Instructions
Demonstrations
Experiments
Sample Data

Instruction Manual

No. 012-08798A

String Vibrator

WA-9857

PASCO ®

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Contents

String Vibrator

Model No. WA-9857

Included Equipment	Replacement Part Number
String Vibrator	WA-9857
Power Supply	540-050
Wave Cord (3 meters, not pictured)	SE-9409 (90 m roll)

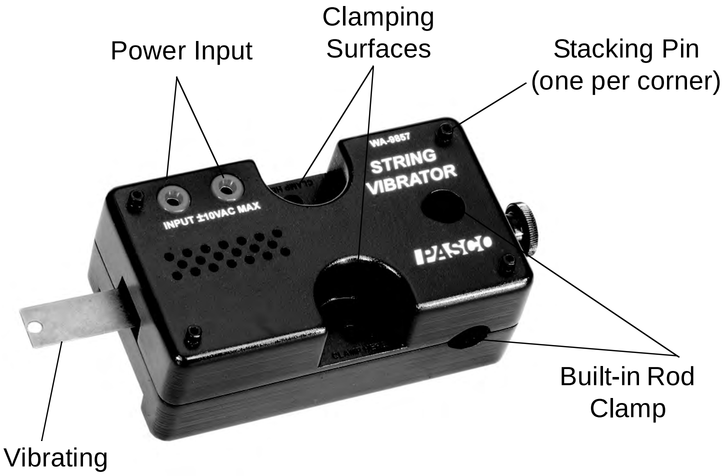
The demonstrations and experiments described in this manual call for additional equipment. For details, see the equipment list for each activity.

Introduction

The PASCO scientific WA-9857 String Vibrator drives a string or elastic cord to produce a standing wave. With it, you can study frequency, wavelength, and resonance, as well as the factors that affect those properties. It is well-suited for classroom demonstrations and hands-on experiments.

The String Vibrator uses a coil-and-magnet design to vibrate a stainless steel blade, to which you attach a string or elastic cord. The driving signal and power come from the included power supply, or (for a variable signal) from an optional signal generator, such as the WA-9867 Sine Wave Generator.

Equipment Setup



Power

The AC Power supply plugs into the Power Input of the String Vibrator. It drives the String Vibrator with a constant-frequency, constant-amplitude sine wave. The driving frequency equals the frequency of the mains power supply (50 or 60 Hz in most countries).

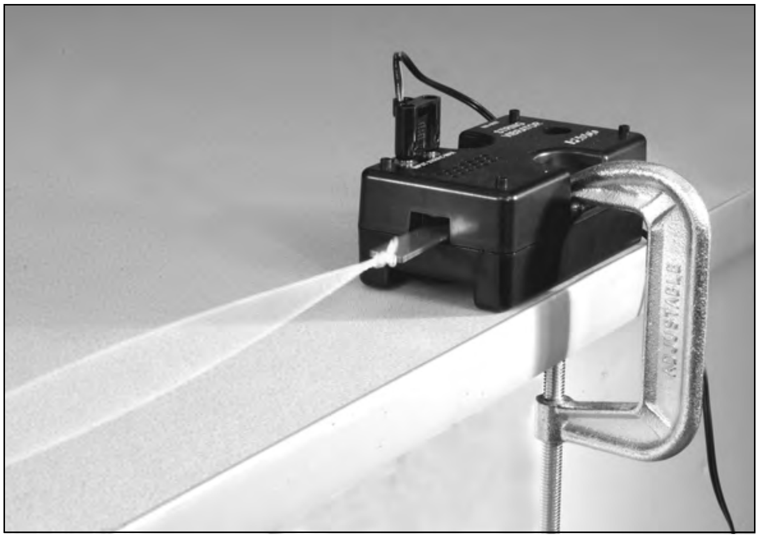
If you would like to drive the String Vibrator with a variable signal, you can use any function generator capable of producing a 10 V amplitude sine wave at up to 1 A, including the following:

- Sine Wave Generator (WA-9867)
- Digital Function Generator (PI-9587)
- 750 or 700 Interface with Power Amplifier II (CI-6552A)

Mounting Options

The String Vibrator can be fastened to a table in a variety of ways.

C-Clamp



Two recessed Clamping Surfaces on the String Vibrator allow it to be secured to a table with a C-clamp. You must use a C-clamp wide enough to accommodate the thickness of the tabletop plus 3 cm (1¼ inch).

The PASCO Small C-Clamp (SE-7286, 6-pack) can clamp the String Vibrator to tables up to 5 cm (2¾ inches) thick; the Large C-Clamp (SE-7285, 6-pack) accommodates tables up to 7 cm (2¾ inches) thick.

Rod Clamp

The case of the String Vibrator has a built-in rod clamp for mounting it either horizontally or vertically on a rod with a diameter up to 12.7 mm (1/2 inch). Slide the rod through the case in the preferred orientation and tighten the thumb screw.

The Universal Table Clamp (ME-9472) and 45 cm Rod (ME-8736) work well in this application because you can clamp the rod vertically to the edge of a table.

Permanent Mounting

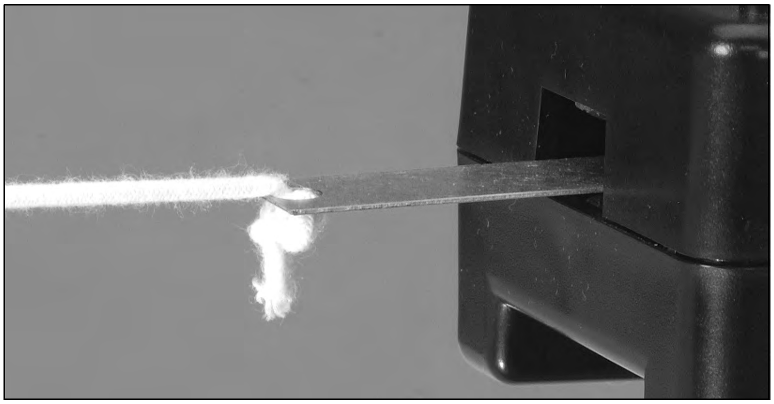
Two through-holes in the clamping surfaces allow the String Vibrator to be mounted permanently on a flat surface. Place a washer under each screw head to protect the plastic case.

String Setup

String Selection

The included elastic wave cord works well for demonstrations and many lab activities. The elastic cord is easy to see, produces good amplitude, and it does not require a hanging mass to provide tension, but it does not have constant linear density under tension. For experiments exploring the relationship between wave speed and string density, it is better to use an inelastic string such as Braided String (SE-8050) or Yellow Cord (ME-9876).

Attaching the String



If you are using the included elastic cord, or any other thick cord, pass it through the grommet, then tie a free-standing knot that cannot pass through the hole when you pull back on the cord. If the end of the cord is frayed, trim it to make it easier to thread through the grommet.

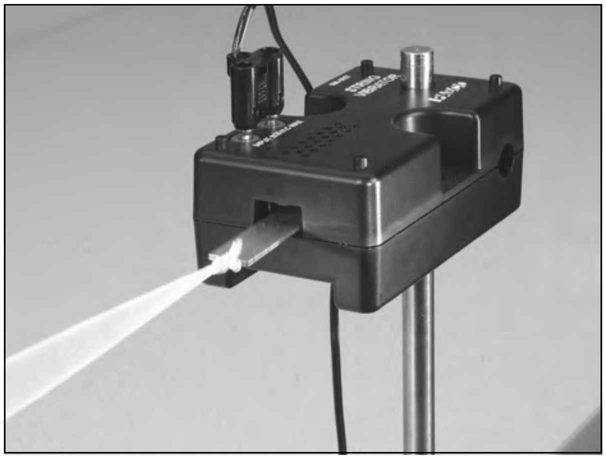
If you are using thin string, thread it through the grommet at the end of the blade and tie it in a loop.

Vertical String

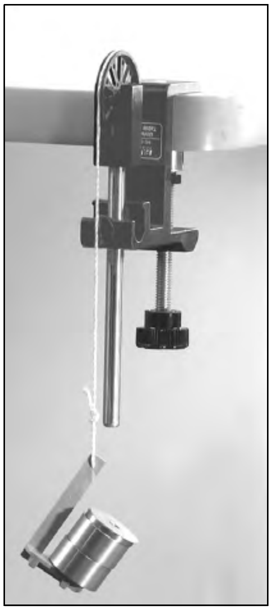
The vertical arrangement with the elastic cord makes a good classroom or lecture demonstration. It requires a vertical rod and a horizontal component at the top of the rod, such as a Pendulum Clamp (SE-9443), to attach the elastic cord. To adjust the length and tension, move the top mount vertically on the rod.

Horizontal String

The pictures below show the horizontal arrangement in two ways. Since the standing waves produced sometimes vibrate in a plane, it may be necessary to rotate the case for the wave to be visible.



In the orientation pictured on the left, the wave is visible from above, but not as easily seen by a student sitting out in the classroom. As shown on the right, the wave is visible from the side, which is most useful for demonstrations.

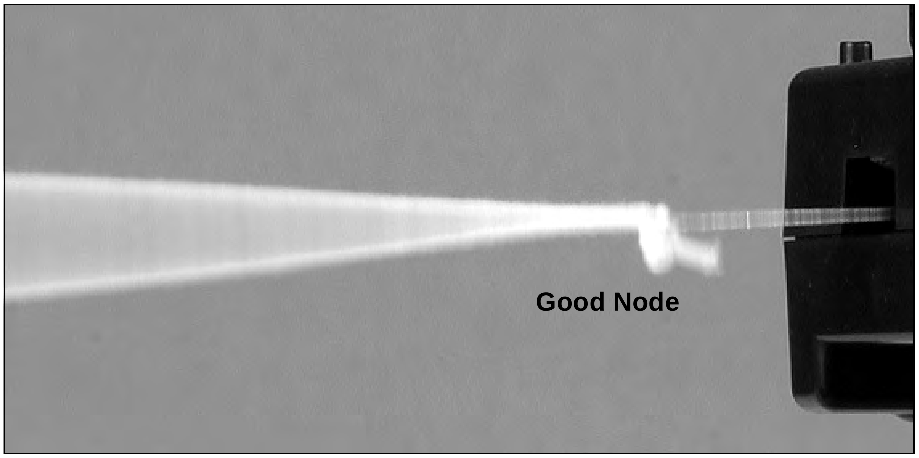


Applying Tension to Inelastic String

When you use inelastic string, it is necessary to apply tension. This can be accomplished with the string oriented horizontally, and with a hanging mass, a pulley and a table clamp as shown here. The tension on the string is equal to the weight of the hanging mass.

Good Nodes Versus Bad Nodes

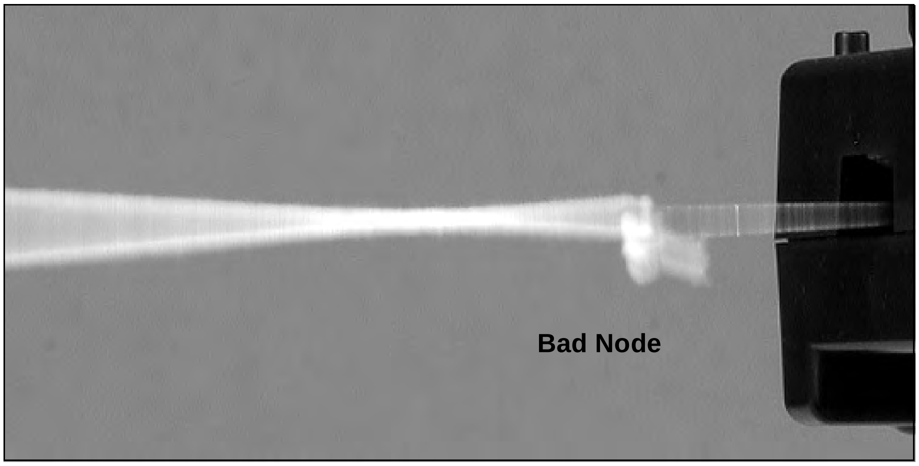
Most demonstrations and experiments involve adjusting the length, tension or frequency to produce a standing wave pattern. It is tempting to look only at the amplitude of the wave and concentrate on making it as large as possible; but it is also important to check that the nodes are “clean” and well defined, especially the node at the vibrating blade.



Check the end of the vibrating blade. There should be a node at the point where the cord attaches, as shown in the first picture to the right.

An example of a bad node is shown in the second picture.

The blade rattling against the plastic case indicates a bad node.



The method for correcting a bad node depends on the type of experimental setup. With the elastic cord, the adjustment is usually made to the length and tension simultaneously by moving one of the end points. With an inelastic string set up with a pulley and a hanging mass, you can adjust the length of the string by moving String Vibrator, or adjust the tension by changing the hanging mass. With either type of string, if you are using a variable-frequency signal generator you can adjust the driving frequency.

Storage

Pins on the top corners and matching holes on the bottom corners of the String Vibrator allow you to stack two or more units for storage.

Introductory Activity

Equipment Required	Part Number
String Vibrator	WA-9857
Power Supply	Part of WA-9857
Elastic Wave Cord (1 meter)	Part of WA-9857 (or SE-9409)
Clamp or other device for securing the String Vibrator	SE-7286 or similar

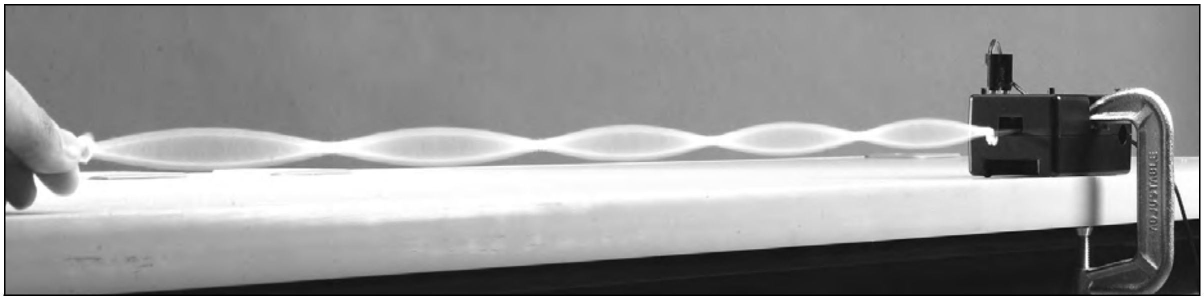
This activity works best with two or more people.

1. Attach the String Vibrator to the table. You'll be stretching the cord to about 2 m, so leave enough space.

2. Cut 1 m of elastic cord and attach one end to the vibrating blade.

3. Connect the AC power supply to the String Vibrator.

4. Hold the free end of the cord as shown, and slowly increase the tension by pulling it away from the String Vibrator.



5. Observe the standing wave patterns that occur as you stretch the cord. Note what happens to the number of segments as you increase the tension. Does increasing the tension cause the number of segments to increase or decrease?

6. Adjust the tension until the cord vibrates in 4 segments. Then adjust the tension slightly so that there is a good node at the blade. Maintain that tension for the rest of the activity.

7. Measure the wavelength. (How is the wavelength related to the length of one segment?)

8. Touch the cord at one of the antinodes (the points of maximum vibration). What happens?

9. Touch the cord at one of the nodes. What happens? How is touching the cord at a node different from touching it at an antinode?

10. Have a lab partner pinch the cord at the middle node without changing the tension. What happens to the wavelength?

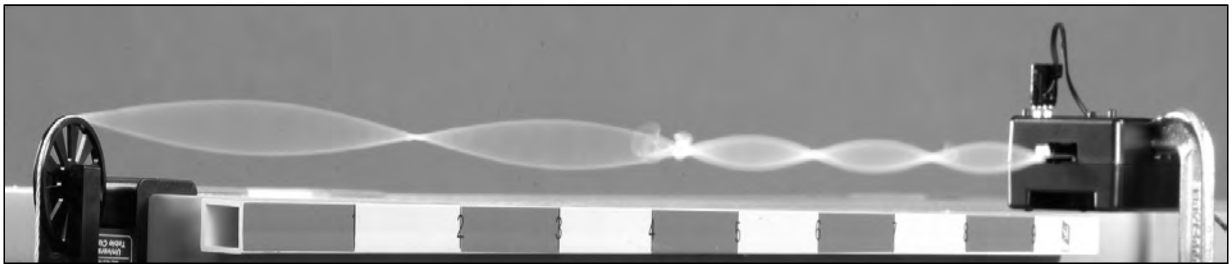
Demonstration 1:
String Density and Wavelength

Equipment Required	Part Number
String Vibrator	WA-9857
Power Supply	Part of WA-9857
Elastic Wave Cord (50 cm)	Part of WA-9857 (or SE-9409)
Inelastic Cord (80 cm)*	ME-9876 or similar
Clamp or other device for securing the String Vibrator	SE-7286 or similar
Super Pulley	ME-9450
Mounting Rod for Super Pulley	SA-9242
Universal Table Clamp	ME-9472 or similar
Mass and Hanger Set, or a ~100 g mass	ME-8967 or similar

Optional Equipment**	
Sine Wave Generator (or equivalent)	WA-9867
Banana Patch Cords	SE-9750

*The recommended inelastic cord (PASCO part ME-9876) has a linear density of 1.5 g/m.

**This demonstration is easier to set up with a Sine Wave Generator (ME-9867), or another ±10 V, 1 A function generator in place of the fixed-frequency power supply, because it allows you to adjust the driving frequency instead of the elastic cord length.



Setup

1. Cut approximately 50 cm of the elastic cord and 80 cm of the inelastic cord. Tie both pieces together and attach the elastic cord to the blade of the String Vibrator. (Make the knots as small as possible.)

2. Clamp the pulley at the end of the table, and clamp the String Vibrator about 1 meter away. Attach a 100 g mass to the end of the inelastic cord, and run the cord over the pulley.

3. Connect the power source to the String Vibrator. If you are using the Sine Wave Generator, set the frequency at around 50 Hz and turn up the amplitude midway.

4. Loosen the clamp on the String Vibrator and slide it along the table to adjust the length of the vibrating part of the inelastic cord. Adjust it so that knot connecting the elastic and inelastic cords is at a node. (The amplitude may be low, but it will increase after the next steps.)
5. Observe the elastic cord. You want a node to occur at the point where the cord is attached to the vibrating blade, but that will probably not be the case initially. If you are using the fixed-frequency power supply continue to the next step. If you are using the Sine Wave Generator, skip to the optional setup section.
6. With a felt-tip pen, mark the elastic cord at the node closest to the blade.
7. Disconnect the power. Adjust the elastic cord so that it is attached to the blade at the point that you marked. Restore the power connection.
8. Adjust the position of the String Vibrator again so that the knot connecting the elastic and inelastic cords is at a node. Confirm that the connection to the blade is also at a node.

Optional Setup for Variable-frequency Sine Wave Generator

First follow steps 1–5. After you have positioned the String Vibrator so that a node occurs at the knot, adjust the driving frequency so that another node occurs at the blade. As you adjust the frequency, adjust the position of the String Vibrator so that the knot stays at a node.

Demonstration

The picture above shows the demonstration using the constant-frequency AC power supply. You can see that the cord with the higher linear density (the elastic cord) has a smaller wavelength. Since both have the same frequency, the denser cord must have a lower wave speed.

Further Demonstration

Compare the wavelengths of two parallel strings. Tie both strings to the same String Vibrator, but run them out to separate pulleys. Apply the same tension to both strings, but adjust the lengths separately (by moving the pulleys along the edge of the table) to achieve standing waves of different wavelengths.

Demonstration 2:
Closed Tube Analogy

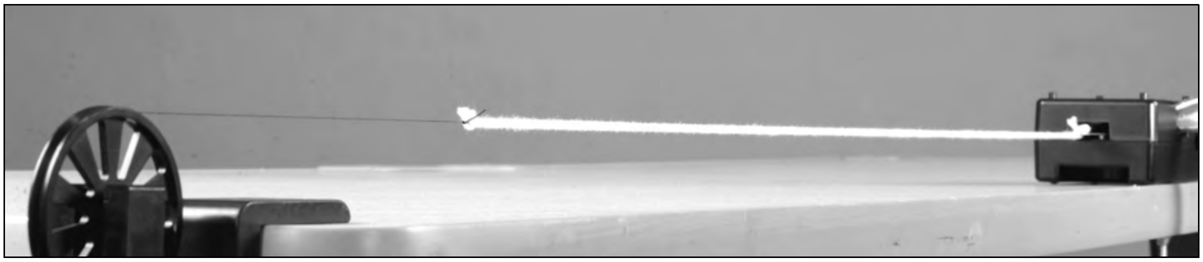
Equipment Required	Part Number
String Vibrator	WA-9857
Power Supply	Part of WA-9857
Elastic Wave Cord (50 cm)	Part of WA-9857 (or SE-9409)
Black Thread (50 cm)	ME-9875 or similar
Clamp or other device for securing the String Vibrator	SE-7286 or similar
Super Pulley	ME-9450
Mounting Rod for Super Pulley	SA-9242
Universal Table Clamp	ME-9472 or similar
Mass and Hanger Set*	ME-8967 or similar

Optional Equipment*	
Sine Wave Generator (or equivalent)	WA-9867
Banana Patch Cords	SE-9750

*With a Sine Wave Generator (ME-9867), or another a ±10 V, 1 A function generator in place of the fixed-frequency power supply, this demonstration is easier to set up, and requires only a single mass of about 150 g rather than an adjustable set of masses.

Setup

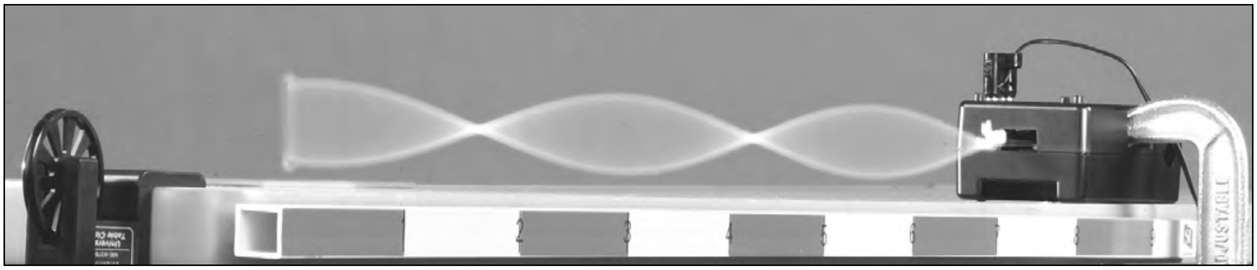
1. Cut approximately 50 cm of elastic cord and 50 cm of black thread. Tie both pieces together and attach the elastic cord to the blade of the String Vibrator. (Make the knots as small as possible.)
2. Clamp the pulley at the end of the table, and clamp the String Vibrator to the table about 70 cm away. Hang a 150 g mass on the thread over the pulley.



3. Connect the power source to the String Vibrator. If you are using the Sine Wave Generator, set the frequency to around 50 Hz, and turn up the amplitude midway.

4. Adjust the hanging mass (or the driving frequency) so that there is a node at the blade and an anti-node at the knot connecting the thread and the elastic cord.

Demonstration



This demonstration is analogous to sound produced by a pipe with one open end and one closed end. Notice that the segment with the anti-node on the end is a quarter wavelength, where the other segments are half wavelengths.

A dark background placed behind the wave can hide how this is done; the white elastic cord shows up very well, but the black thread disappears when the String Vibrator is running.

Experiment 1:
Wave Speed

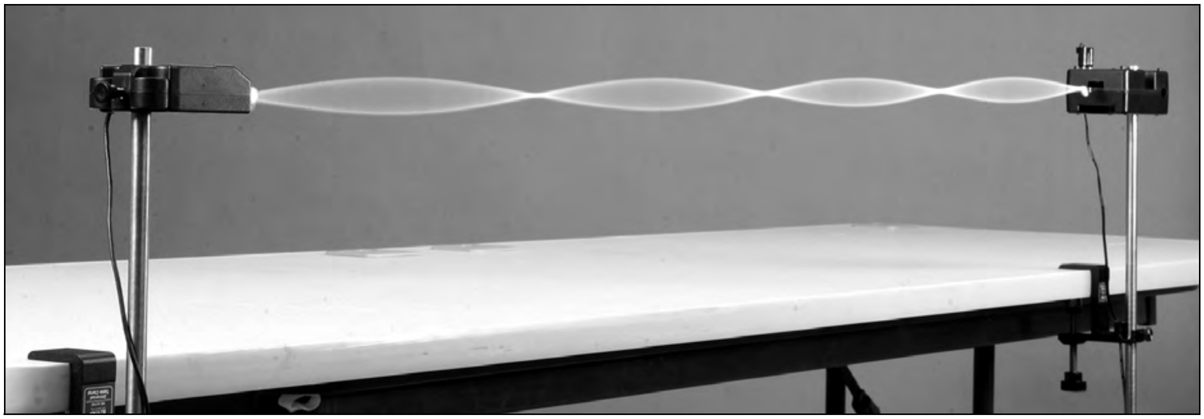
Equipment Required	Part Number
String Vibrator	WA-9857
Power Supply	Part of WA-9857
Elastic Wave Cord (50 cm)	Part of WA-9857 (or SE-9409)
Universal Table Clamps (qty. 2)	ME-9472 or similar
45 cm Rods (qty. 2)	ME-8736 or similar
Force Sensor	CI-6746, CI-6537, or PS-2104
Voltage Sensor	CI-6503 or PS-2115
Computer Interface(s) and software, compatible with sensors	Various, see PASCO catalog
Balance	SE-8765A or similar
Tape Measure	SE-8712A or similar

Introduction

In this experiment you will determine the wave speed in a stretched string using three methods. First, you will calculate the speed based on the wavelength and frequency of a standing wave in the string. Next, you will calculate the speed based on the linear density and tension of the string. Finally, you will measure the time for a single pulse to travel a known distance, and calculate the speed of the pulse.

Procedure

1. Use rods and clamps to connect the Force Sensor and String Vibrator to the table as shown.



2. Cut about 1 m of elastic cord. Measure its exact *unstretched* length. Measure the mass using a balance. Calculate the Unstretched Linear Density (mass/length).

   (If your balance is not precise enough to measure 1 meter of cord, measure the mass and length of a much longer piece of cord, and use those measurements to calculate the linear density.)

3. Attach the cord to the blade of the String Vibrator. Tie a short loop in the other end and slip it onto the hook on the Force Sensor.

4. Plug in the AC power supply, and connect it to the String Vibrator.

5. Move the force sensor or String Vibrator to adjust the tension in the cord so that it vibrates in three or four segments. As you adjust the tension, check the end of the vibrating blade; there should be a node at the point where the cord attaches to the blade. It is more important to have a good node at the blade than to have the largest possible amplitude.

6. Record the number of segments

Tension

You will use the force sensor to measure the tension of the cord.

1. Set the sample rate to 100 Hz.

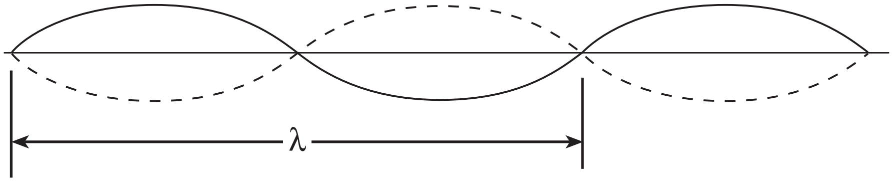
2. Unhook the cord from the force sensor and zero (or tare) the sensor. Reattach the cord.

3. Record data for a few seconds.

4. Find the average force. This is the tension (F) of the cord.

Wave Speed Calculated from Wavelength and Frequency

1. Measure the *stretched* length of the cord (L) from the force sensor hook to the String Vibrator blade. Use this measurement and the number of wave segments to calculate the wavelength, λ. Hint: one wavelength is *two* segments.



2. The speed of the wave (v) is related to the wavelength (λ) and the frequency (f) by

(eq. 1)

$$v = \lambda f$$

   Calculate the speed of the wave.

   (f = 60.0 Hz in the U.S., f = 50.0 Hz in most other countries.)

Wave Speed Calculated from Tension and String Density

You can also calculate the wave speed from the tension (F) and the linear density (μ) of the cord with:

$$v = \sqrt{\frac{F}{\mu}} \qquad \textit{(eq. 2)}$$

The linear density is the mass per unit length of the cord *when it is stretched*. This will be less than the value that you calculated for the *unstretched* cord. You will now calculate the stretched linear density.

1. Unhook the cord from the Force Sensor and measure its unstretched length (from the String Vibrator blade to the loop on the other end).

2. Calculate the stretched density using the formula:

$$\text{Stretched Linear Density} = \mu = \frac{(\text{Unstretched Length})}{(\text{Stretched Length})} \times (\text{Unstretched Linear Density})$$

3. Calculate the speed of the wave from your values of F and μ.

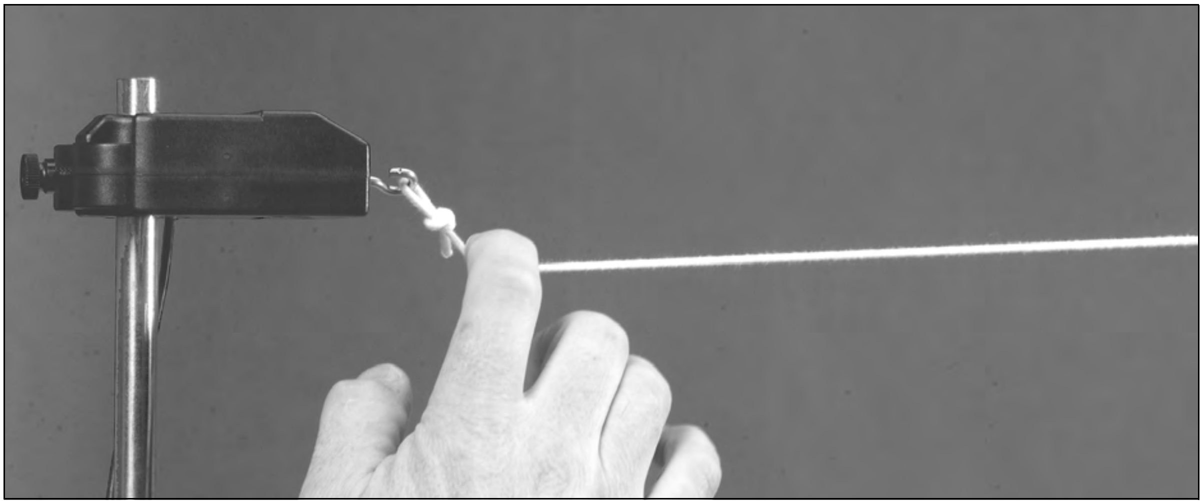
Speed of a Single Pulse

Another way to find the wave speed is to measure the speed of a single pulse. You will use the force sensor and the voltage sensor, to time a pulse traveling down the cord.

1. Unplug the power supply from the String Vibrator. Connect the voltage sensor to the power input of the String Vibrator.

2. Set the sampling rates of force sensor and the voltage sensor to 1000 Hz.

3. To activate the wave, pluck the string vertically as close as possible to the force sensor (as shown in the picture). Notice that when the pulse reaches the String Vibrator, it makes the blade move up and down; this motion moves a magnet inside a coil, which generates a voltage spike that the voltage sensor will measure.



4. Start recording data just before you pluck the string, then immediately stop recording.
5. View the force and voltage data on a graph, and find the elapsed time, Δt, between the sudden decrease in tension and the change in voltage.
6. Calculate the pulse speed:

(eq. 3)

$$\mathrm{v} = \frac{L}{\Delta t}$$

Conclusions

You have calculated the wave speed using three methods.

1) Compare your results. Are the similar? If they deviate from one another, can you explain why?

2) Which method do you think is the most accurate? Explain why.

Further Investigation

Repeat this experiment with a different length of cord (you will find that the tension to achieve a standing wave will be different). Before you measure v using the three methods, predict how the results will differ from your initial findings.

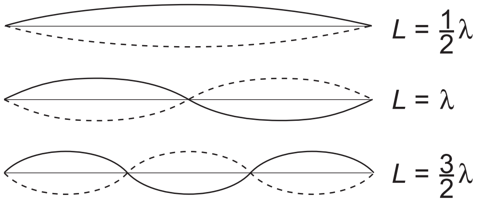
Experiment 2:
Standing Waves In Strings

Equipment Required	Part Number
String Vibrator	WA-9857
Power Supply	Part of WA-9857
Inelastic Braided String	SE-8050 or similar
Clamp or other device of securing the String Vibrator	SE-7286 or similar
Super Pulley	ME-9450
Mounting Rod for Super Pulley	SA-9242
Universal Table Clamp	ME-9472 or similar
Mass and Hanger Set	ME-8967 or similar
Balance	SE-8765A or similar
Tape Measure	SE-8712A or similar

Purpose

The general appearance of waves can be shown by means of standing waves in a string. This type of wave is very important because most of the vibrations of extended bodies, such as the prongs of a tuning fork or the strings of a piano, are standing waves. The purpose of this experiment is to study how the speed of the wave in a vibrating string is affected by the stretching force and the frequency of the wave.

Theory



Standing waves (stationary waves) are produced by the interference of two traveling waves, both of which have the same wavelength, speed and amplitude, but travel in opposite directions through the same medium. The necessary conditions for the production of standing waves can be met in the case of a stretched string by having waves set up by some vibrating body, reflected at the end of the string and then interfering with the oncoming waves.

A stretched string has many natural modes of vibration (three examples are shown above). If the string is fixed at both ends then there must be a node at each end. It may vibrate as a single segment, in which case the length (L) of the string is equal to 1/2 the wavelength (λ) of the wave. It may also vibrate in two segments with a node at each end and one node in the middle; then the wavelength is equal to the length of the string. It may also vibrate with a larger integer number of segments. In every case, the length of the string equals some integer number of half wavelengths.

If you drive a stretched string at an arbitrary frequency, you will probably not see any particular mode; many modes will be mixed together. But, if the tension and the string's length are correctly adjusted to the frequency of the driving vibrator, one vibrational mode will occur at a much greater amplitude than the other modes.

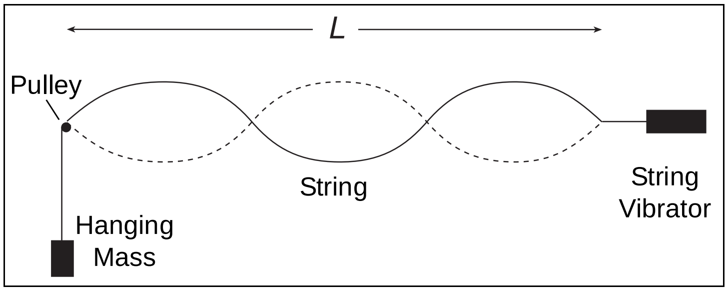
For any wave with wavelength λ and frequency f, the speed, v, is

$$v = \lambda f \qquad \textit{(eq. 1)}$$

The speed of a wave on a string is also given by

$$v = \sqrt{\frac{F}{\mu}} \qquad \textit{(eq. 2)}$$

where F is the tension in the string and μ is the linear density (mass/length) of the string.



In this experiment, standing waves are set up in a stretched string by the vibrations of an electrically-driven String Vibrator. The arrangement of the apparatus is shown to the right. The tension in the string equals the weight of the masses suspended over the pulley. You can alter the tension by changing the masses.

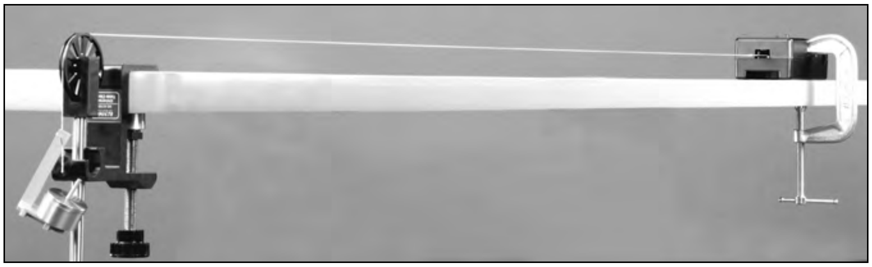
L is the length of the string and n is the number of segments. (Note that n is *not* the number of nodes). Since a segment is 1/2 wavelength then

$$\lambda = \frac{2L}{n} \qquad n = 1, 2, 3, \ldots \qquad \textit{(eq. 3)}$$

Setup

1. Measure the exact length of a piece of string several meters long. Measure the mass of the string and calculate the linear density, μ (mass/length).

(If your balance is not precise enough to measure that length of string, use a much longer piece of string to calculate the linear density.)



2. As shown in the picture, clamp the String Vibrator and pulley about 100 cm apart. Attach the string to the vibrating blade, run it over the pulley, and hang about 100 g of mass from it. Cut off the excess string.

3. Measure from the knot where the string attaches to the String Vibrator to the top of the pulley. This is distance L. (L is *not* the total length of the string that you measured in step 1.)

4. Connect the AC power supply to the String Vibrator.

Procedure

1. Adjust the tension by adding to or subtracting from the hanging mass so that the string vibrates in 2 segments. Adjust the tension further to achieve a “clean” node at the center. Also check the end of the vibrating blade; the point where the string attaches should be a node. It is more important to have a good node at the blade than it is to have the largest amplitude possible. However, it is desirable to have the largest amplitude possible while keeping a good node.

2. Record the hanging mass, m (do not forget to include the mass of the hanger). How much uncertainty is there in your value? By how much can you change the hanging mass before you see an effect? Record the uncertainty.

Analysis Method 1

1. Calculate the tension (including the uncertainty) in the string.

$$\text{Tension} = F = mg$$

2. Calculate the speed (including uncertainty) of the wave from your observed values of tension (F) and linear density (μ).

$$v_{F\mu} = \sqrt{\frac{F}{\mu}}$$

   Record your calculated value with the uncertainty and the correct number of significant figures.

3. Calculate the speed from the wavelength (λ) and frequency (f).

$$v_{\lambda f} = \lambda f$$

   (In the U.S. $f = 60.0$ Hz. In most other countries $f = 50.0$ Hz.)

4. Compare the two values of speed. What is the difference? How does the difference compare to the uncertainty that you determined in step 2?

5. Calculate the percentage by which $v_{F\mu}$ deviates from $v_{\lambda f}$.

$$\%\ \text{Deviation} = \frac{v_{F\mu} - v_{\lambda f}}{v_{\lambda f}} \times 100\%$$

6. Repeat the Procedure and this analysis for standing waves of three and four segments.

Analysis Method 2

1. Repeat the Procedure for standing waves of 3, 4, 5, etc. segments. Get as many as you can. Record the mass, m, (including uncertainty) and the number of segments, n, in a table.

2. For every value of mass, calculate the tension (including uncertainty) in the string.

$$\text{Tension} = F = mg$$

3. Make a graph of F versus n. Describe in words the shape of the graph.

4. For every value of n, calculate $1/n^2$. Make a graph of F versus $1/n^2$. Does the graph look linear?

5. Find the slope (including uncertainty) of the best fit line through this data.

6. Combine equations *1*, *2*, and *3* (from the Theory section), and show that the tension can be written as:

$$F = \left(4\mu f^2 L^2\right)\left(\frac{1}{n^2}\right)$$

   Thus the slope of an F versus $1/n^2$ graph is $4\mu f^2 L^2$.

7. Use the slope from your graph to calculate the density, μ, of the string. Also calculate the uncertainty of μ.

8. Compare this measured value of density to the accepted value. (You calculated the accepted value of μ from the mass and length of the string). What is the difference? How does the difference to compare the uncertainty that you calculated in step 7?

9. Calculate the percent deviation of the measured value of μ from the accepted value of μ.

$$\%\ \text{Deviation} = \frac{\text{Measured} - \text{Accepted}}{\text{Accepted}} \times 100\%$$

Further Investigations

1. Hang a mass on the string with a value that is about halfway between the masses that produced standing waves of 3 and 4 segments. The string should show no particular mode.

   Place a “bridge” so that you can see the exact fundamental ($n = 1$) between the String Vibrator and the bride. What is the wavelength?

   Slide the bridge away from String Vibrator until the string vibrates in 2 segments. How does the wavelength of the two-segment wave compare to the wavelength of the previous one-segment wave?

   Why is a standing wave created only when the bridge is at certain locations? What are these locations called?

2. If a strobe is available, observe the standing wave on a string with the strobe light. Draw a diagram explaining the motion of the string.

Experiment 1:
Teachers' Notes–Wave Speed

Equipment Notes

Clamps

Instead of table clamps and rods, you can use two C-clamps to fasten the String Vibrator and force sensor to the table. Use a block or book to elevate the force sensor a few centimeters above the surface of the table. *Be careful when applying clamping pressure to the force sensor.*

Balance

The density of the elastic wave cord is about 1.5 g/m, so it's best to use a balance readable to 0.01 g. If you have a less-precise balance, have a long piece of cord available for students to measure the length and mass of.

Sensors and Interface

This experiment calls for simultaneous data collection from a force sensor and a voltage sensor. There are several sensor options available; contact Technical Support, or see the PASCO website and catalog for more information. One convenient combination of equipment (which was used for the sample data below) is:

- PASPORT Force Sensor (PS-2104)
- PASPORT Voltage/Current Sensor (PS-2115)
- PowerLink interface (PS-2001)
- DataStudio® software

Because of the variety of equipment that may be used, the instructions here do not go into detail about collecting data. Students should be prepared to use the sensors, interface and software to:

- Set up the hardware and software to collect data from voltage and force sensors (sensor setup)
- Change the sampling rate of the sensors
- Record data (data collection)
- Display the data in a graph (display windows: adding an input)
- Find the average value of a data set (Statistics)

In DataStudio, click on the Help menu, select search, and look up the underlined terms in the index for detailed instructions.

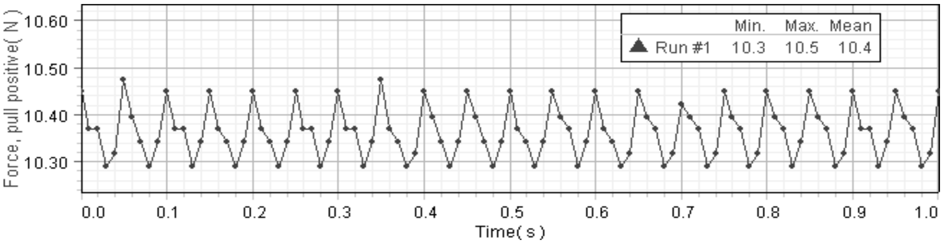
Procedure Notes and Sample Data

The cord will stretch by a factor of about 2. If you don't have enough lab space to accommodate that length of cord, start with a shorter piece.

Unstretched Length (without knots) = 1.354 m
Mass = 5.74 g
Unstretched Linear Density = 4.24×10^{-3} kg/m

Tension

$F = 10.4$ N



Wave Speed Calculated from Wavelength and Frequency

Stretched Length = L = 2.343 m
Number of segments = 4
$\lambda = 1.172$ m
$f = 60.0$ Hz
$v = \lambda f = 70.2$ m/s

Wave Speed Calculated from Tension and String Density

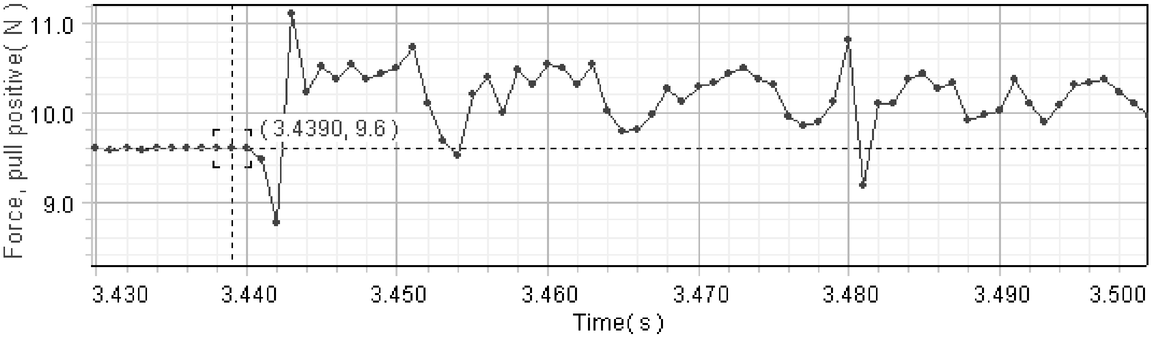
The unstretched length measured in this part of the experiment will be less than the unstretched length measured initially because of the knots tied in the ends.

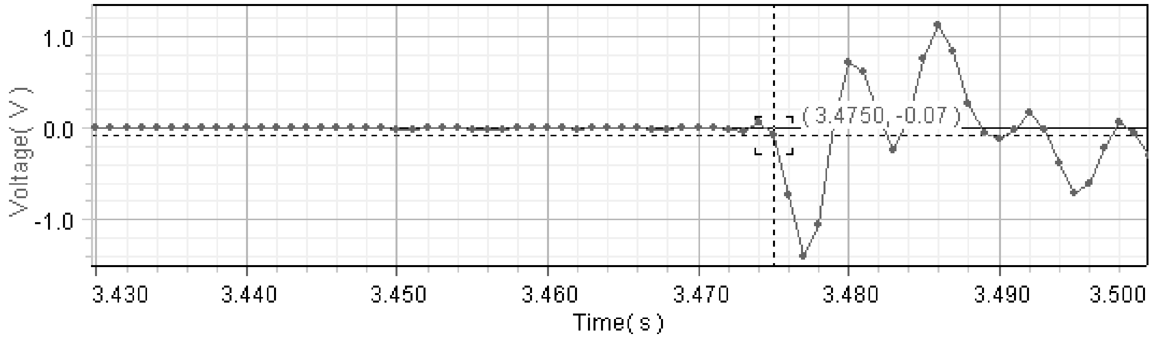
Unstretched Length (with knots) = 1.162 m

$\mu = 2.11 \times 10^{-3}$ kg/m

$$v = \sqrt{\frac{F}{\mu}} = 70.2 \text{ m/s}$$

Speed of a Single Pulse





The sudden decrease in tension may appear on the graph as a sudden decrease *or* increase in force, depending on whether the force sensor is set up to register tension as a positive or negative force.

Be sure to measure from the *sudden* force change, not the relatively slow variation that may occur before the actual pluck. It may be helpful to repeat the measurement a few times and take the average value.

$\Delta t = 3.4 \times 10^{-2}$ s
v = $L/\Delta t$ = 68.8 m/s

Conclusions

1) In the sample data above, all three calculations of v were within 5% of each other. (The first two calculations were exactly equal, but that is not typical.) With a sample rate of 1000 Hz, the uncertainty of the pulse timing measurement was about 1 ms, or 3% of Δt, which would account for much of the 5% deviation observed.

2) The method based on frequency and wavelength was probably the most accurate because it involved only one measurement, length, which was probably accurate to within a few millimeters (or about 0.1%). The frequency of the AC power is usually very close to its nominal value, so you can ignore its uncertainty. You can also use the voltage sensor plugged into the output of the power supply to measure the frequency. Do not attempt to measure the voltage directly from the wall.

Experiment 2:
Teachers' Notes–Standing Waves In Strings

The density of the recommended string is about 0.266 g/m, so it's best to use a balance readable to 0.01 g. If you have a less-precise balance, have a long piece of string available for students to measure the length and mass of.

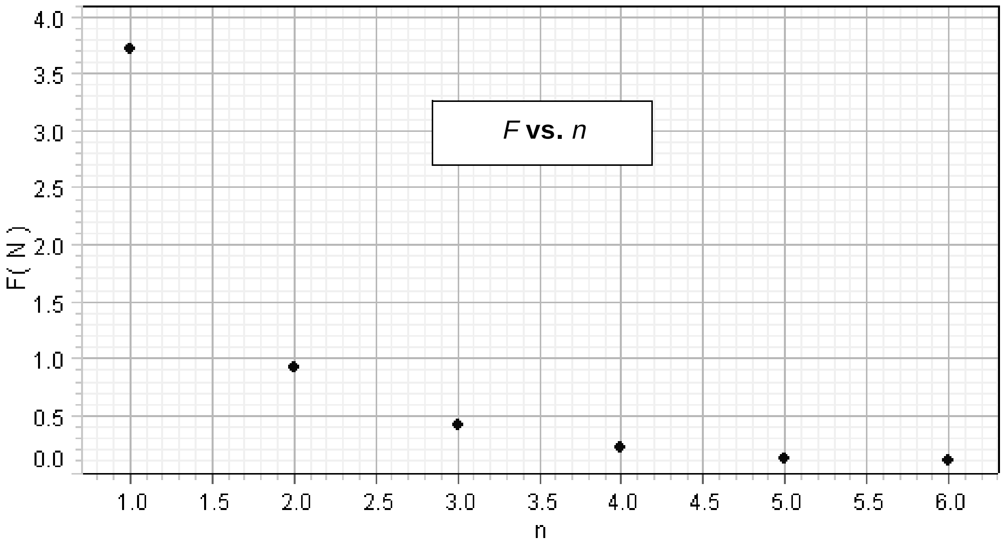
Standing waves of n = 1, 2 and 3 are fairly easy to achieve. Standing waves of $n \geq 4$ may require mass adjustments of 1 g or less. You can make these adjustments by adding pieces of paper to the hanging mass. It will suffice to estimate the mass to within 0.5 g.

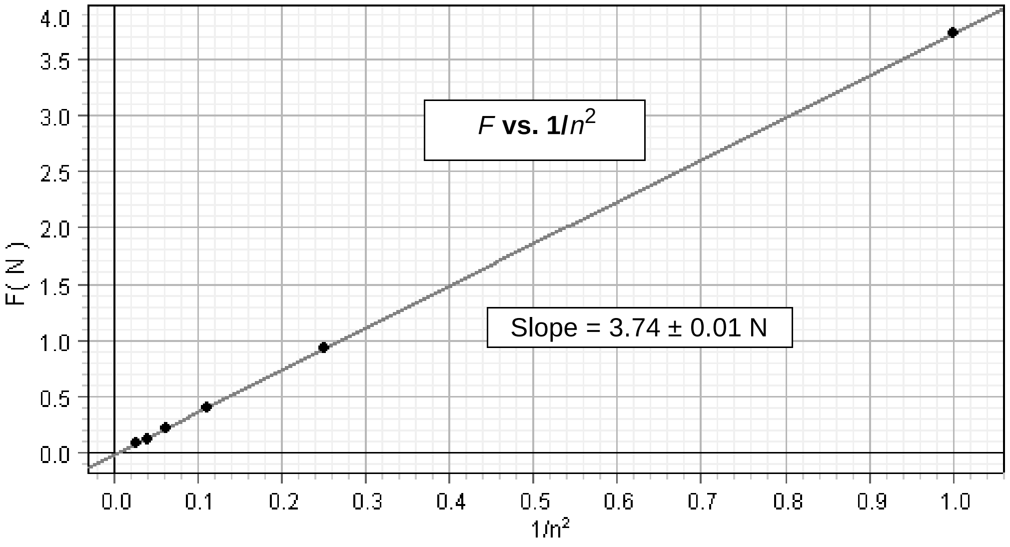
Analysis Method 1

L = 0.987 m
f = 60.0 Hz
$\mu = 2.66 \times 10^{-4}$ kg/m

Number of Segments	Hanging Mass (g)	Uncertainty (g)	$v_{F\mu}$ (m/s)	$v_{\lambda f}$ (m/s)	% Deviation
1	380	10	120	118	1.7%
2	95	2	60.	59.2	1.3%
3	41	1	39	39.5	1.3%
4	22.5	1	29	29.6	2.0%
5	14	1	23	23.7	3.0%
6	9	1	20	19.7	1.5%

Analysis Method 2





$4\mu f^2L^2 = 3.74 \pm 0.01\text{ N}$
$f = (60.0 \pm 0.1)\text{ Hz}$
$L = (0.987 \pm 0.001\text{ m})$

$$\mu = \frac{(3.74 \pm 0.01\text{ N})}{4f^2L^2} = (2.67 \pm 0.01) \times 10^{-4}\text{ kg/m}$$

This result differs from the direct measurement of linear density by 0.01×10^{-4} kg/m. It is within the estimated uncertainty.

$$\%\text{ Deviation} = \frac{2.67 \times 10^{-4}\text{ kg/m} - 2.66 \times 10^{-4}\text{ kg/m}}{2.66 \times 10^{-4}\text{ kg/m}} \times 100\% = 0.4\%$$

Safety

Read the instructions before using this product. Students should be supervised by their instructors. When using this product, follow the instructions in this manual and all local safety guidelines that apply to you.

Technical Support

For assistance with any PASCO product, contact PASCO at:

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Phone: (916) 786-3800
(800) 772-8700
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Limited Warranty

For a description of the product warranty, see the PASCO catalog.

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