Standing Waves in Strings

Qty	Description	Part #
1	Sine Wave Generator	WA-9867
1	String Vibrator	WA-9857A
1	Physics (Braided) String	SE-8050
1	Yellow Braided Cord	
1	Elastic Wave Cord	SE-9409
1	Banana Patch Cords	SE-9750
2	Universal Table Clamp	ME-9376B
1	Super Pulley	ME-9450A
1	Mounting Rod for Super Pulley	SA-9242
1	Adjustable Angle Clamp	ME-8744
2	45 cm Rod	ME-8736
1	Mass and Hanger Set	ME-8979

Required but not included:

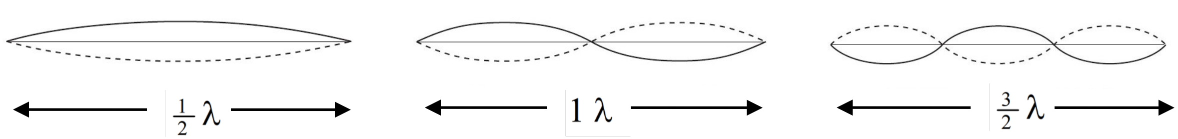
Qty	Description	Part #
1	Balance	SE-8725 or similar
1	Tape Measure	SE-8712A or similar

INTRODUCTION

A sine wave generator drives a string vibrator to create a standing wave pattern in a stretched string. The driving frequency and the length, density, and tension of the string are varied to investigate their effect on the speed of the wave in the vibrating string.

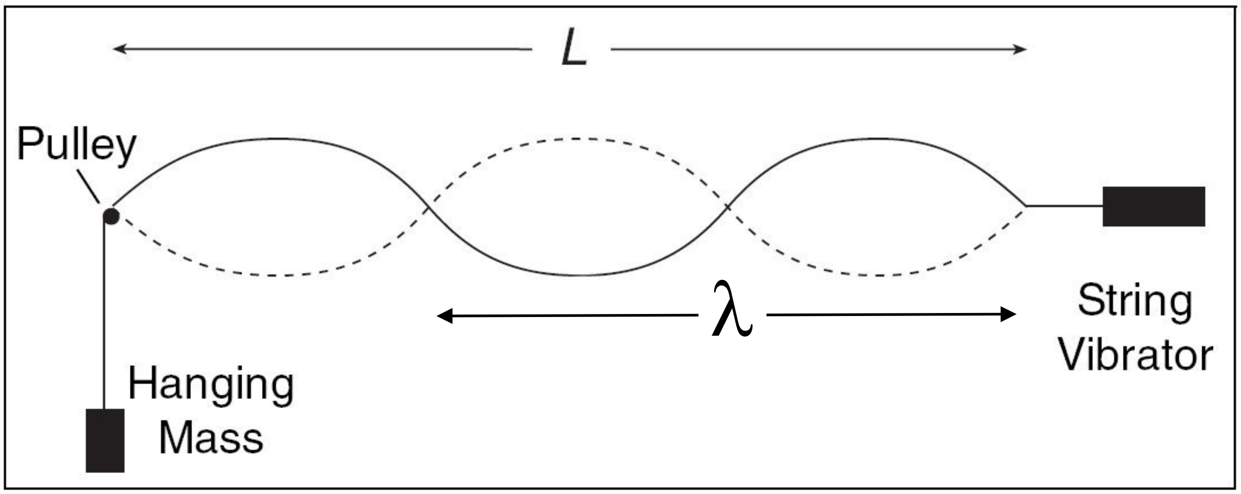
THEORY

A stretched string has many natural modes of vibration (three examples are shown below). If the string is fixed at both ends then there must be a node (place of no amplitude) at each end and at least one anti-node (place of maximum amplitude). 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 driving frequency, the tension and the length are adjusted correctly, one vibrational mode will occur at a much greater amplitude than the other modes.

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 below. The tension in the string equals the weight of the masses suspended over the pulley. You can alter the tension by changing the masses. You can adjust the amplitude and frequency of the wave by adjusting the output of the Sine Wave Generator, which powers the string vibrator.



L is the length of the vibrating part of the string and λ is the wavelength of the wave. For the string shown above vibrating in 3 segments, $\lambda = \frac{2}{3}L$.

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

$$v = \lambda f \qquad (1)$$

In addition, the speed of a wave on a string is also given by

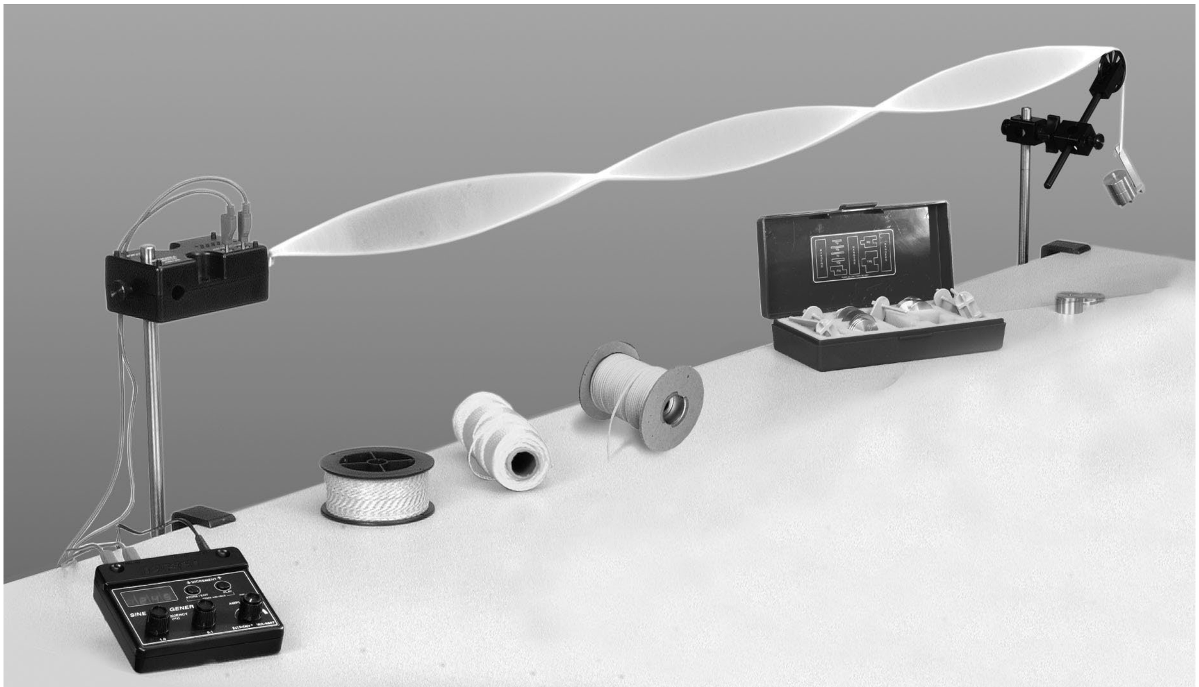
$$v = \sqrt{\frac{F}{\mu}} \qquad (2)$$

The linear density (μ) is the mass per unit length of the string. The Tension (*F*) is applied by the hanging a mass (*m*), and is equal to the weight (*mg*) of the hanging mass.

SETUP

1. Measure the exact length of a piece of the braided string several meters long. Measure the mass of the string and calculate the linear density, μ (mass/length). (If your balance can not read to 0.01 g, you may want to use a longer piece of string to calculate the linear density.)

2. As shown in the picture, use the two clamps to position the Sine Wave Generator and pulley about 120 cm apart. Attach about 1.5 m of braided string to the vibrating blade, run it over the pulley, and hang about 150 g of mass from it.



3. Measure from the knot where the string attaches to the string vibrator to the top of the pulley. This is distance L. (Note that L is *not* the total length of the string, only the part that is vibrating.)

4. Turn on the Sine Wave Generator and turn the Amplitude knob all the way down (counter-clockwise). Connect the Sine Wave Generator to the string vibrator using two banana patch cords. Polarity does not matter.

PROCEDURE

Part I:

1. Set the Amplitude knob about midway. Use the Coarse (1.0) and Fine (0.1) Frequency knobs of the Sine Wave Generator to adjust the vibrations so that the string vibrates in *one* segment. Adjust the driving amplitude and frequency to obtain a large-amplitude wave, but 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 a large amplitude while keeping a good node.

2. Record the frequency. How much uncertainty is there in this value? How much can you change the frequency before you see an effect?

3. Repeat steps 1 and 2 for a standing wave with *two* segments. The string should vibrate with a node at each end and one node in the center. Do not change the hanging mass.

4. How is the frequency of the two-segment wave related to the frequency of the one-segment wave? Calculate the ratio of the frequencies. Is the ratio what you would expect?

5. With the wave vibrating in two segments, the length of the string, L, is one wavelength ($L = \lambda$). Does it look like one wavelength? Since the string vibrates up and down so fast, it is hard to see that when one side is up, the other is down. Try touching the string at an anti-node. What happens? Try touching the string at the central node. Can you hold the string at the node and not significantly effect the vibration?

6. What was the wavelength when the string was vibrating in one segment? Use Equation 1 to calculate the speed of the one-segment wave. Calculate the speed of the two-segment wave. How do these two values compare? Are they *about* the same? Why?

7. Calculate the tension in the string caused by the hanging mass (don't forget the mass hanger) and using your measured density of the string, calculate the speed of the wave using equation (2). How does this compare to your answer in part 6?

8. Adjust the frequency so that the string vibrates in *three* segments. What is the velocity now? Has it changed? Does the speed of the wave depend on the wavelength and the frequency?

9. Set the frequency to a value between the frequencies that produced waves of two and three segments. Adjust the frequency so that no particular standing waveform is present. Unclamp the string vibrator on the table and slowly move it towards the pulley. (Do not let go of the string vibrator without clamping it to the table again.). Without changing the driving frequency or the hanging mass decrease the length of vibrating string until it vibrates in *two* segments. Measure the new wavelength and calculate the speed of the wave. Is it about the same as before? Does the speed of the wave depend on the length of the string?

Part II:

1. Clamp the String Vibrator back at its original position, about 120 cm from the pulley. You should re-measure the length, L. Hang about 50 g from the string over the pulley. Record the total hanging mass, including the mass hanger.

2. Adjust the frequency of the Sine Wave Generator so that the string vibrates in *four* segments. As before, adjust the driving amplitude and frequency to obtain a large-amplitude wave, *and* clean nodes, including the node at the end of the blade. Record the frequency.

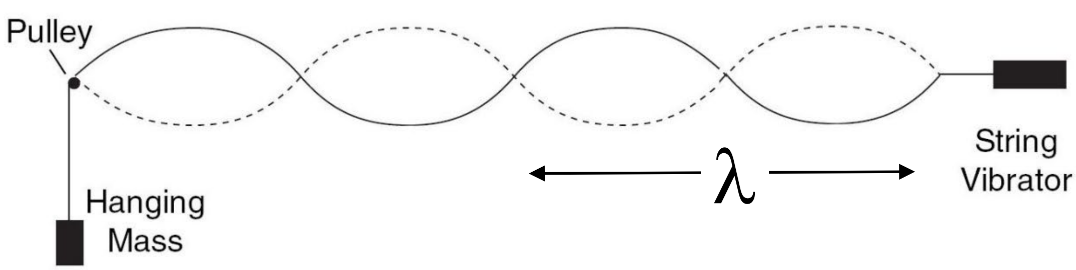
Note: For this part of the experiment, you will always adjust the frequency so that the wave vibrates in *four* segments.

3. Add 50 g to the hanging mass and repeat steps 1 and 2.

4. Repeat at intervals of 50 g up to at least 250 g. Record your data in a table.

ANALYSIS

1. For this part of the experiment, you always adjusted the frequency so that the wave vibrated in *four* segments, and thus the length of the string was always equal to two wavelengths ($L = 2\lambda$).



Use this information to show that equations (1) and (2) can be combined to yield

$$f^2 = \frac{4g}{\mu L^2} m \qquad (3)$$

where: f = driving frequency of the Sine Wave Generator
g = acceleration due to gravity
m = total hanging mass
L = length of string (vibrating part only)
μ = linear density of the string (mass/length)

2. Make a graph of the square of the frequency (f^2) versus hanging mass, *m*. (The units will be easier to work with later if you graph the mass in kilograms.) Is the graph linear?
3. Find the slope (including uncertainty) of the best-fit line through this data.
4. As you can determine from Equation *3*, the slope of the f^2 vs. *m* graph is:

$$\text{slope} = \frac{4g}{\mu L^2}$$

From the slope of your graph, calculate the density (μ) of the string. What is the uncertainty?

5. Compare the density that you measured from the graph to the actual density that you determined when you weighed the string. Calculate the percent deviation.

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

FURTHER INVESTIGATIONS

1. Repeat the procedure (for Part II only) using the yellow cord. Put the data from the string and cord on the same graph to show the difference in their densities.

2. Repeat the procedure with elastic cord. The density is much larger, so put the data on a separate graph. Look carefully at the graph. Is it linear like the first two? Calculate the density using both the minimum and maximum slopes.

3. Measure how much the elastic cord stretches when you place the maximum mass on the hanger. Based on the un-stretched density of the cord, and the amount that it stretches, estimate the “stretched” density of the cord. Compare this value to the densities that you calculated from your graph.

CONCLUSION

Summarize the quantities that affect the speed of a wave in a string: Consider the number of segments, the frequency, the tension in the string, and the length and density of the string.