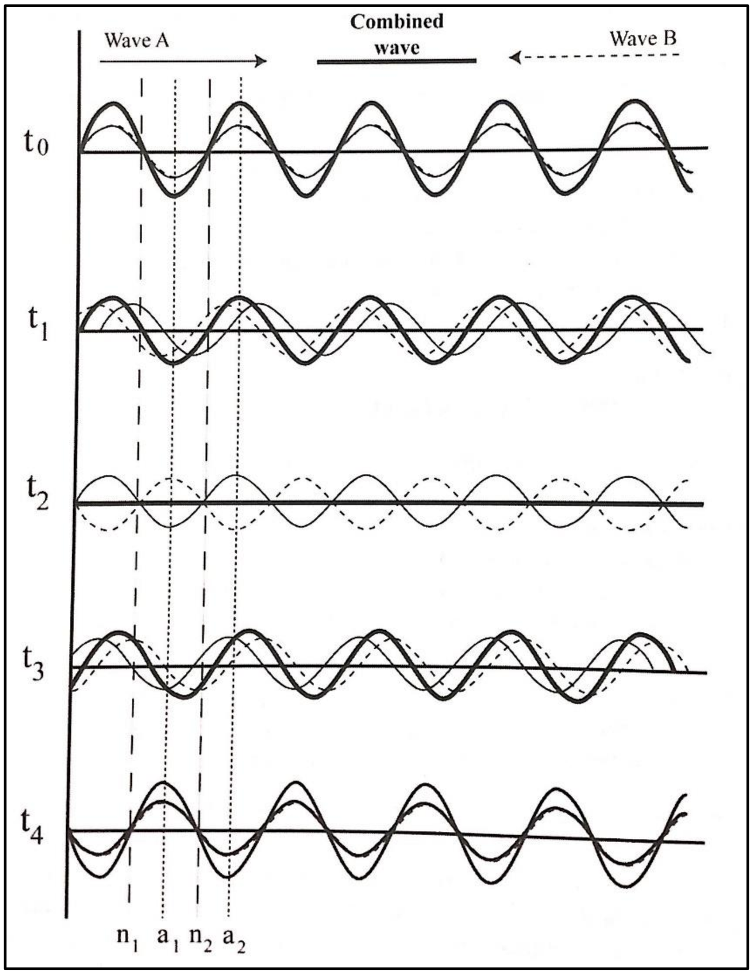
AP Lab #13: Velocity of a wave on a String (Big Idea 6)

Big Idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

In this investigation you will explore the behavior of a standing wave created by a vibrating string and examine the relationship between two of the four variables that affect how the wave behaves.

Velocity of a Wave on a String Background:

No doubt you have been attempted to move a skipping rope, garden hose, or extension cord by giving it a quick flick of your wrist. The flick of your wrist creates a disturbance in the cord causing the cord to shift position. The bump that moves along the cord is called a wave. If the opposite end of the cord is not attached to anything, the end of the cord may snap slightly like the end of a whip. However, if the end of the cord is tied to a fixed object, the wave reflects back at you. If you flick the cord over and over again, the cord may wiggle chaotically as the reflecting waves interfere with the outgoing waves. If, however, you produce the series of flicks with just the right frequency you may create a wave that appears to be frozen in position between the ends of the string. We call the phenomenon a standing wave.



The reason the wave appears to stand is that the waves you produce are coordinated with one another. Imagine sending out a single pulse by flicking your hand to the right. The pulse leaves your hand on the right side of the cord, continues to the end of the string, and then reflects on the left side of the cord as it returns to your hand. If you produce a second wave, but this time on the left, at the very moment the first wave reflects off the fixed end, the two waves will interfere with each other constructively, producing a wave which is the sum of the two. Then your hand flicks to the right and this third pulse interferes constructively with the second pulse as it reflects on the right side of the cord. As this process continues, the cord appears to oscillate back and forth with a single antinode present (see figure below). If you double how often you flick your hand (i.e., the frequency), you will produce two antinodes, and so on.

The series of figures to the right show how two opposing pulses travel toward one another. Initially, at t_0, the two waves are in phase (i.e., lined up) and add together, producing a wave that is equal to the sum of the two smaller waves. As the waves move through time, they get out of phase, with constructive interference decreasing, while destructive interference increases until the waves cancel each other out at t_2. The process continues and the wave seems to have flipped by t_4. Notice that between t_0 and t_4 the antinodes a_1 and a_2 appear to have flipped positions, while during the entire course of time no movement occurs in nodes n_1 and n_2. Because the nodes remain stationary, the wave appears as if it is standing in one position. In reality, energy is moving in both directions.

In this lab you will be using a vibrating string apparatus. It consists of three main components: a string vibrator, a string, and a pulley and clamp (see the figure on right). The string is attached to the string vibrator and then draped over the pulley. A mass that provides the tension in the string is suspended from the end of the string below the pulley. The length of the string and size of the mass may be adjusted accordingly to produce a standing wave on the string. Only discrete combinations of length and mass will cause the string to vibrate. In figure 1 below, notice the length of the string is subdivided by three half waves ($L = 3/2\ \lambda$). A string will resonate only at whole number multiples of $1/2\ \lambda$. When $L = 1/2\ \lambda$, $2/2\ \lambda$, $3/2\ \lambda$, etc., a resonance will occur. Resonance will not occur at $2/3\ \lambda$, since the length is not a whole number multiple of $1/2\ \lambda$. Lastly, the linear mass density (μ) refers to the mass per unit length of material. The linear mass density is generally used to describe the mass per unit length of strings and wires. The SI units for this measurement are kg/m. You may also see linear mass density represented as ρ or M_L. You can determine this measurement by simply finding the mass of a given length of string. If an analytical balance is not available, you may choose to find the mass of a greater length of string (e.g., 25 m) to ensure the accuracy of the data. Considering the aforementioned, it has been found that the wavelength (λ) of a standing wave is affected by the tension of the string (F_T), the frequency of the wave generator (f), and the linear mass density (μ). The overall equation is shown to the right.

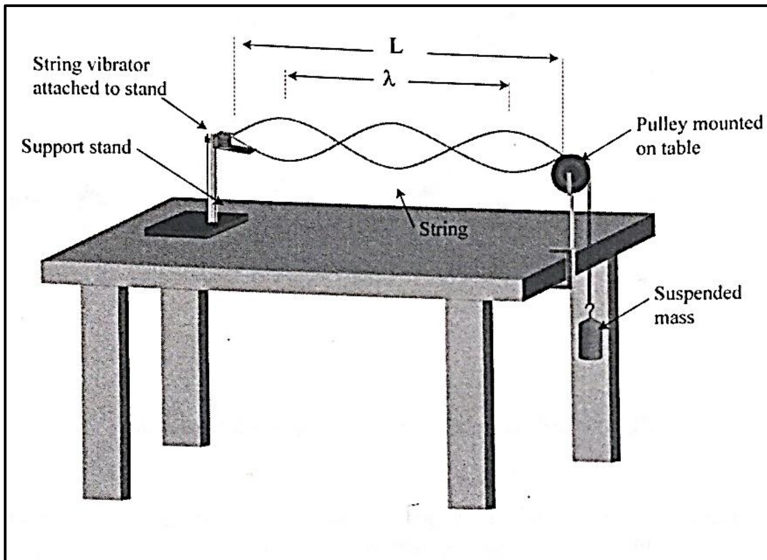
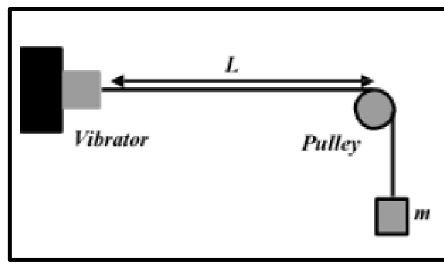


Figure 1: Set-up of Vibrating String Apparatus

$$\lambda = \frac{1}{f}\sqrt{\frac{Ft}{\mu}}$$

Velocity of a Wave on a String Pre-Lab:



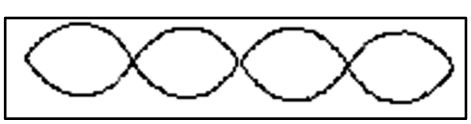
1). The system to be studied is shown in the figure; a horizontal string passes over a pulley, and a mass hangs vertically from the string. (a) If the mass is at rest and the mass of the pulley can be neglected, find the tension in the string. (b) If the vibrator is turned on, a wave will travel along the string. Write down the equation for the velocity of a wave in terms of the wave's wavelength and frequency (check the problem set if needed)

2). A cord 15.50 m long has a mass of 3.050 $grams$. What is its linear mass density in kg/m? For the same cord, if the tension were provided by a 2.550 kg mass, how long would the cord have to be to vibrate with four antinodes? Assume f = 120.0 Hz.

3). When standing waves are produced in this experiment, does increasing the tension produce a larger or smaller number of antinodes along the string? Please answer using semi-quantitative reasoning.

4). List two ways in which the velocity of the wave along the string can be quadrupled. In each case, explain to detail why such a change would double the velocity.

5). The drawing shows a 1.025 $meter$ long string vibrating at 140.0 Hz (vibrations per second). (a) Calculate the wavelength and speed of the wave. (b) If the linear mass density of the string is 0.001350 kg/m, find the tension in the string. Please show detailed calculation.



Velocity of a Wave on a String Lab:

Materials: 60 Hz AC string vibrator, ring stand, c-clamp, pulley (w/ table clamp), braided pulley string (~3m), scissors, hanging mass set, meter stick, video analysis (optional).

General Set-up (see figure 1): *In this activity you will explore the behavior of a standing wave created by a vibrating string and examine the relationship between two of the four variables that affect how the wave behaves.*

1). Use the pulley clamp to secure the pulley at the end of a table. Do not overtighten.

2). Use a c-clamp to secure a ring stand on the table located about 1-2 meters away from the pulley.

3). Mount the string vibrator onto the ring stand. There are two different models available. You will most likely want the metal strip upward and facing toward the pulley. However, feel free to try different set-ups.

4). **DO NOT** run the string vibrators excessively. Always unplug when not in use to allow the motor to cool.

5). When using the vibrating string apparatus, you may notice that the waveform becomes distorted at either end of the string, next to the pulley and vibrator. It is recommended that at least two complete waves be formed on the string in order to measure the wavelength through the string. The wavelength is most easily measured from one node to the next node.

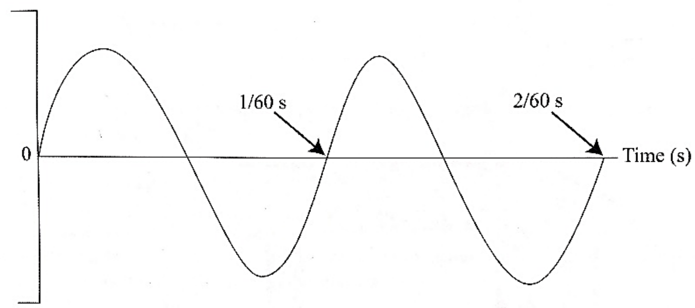


Figure 3: Frequency Created From a 60 Hz Outlet

6). The string vibrator consists of a coil of wire surrounding a short iron rod. When electricity passes through the wire coil it functions as an electromagnet. A strip of steel is secured to the body of the string vibrator. When the magnet is activated it pulls the strip of metal toward the magnet. If plugged into an AC source, the magnet turns on and off causing the strip to vibrate down and up at the frequency of the AC power source. The outlets in North America provide AC electricity at a rate of 60 Hz. This means that there are 60 complete wave cycles every second. Please examine figure 3. Since the wave cycle consists of one positive pulse of electrical current and one negative pulse, the magnet is turned on and off twice during each wave cycle. Consequently, electricity delivered at a frequency of 60 Hz will move the metal strip 120 times each second.

Design an Experiment:

1) Design an experiment using the provided materials to examine the relationship between two of the four variables that affect the vibration of the string. Decide which two to explore: λ, μ, F_T, or f; the other two variables will need to remain unchanged during the investigation.

2) As always, sketch free body diagrams of the system and create a data table suitable for your data set. Also, please show all of your calculations and include a labeled sketch of the apparatus. Conduct multiple trials.

3). Using the data you collected, plot a graph of the two variables you explored. Ensure your graph is ¾- 1 page in size and labeled appropriately.

4). Explain how to linearize your data and create a second, linearized graph. Please note in addition to the second linearized graph, you must explain how the data were linearized.

5). What is the significance of the slope of your linearized graph?

6). Please self-assess your lab report using the rubric/checklist.