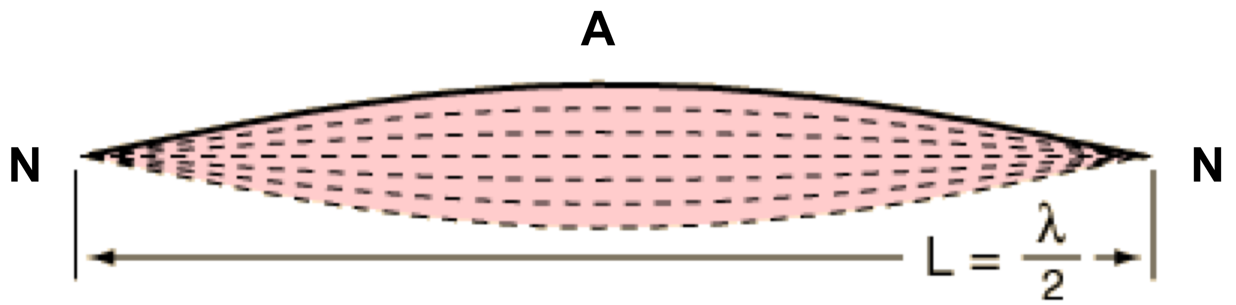
Standing Waves

Introduction

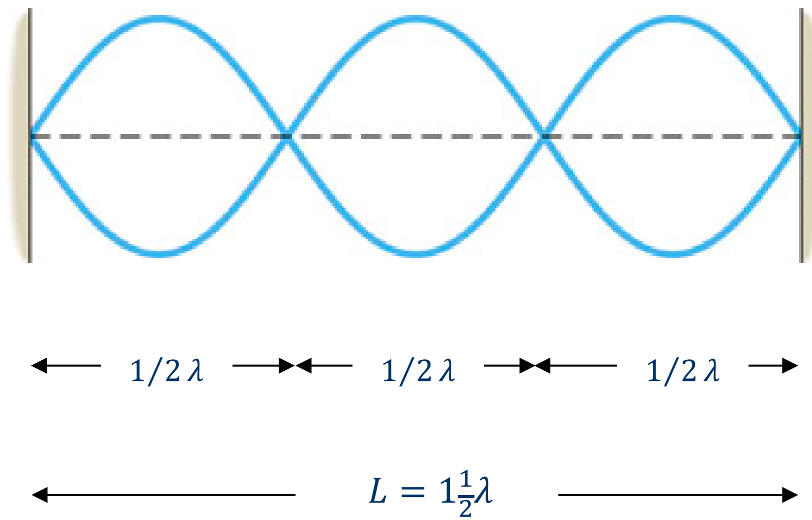
Waves on strings are transverse waves. When a string is vibrating at its fundamental frequency, the wave pattern looks like the one shown below.



There is an antinode A at the middle where the displacement of the string is at a maximum. There are nodes N at the fixed ends of the strings where there is no displacement of the string.

Introduction

For strings vibrating at a frequency other than the fundamental, the standing wave pattern may resemble the one shown below.



In this picture, there are 1½ wavelengths present on the string. If we are able to measure the length of the string, it is straightforward to determine the wavelength.

Introduction

For all waves, the speed is given by

$$v = f\lambda$$

where f is the frequency of the oscillation and λ is the wavelength of the standing waves.

For waves on a string, the wave velocity is also given by

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

where T is the tension in the string and μ is the mass per unit length or linear density.

Combining the above equations gives the wavelength of the wave on the string as

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

Objectives

In this experiment, you will determine the mass per unit length of a piece of string.

To do this, you will produce standing waves on a string and measure the wavelength as a function of tension for a given frequency.

You will then analyze your data to determine the mass per unit length of the string.

Finally, you will be asked to compare this value with an accepted value for the mass per unit length of your string and determine if they agree with each other or not.

Apparatus

You will use the following apparatus in your experiment:

- Fixed frequency vibrator (either blue **or** black: both are shown at right)
- String
- Hooked masses
- Pulley with clamp
- Paper
- Tape
- Orange triangular rulers
- Meter stick

Choosing your Masses

To provide the tension in the string, masses are hung over a pulley. If we assume that the pulley is massless and frictionless, then the tension in the string will be equal to the weight W of the hanging mass.

- If you have the blue metal type vibrator with black string:
  - your frequency is $120\ Hz$
  - you need to use masses of 100, 90, 80, 70 ,60, 50, 40, and 30 grams for your experiment.

- If you have the black plastic type vibrator with yellow string:
  - your frequency is $60\ Hz$
  - you need to use masses of 200, 180, 160, 140, 120, 100, 80, and 60 grams.

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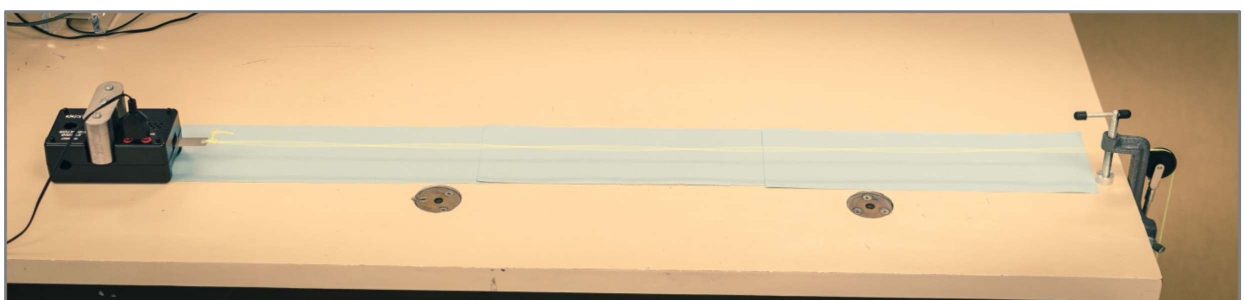
Indicate your frequency and string colour in your lab workbook.

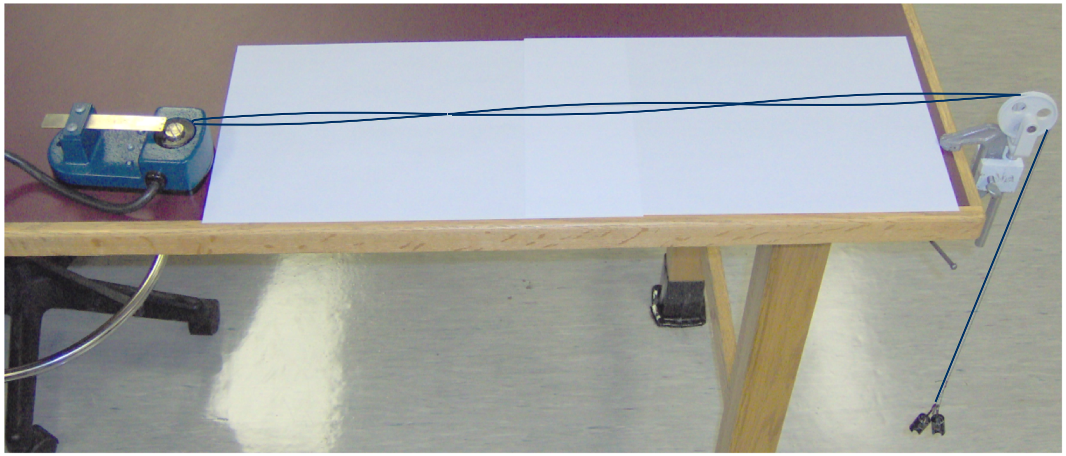
Experimental Setup

- Assemble your apparatus as shown:
  - Clamp the pulley to the desktop.
  - Hang the string over the pulley.
  - Hang your largest mass, from the list on the previous slide, from the string. Make sure the pulley wheel turns freely.
  - Make sure your string is level to avoid a systematic uncertainty!
  - Plug in the vibrator.



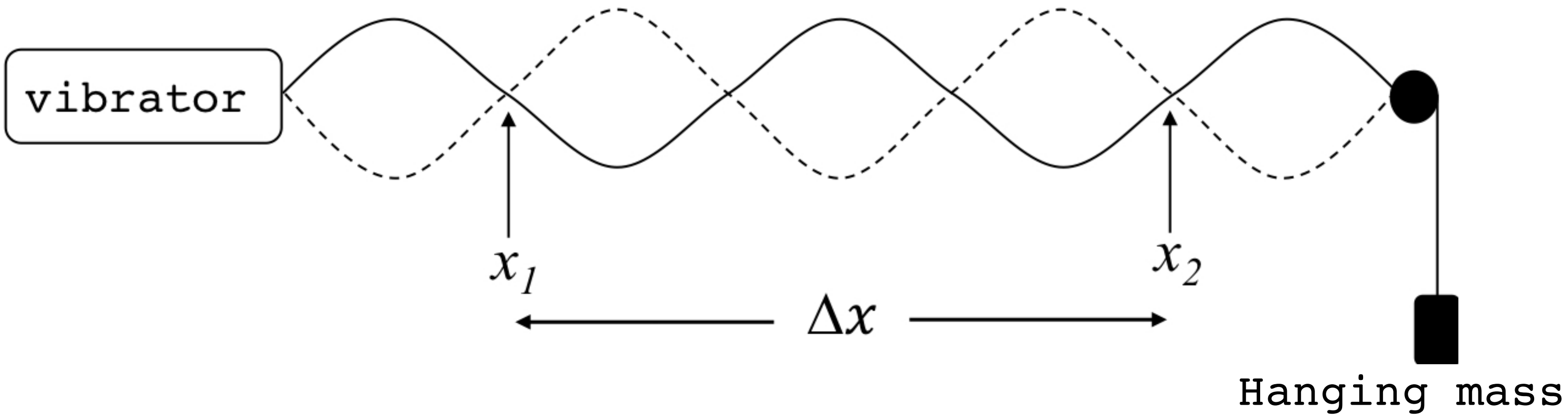
Data Collection

- To observe a standing wave you will need to adjust the position of the string vibrator from the pulley so the wave resonates.
- Hold the string vibrator's position when you see a standing wave with well defined nodes and antinodes. Use as much string as possible.



QUESTION 1: Draw the standing wave you observe in your experimental setup. Clearly label the nodes and antinodes.

Data Collection



- Tape a piece of paper to your bench under your string.
- Carefully mark the position of the first well defined node x_1 near one end of the string and the last one near the other end x_2.
- You may use one of the orange triangles to assist in locating the positions precisely.
- Measure the distance Δx, between x_1 and x_2, and record it in **Table 1** of your Laboratory Workbook.

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Data Collection

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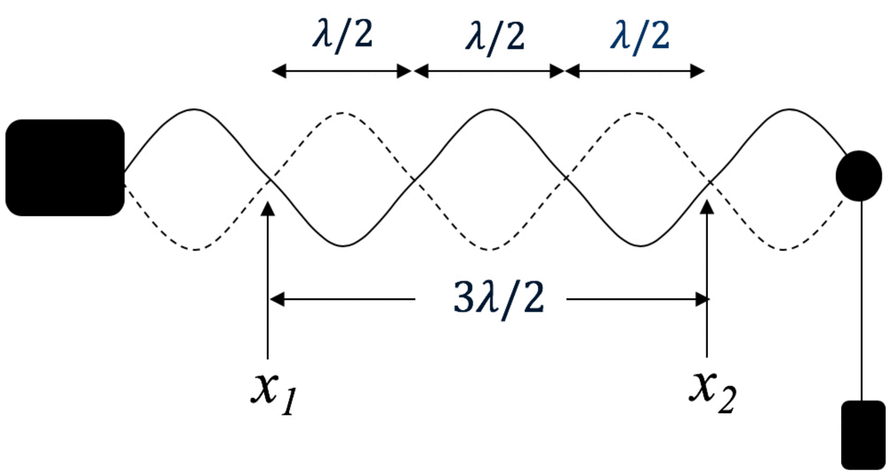
- Count the number of full wavelengths **between the marked nodes** and record this value in **Table 1**.
- Use this information to determine the wavelength λ of your standing wave and record your result in **Table 1**.
- Also record wavelength squared (λ^2).
- Calculate the weight $\boldsymbol{W}$, in newtons, of the hanging mass and record it in **Table 1**.



In the example above, there are $3/2$ or 1.5 **wavelengths** between the indicated nodes. This shows the distance between the indicated nodes, Δx, equals $3/2\ \lambda$.

Data Collection

CP Have an instructor come check your work and initial your lab report.

- Decrease the hanging mass to the next lower value.
- Readjust the position of the vibrator to produce a standing wave.
- LW Repeat the previous procedure to determine the wavelength of your standing wave, recording your results in **Table 1**.
- LW Decrease the mass at the correct increments and repeat, recording your results in **Table 1**, until you have completed the table.

! The fixed frequency vibrator may get **very hot**! Unplug while not in use.

Expectations

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QUESTION 2: With the string vibrator at a resonance point, determine the wavelength. You may choose any previous mass value to provide the tension. Now move the vibrator towards or away from the pulley by half of the wavelength. Explain the result.

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QUESTION 3: Given the equation below, determine the expression for the slope of a graph of tension vs wavelength squared. Start by squaring both sides. Include a sketch of the expected graph.

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

!

This is a derivation, so symbols only, no numbers.

Data Analysis

- Click on the icon below to launch **Graphical Analysis**.

CLICK HERE → GA ← CLICK HERE

- Plot Tension in the string as a function of the wavelength squared.
- Click **Analyze** then **Linear fit** to obtain a regression line.
- Double click the fit box which appears and click on “Show Uncertainties”.
- Record your results for slope and intercept in **Table 2** of your Laboratory workbook.

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Print your graph and attach it to your Laboratory workbook.

Print your graph by a) Click **File** then **Page Setup,** select **landscape** orientation and click **OK**; b) Click **File** then **Print**, change number of copies to **2** (one for each partner) and **Pages** from: 1 to 1, clicking **Print** then **Print.**

Data Analysis

QUESTION 4: Using the slope of your graph and your results from Question 3, determine the mass per unit length of your string and its uncertainty. Write your answer in the form $\mu \pm \delta\mu$.

You may assume $\delta f = 0$.

QUESTION 5: Is your mass per unit length equal to the expected value of the mass per unit length (provided below) within the uncertainties? Calculate the ranges of both your value and the accepted value in order to answer this.

$$\mu_{black} = 1.42\times10^{-4} kg/m \qquad \mu_{yellow} = 1.50\times10^{-3} kg/m$$

$$\frac{\delta\mu}{\mu} = 0.03$$

Summary

QUESTION 6: Explain why the position of the string vibrator had to be adjusted during the experiment.

QUESTION 7: We assumed the relationship between T and λ^2 would be linear, based on our physics equation in Question 3. Does your graph support this assumption? Comment on any differences.

QUESTION 8: Give two sources of uncertainty in this experiment and classify them as random or systematic.

- Attach the *tension vs wavelength squared* graph (from Graphical Analysis) to your Laboratory Workbook in the appropriate space.
- Close all applications and log out of the computer.
- Be sure to place your workbook in the appropriate place and sign the attendance sheet before leaving.