Fluids, Thermodynamics, Waves, & Optics
Waves
Lab 6
The Sonometer

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Overview

- Purpose
- Theory
- Equipment & Setup
- Procedure

Purpose of the Lab

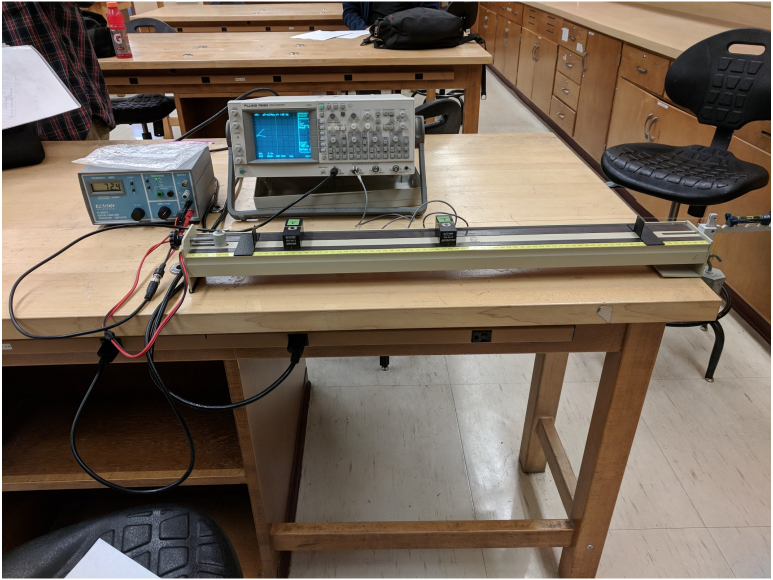
To explore the behavior of standing waves on a string.

You will set up a string under tension, then drive an oscillations in the string and measure the frequency and wavelengths that result.

From these measurements you will determine the speed of the waves on the string.

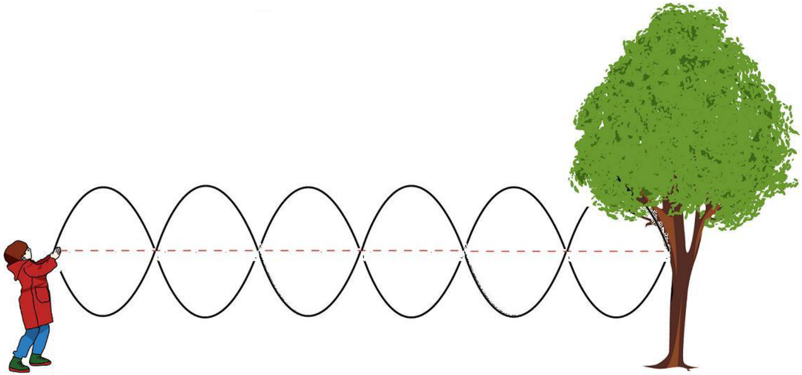
You will compare your result to the speed expected for a string of linear density μ under tension T.

Equipment



Theory: Standing Waves

Standing waves are formed from sine waves that are traveling in opposite directions.



Notice that there are a whole number of half wavelengths between the child and the tree.

Standing Waves

The incoming wave:

$$y_1(x, t) = A\sin(kx - \omega t)$$

Reflected wave:

$$y_2(x, t) = A\sin(kx + \omega t)$$

Using the trig identity:

$$\sin(\theta \pm \psi) = \sin\theta\cos\psi \pm \cos\theta\sin\psi$$

The resultant wave is:

$$y = \underset{\substack{\uparrow \\ \textbf{Amplitude at } x}}{[2A\sin(kx)]}\ \ \underset{\substack{\uparrow \\ \textbf{SHM oscillation}}}{\cos(\omega t)}$$

Standing Waves

$$y = [2A \sin(kx)] \ \cos(\omega t)$$

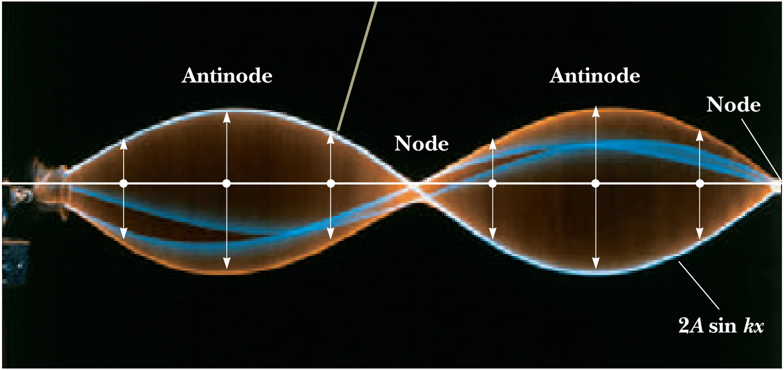
This does not correspond to a traveling wave!

It is a **standing wave**.

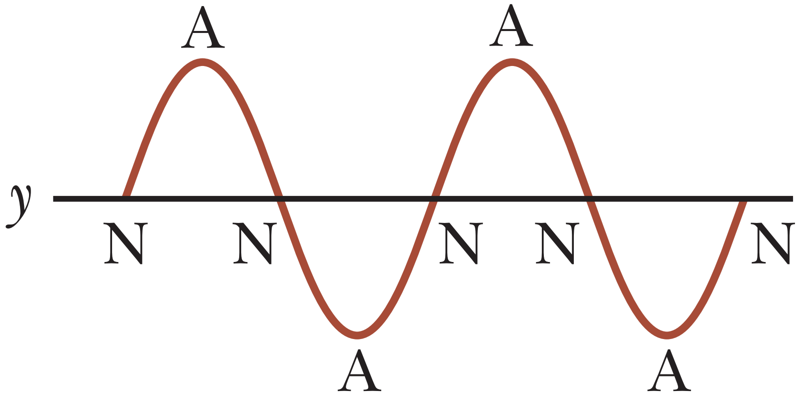
Points where $\sin kx = 0$ are called **nodes**. At these points the medium does not move.

Points where $\sin kx = \pm 1$ are called **antinodes**. At these points particles in the medium undergo their largest displacement.

Nodes and Antinodes



Nodes and Antinodes



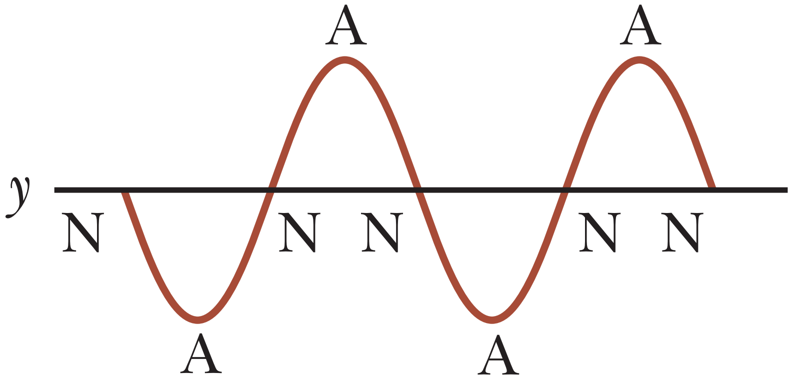
$t = 0$

Nodes and Antinodes

y

$t = T/4$

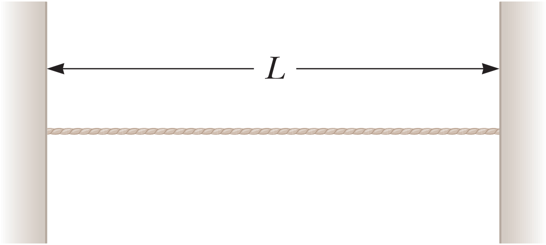
Nodes and Antinodes



$$t = T/2$$

Standing Waves and Resonance on a String

For a given string, fixed at both ends, only some wavelengths can correspond to standing waves.



The boundary conditions are now

$$y(x = 0, t) = y(x = L, t) = 0$$

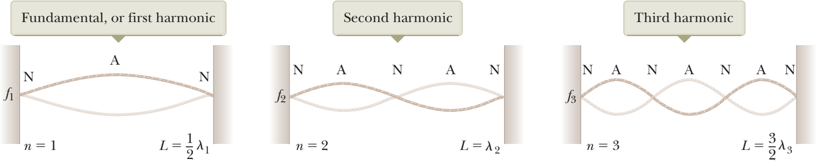
$x = 0$ and $x = L$ must be the positions of nodes.

Standing Waves and Resonance on a String

The wavelengths of these normal modes are given by the constraint $\sin(0) = \sin(kL) = 0$:

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

where n is a positive natural number (1, 2, 3...).



$\lambda_1 = 2L$ $\qquad$ $\lambda_2 = L$ $\qquad$ $\lambda_3 = \frac{2L}{3}$

Standing Waves and Resonance on a String

$$v = f\lambda \qquad ; \qquad \lambda_n = \frac{2L}{n}$$

The frequencies that correspond to these wavelengths are called the **natural frequencies**:

$$f_n = \frac{nv}{2L} = n\,f_1$$

where n is a positive natural number.

where v is the speed of the wave.

Theory

For a string of density μ under tension T, the wave speed is constant

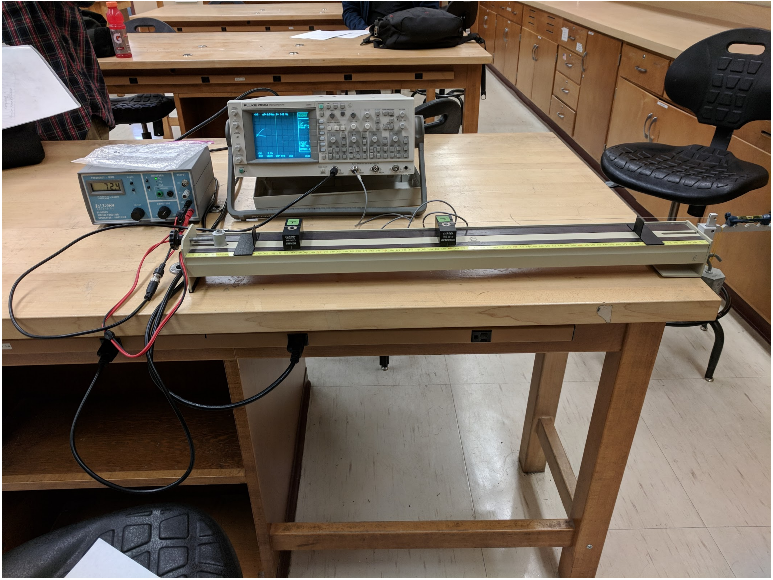
$$v = \sqrt{\frac{T}{\mu}}$$

This should equal to the product of the measured frequency and wavelength.

$$v = f\lambda$$

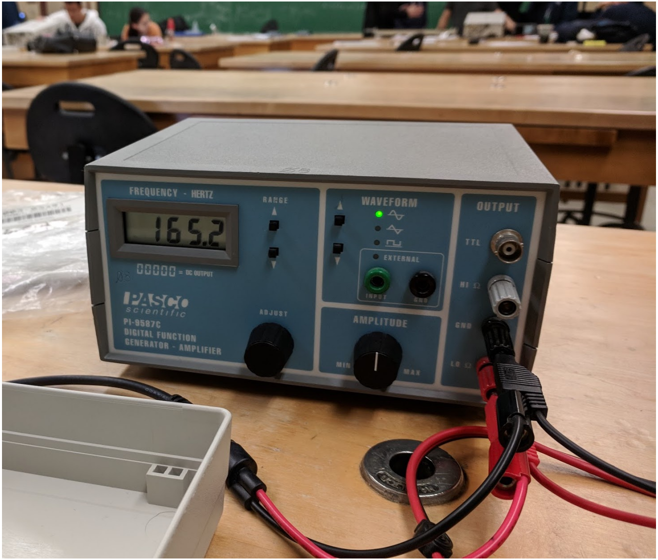
Theory

Equipment

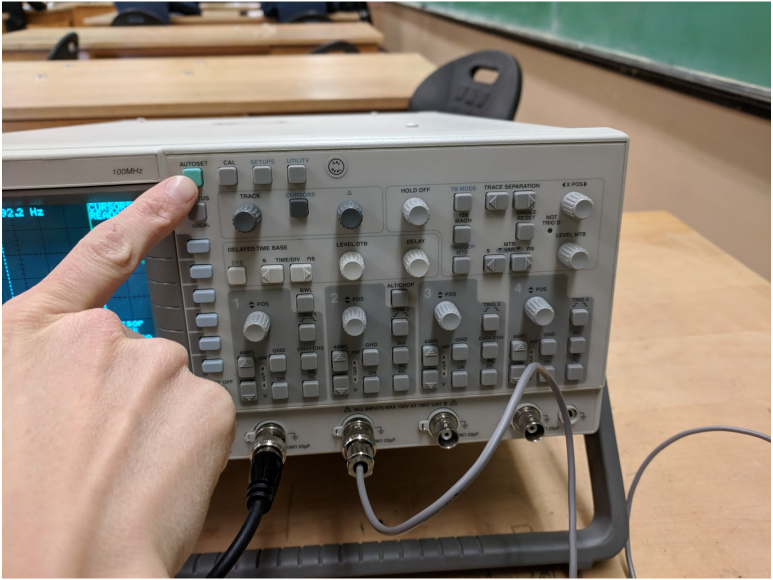


Setting Up the String: Tensioning Lever

Function Generator



Using the Oscilloscope

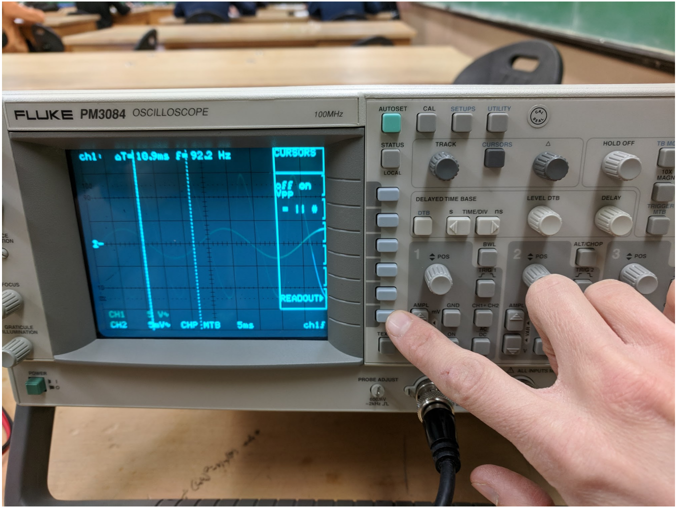


Using the Oscilloscope

Turning on the cursors.

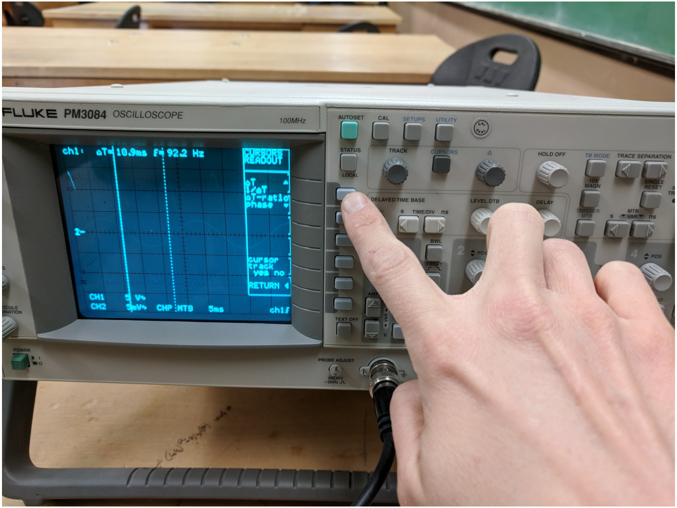
Using the Oscilloscope

Displaying the frequency (as measured by the time period between the cursors).



Using the Oscilloscope

Displaying the frequency (as measured by the time period between the cursors).

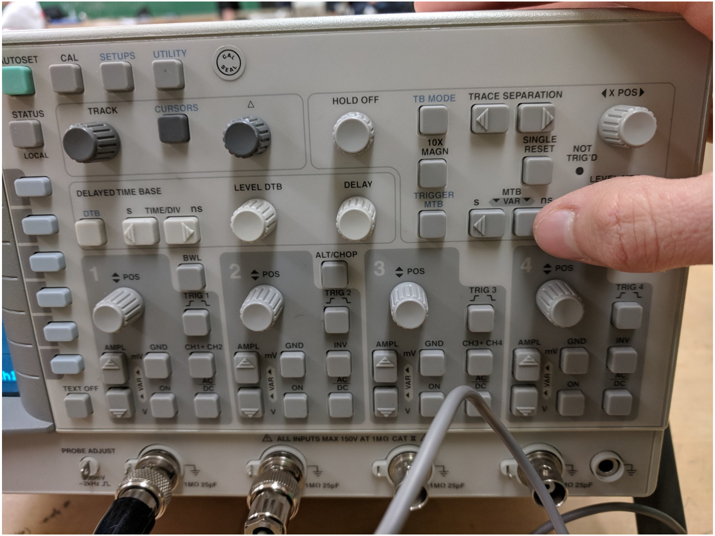


Using the Oscilloscope

Adjusting the cursor locations.

Using the Oscilloscope

Adjusting the time base.



Lab Activity

First, characterize the string.

1. Pick a string. Using masking tape, but a label with your names on it on the bag. You will use this string next week also.

2. Use the micrometer to measure the diameter of the string and confirm that the bag reflected the correct value.

3. Weigh the string and record the uncertainty.

4. Weigh the sample washer and nut (connectors) at the front of the lab room. Subtract these from the total weight of the string and calculate the uncertainty.

5. Measure the length of the string and calculate μ with uncertainty.

Lab Activity

1. Set up the equipment. Have the bridges set 60 cm apart.
2. Slowly increase the frequency on the function generator and watch the oscilloscope for a resonance. (You may also be able to hear the resonance.)
3. Record the frequency of the string's oscillation, f_n, **as shown on the oscilloscope**.
4. Move the detector along the string starting from the bridge opposite the oscillation driver and find the location of the next node. Record this distance.
5. Use that distance measurement, plus your knowledge of the resonant wavelengths to determine λ_n.

Lab Activity

1. Repeat: slowly increase the frequency and find the next resonance.

2. Try to record $\lambda_n,\ f_n$ for $n \in \{1, 2, 3, 4, 5\}$. You may find higher modes first; you can record those also.

3. Find $v = f\lambda$ for each pair of λ, f values. (You should have at least 5 values.)

4. Calculate the average wave speed, $\bar{v}$.

5. Calculate the **standard error** of the sample mean using this formula:

$$\text{s.e.}(v) = \sqrt{\frac{\sum_{i=1}^{N}(v_i - \bar{v})^2}{N(N-1)}}$$

Lab Activity

Does the uncertainty range for the value for the speed from the tension overlap with the uncertainty for the speed from the frequency and wavelength measurements?