Steps 7 and 8.
10. Add (approximately) an additional 0.5 kg to the mass hanger and repeat Steps 7 and 8.
11. You should have three sets of data – one for each mass.
12. From the frequencies, calculate the periods, T.
13. For each of the three different masses, plot wavelength vs. period for the different harmonics. Find the best fit line and make sure it intercepts zero if it is supposed to. Be sure to write the equation the graph is plotting on the graph and identify what the slope represents. Attach the graphs.
14. Tabulate the slopes, wave speed, of each line from the graphs in Table 13.2.
15. Compare the measured wave speeds to theoretical wave speed and calculate and enter in Table 13.2.

Post-Lab Questions – Answer on a separate page and attach

1. In the graphs of wavelength vs. period, what should the slope represent?
2. Should the plot of wavelength vs. period intercept zero? Explain.
3. For each of the three different cases, what were the fundamental frequencies and wavelengths?
4. How many natural frequencies (normal modes) does a simple pendulum have? A mass on a spring? Explain.
5. A violin's E string vibrates at 660 Hz, the distance between clamps is 330 mm, and $\mu = 4 \times 10^{-4}\ \frac{\text{kg}}{\text{m}}$. What is the tension at resonance?
6. What length would the string in Question 5 need to be to resonate at 880 Hz (A about concert A)? How is that length achieved during play by a violinist?
7. What μ would the string in Question 5 require to resonate at concert A (440 Hz)? Is this a thicker or thinner string than the string of Question 5?
8. An tube open at both ends behaves similarly to a standing wave on a string. For the lowest resonance frequency, half a wavelength is the length of the tube, however the open ends are antinodes instead of nodes (like a string). A closed end makes a node. So a tube closed at one end consists of a node and antinode. Express, as a function of the tube's length L, the sequence of resonance wavelengths of a closed tube.
9. A closed tube is 30 cm long and the speed of sound is 343 m/sec. What are the first three harmonics of that tube?

Comment [O1]: 100 points total

Comment [O2]: 15 points for graphs – 5 points each based on rubric in "To Instructors" document.

Comment [O3]: 2 points

Comment [O4]: 5 points per Bloom's (see "To Instructors")

Comment [O5]: 6 points

Comment [O6]: 5 points per Bloom's

Comment [O7]: 5 points per SOLVE (see "To Instructors")

Comment [O8]: 5 poins per SOLVE

Comment [O9]: 5 points per SOLVE

Comment [O10]: 4 points per SOLV (skip the E)

Comment [O11]: 2 points

Lab 13 Report: Names ____

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Table 13.1 – Data Table Recording Mass, Wavelength, Mass Density, Etc.

String Mass, m_s = ________ (   ), String Length, l_s = ________ (   )

Mass Density, μ = ________ (   ), Distance between string clamps, L = ________ (   )

Mass on Hanger	Tension Force	Theoretical Wave Speed	Harmonic n	Wavelength λ ( )	Frequency f ( )	Period T ( )
M_h = ________ ( )	F_T = ________ ( )	v_t = ________ ( )	1			
			2			
			3			
			4			
			5			
			6			
			7			
M_h = ________ ( )	F_T = ________ ( )	v_t = ________ ( )	1			
			2			
			3			
			4			
			5			
			6			
			7			
M_h = ________ ( )	F_T = ________ ( )	v_t = ________ ( )	1			
			2			
			3			
			4			
			5			
			6			
			7			

Comment [O12]: 8 points for top data & units

Comment [O14]: 3 points for proper units on top row

Comment [O13]: 18 points for hanger mass, tension force, & theoretical speed & proper units.

Comment [O15]: 8 points for table data

Table 13.2 – Theoretical vs. Measured Wave Speed

Mass ( )	Theoretical Wave Speed, v_t ( )	Measured Wave Speed, v_m ( )	Percent Error

Comment [O16]: 3 points for proper header units, 6 points for table data