GENERAL PHYSICS

EXPERIMENT 11

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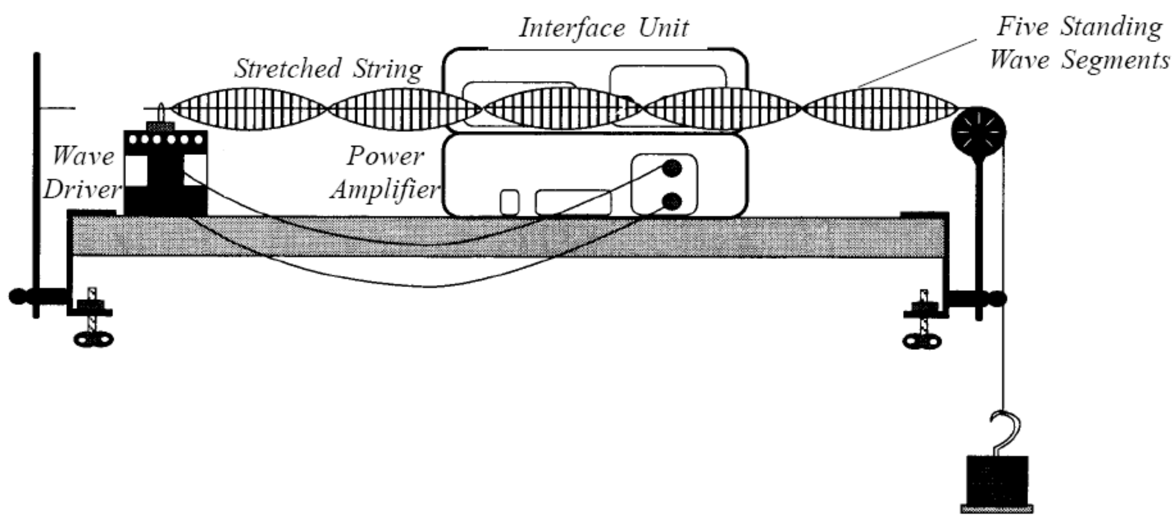
COLLIN COLLEGE

Standing Waves in a String



Produced by the Physics Staff at Collin College

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

Web simulation found at: https://ophysics.com/w8.html

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 wavelength of the interfering waves, the interference pattern will be stationary in the string. Such a stationary wave pattern is called a *standing wave*.

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:

$$v = \lambda f$$

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. Waves in a vibrating slinky spring and 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.

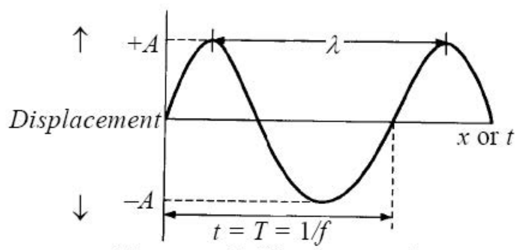


Figure 1. Wave properties

As each particle oscillates, its maximum displacement up and down is called the wave's *amplitude*, designated as $+A$ or $-A$. Figure 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 $T = 1/f$.

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. 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.

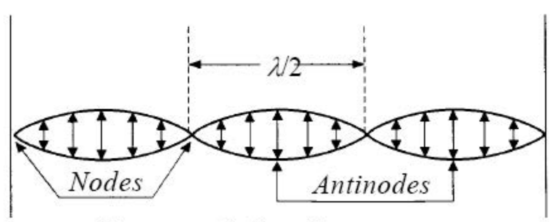


Figure 2. Standing wave

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 higher frequencies are known as *harmonics* (see Figure 3).

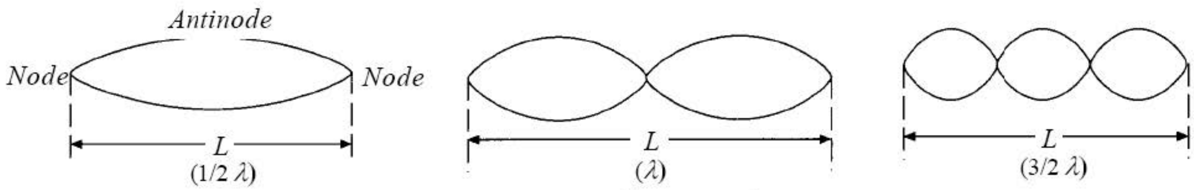


Figure 3. Standing wave harmonics

Note that each segment is equal to one-half of a wavelength. Thus, for a given harmonic, the wave-length becomes:

$$\lambda = \frac{2L}{n}$$

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:

$$v = \frac{2Lf}{n}$$

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

$$v = \sqrt{\frac{F_T}{\mu}}$$

where the tension force F_T is the elastic property in the string and the linear density μ is the inertial property. You can find the value of μ by weighing a known length of string.

$$\mu = \frac{\text{mass}}{\text{length}}$$

You can solve for the tension force by eliminating v between the two equations above:

$$F_T = \frac{4L^2 f^2 \mu}{n^2}$$

If you keep the length and frequency constant but allow the tension to vary, a graph of F_T versus $1/n^2$ yields a straight line whose slope is the numerator of this equation: $4L^2f^2\mu$. Knowing the length and frequency, you can then find the value of μ from the slope of this graph. You can also solve the last equation for the frequency:

$$f = \frac{n}{2L}\sqrt{\frac{F_T}{\mu}}$$

A graph of f vs. n will yield a straight line whose slope is the coefficient of n: $\frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$.

Procedure

In this experiment, you will utilize an online simulator to acquire you data. The simulator is found at the following web address: https://ophysics.com/w8.html

A. Variable Tension, Constant Frequency and Length

1. Open the simulator, and use the slider labeled "Linear Density" to set the linear density of the string to 3.2×10^{-3} kg/m. You can adjust the slider by clicking and dragging the black circle. (Tip: The black circle for each slider is surrounded by a gray outer circle. When you click on the slider, the gray outer circle becomes larger. If you need to adjust the slider more finely than clicking and dragging will allow, you can just single click on the gray outer circle to advance the slider by increments in either direction.)
2. Use the slider labeled "Vibration Frequency" to set the frequency to 125 Hz.
3. Record the linear density μ *(sim)*, the vibration frequency f, and the length of the string L in Table 11.1. The length of the string is shown above the string in the simulation.
4. Use the slider labeled "Tension" to adjust the tension in the string to find the 6th harmonic. Adjust the tension until the antinodes are *maximized* (maximum amplitude). Record the Tension F_T in Table 11.1. Calculate and record $1/n^2$ for this harmonic as well.
5. Now use the Tension slider to reduce the tension to create maximum-amplitude standing waves at each harmonic above 6th (7th through 12th). For each harmonic, record the tension F_T and $1/n^2$ in Table 11.1.
6. Plot a graph of the tension F_T vs. $1/n^2$ and draw a best-fit straight line through the data points. Calculate the slope of the line (to 3 SD), and record its value in Table 11.1.
7. Using this measured value of the slope, calculate the linear density of the string. Record it (to 3 SD) in Table 11.1.
8. Calculate and record the percent difference between this value of μ *(calc)* and the recorded value μ *(sim)* from the linear density slider in the simulation.

B. Variable Frequency, Constant Tension and Length

1. Click on the reset button, ↻, in the upper right corner of the simulation.
2. Verify that the linear density μ *(sim)* is set to 3.2×10^{-3} kg/m and the tension F_T is set to 50 N. Record the linear density, tension, and length of the string in Table 11.2.
3. Use the slider labeled "Vibration Frequency" to adjust the frequency of the vibration to find the 6th harmonic. Adjust the frequency until the antinodes are *maximized* (maximum amplitude). Record the frequency f in Table 11.2.
4. Now use the frequency slider to increase the frequency to create maximum-amplitude standing waves at each harmonic above 6th (7th through 12th). For each harmonic, record the frequency f in Table 11.2.
5. Plot a graph of f vs. n and draw a best-fit straight line through the data points.
6. Calculate the slope of the line and record it (to 3 SD) in Table 11.2.
7. Using the value of the slope, calculate the linear density of the string. Record it (to 3 SD) in Table 11.2.
8. Calculate and record the percent difference between this value of μ *(calc)* and the recorded value μ *(sim)* from the linear density slider in the simulation.