15815 Super Spring - Student

Accessories Needed, Not Included:

- *Required Accessories:*
  - string (2 to 4 meters needed)
  - C-clamp (or any other fixed clamp on a bench)
  - Stopwatch
  - masking tape or labels
  - One or more of the following: heavier cord or rope, different spring, rubber tubing, bungee cord, etc.
  - Meter stick or tape measure
- *Optional Accessories:*
  - Snakey (TSS# 15820)
  - Other springs

PURPOSE

The Super Spring Wave Demonstrator is used to demonstrate properties and behaviors of several types of waves in a way that provides more viewing time with better storage between experiments. The student will observe several types of waves, investigate how these waves are produced and interact, describe the observations and speculate on other related wave behaviors

OBJECTIVES

- To study the motion of waves through a medium
- To study how waves interact with each other
- To study how energy is transferred through a spring
- To study the Law of Superposition

SAFETY

While a Super Spring is not inherently dangerous, care should be taken not to release a stretched Super Spring as it will return to equilibrium rapidly. It may snap back fast, and can cause injury if care is not taken. Also, this rapid return to equilibrium may cause damage to the Super Spring. The Super Spring should not be extended more than 12 meters (39 feet). Eye protection should be worn.

ASSEMBLY

The Super Spring requires no assembly.

CONCEPTS

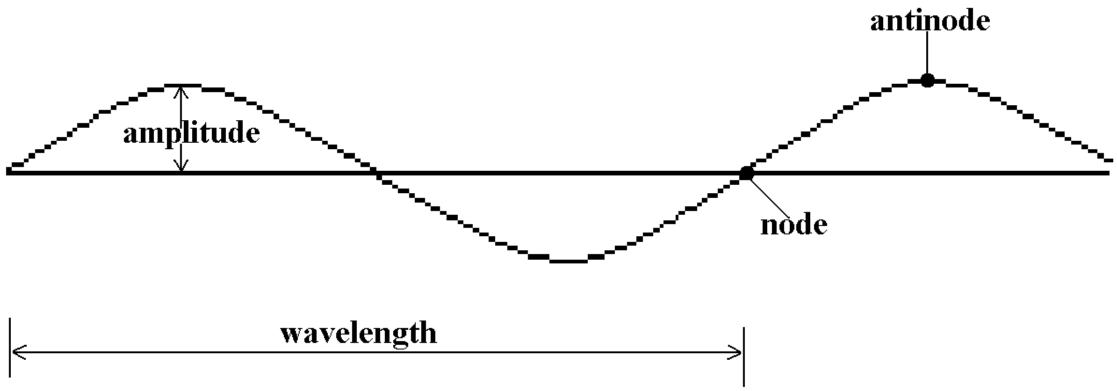
There are many different types of waves. Water waves, electromagnetic waves (including radio, light, gamma rays, etc.), and sound waves are a few examples. This activity will investigate two kinds of mechanical waves. (There is a third type of mechanical wave, but these are not addressed in the following procedures.) A mechanical wave is any kind of wave that displaces a material as it travels through that material. The material that carries a mechanical wave is a ***medium***, and the movement of a wave through a medium is called ***propagatio****n*.

This apparatus can demonstrate two basic types of mechanical waves: transverse waves and longitudinal waves. Transverse waves displace the medium perpendicularly (at right angles, see the sketch below) to the propagation of the wave. Longitudinal waves displace the medium parallel to the propagation of the wave (in the same direction as the movement of the wave).

Although some properties of waves (such as wave speed) are determined by the medium through which the wave travels, most wave properties are the same for many different types of waves. Learning about the properties and behaviors of these mechanical waves should help you to understand many different types of wave motion.

INTRODUCTION

All waves have particular quantities in common. These quantities are shown in the following sketch, and defined below:



Amplitude is the maximum displacement of the wave from the resting position of the medium.

A **node** is a location on the wave where the displacement from the undisturbed medium is zero.

An **antinode** is the location on a wave where maximum amplitude is reached.

Frequency is the rate at which waves are produced, usually expressed in Hertz (Hz) or vibrations-per-second.

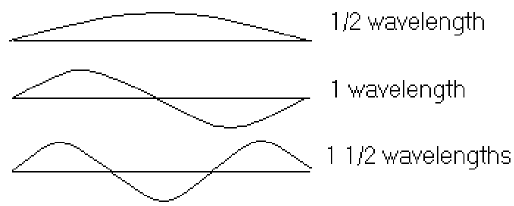
Each section of the wave that moves above or below the center line is sometimes called a "**loop**." Note that one wavelength consists of two loops.

Any initial wave is known as an ***incident* wave**. When an incident wave encounters a new medium, a new wave may be formed at the boundary that changes direction and goes back through the original medium; this is a ***reflected* wave**. Another wave may also continue through the boundary into the new medium; this is called a ***transmitted*** or ***refracted* wave**.

An incident wave will reflect at a boundary depending upon how the spring is attached at that boundary. A spring with a ***fixed end* boundary** is attached firmly to an object (a spring attached to a wall, for example). A spring with a ***free end* boundary** is free to move at that boundary (a spring attached to a string or free to slide on a metal rod, for example). When two media are connected, the boundary between the two media can behave as a fixed end or a free end, depending on the difference between the two media.

When trying to understand **fixed end and free end reflections**, we can imagine that the spring continues through the boundary, and that an imaginary wave of the correct size and orientation is approaching the boundary from the opposite direction. For a fixed end reflection, the imaginary wave is the same amplitude and wavelength as the real incident wave, and is on the opposite side of the spring from the real incident wave. For a free end reflection, the imaginary wave is the same amplitude and wavelength as the real incident wave, and is on the same side of the spring as the real incident wave. We can use the ***Principle of Linear Superposition*** to determine what the reflected wave will look like throughout the interaction with the boundary. (The *Principle of Linear Superposition* states that when two waves meet, the combined wave will have an amplitude that is equal to the sum of the two individual amplitudes.)

Standing waves are waves created in a medium that keep a set pattern. These waves appear to be either standing still or vibrating in place. Standing wave patterns are created when the medium is displaced at specific frequencies. These specific frequencies, called ***harmonic frequencies,*** produce reflected waves which reinforce the incident waves, building larger and larger wave amplitudes. Different harmonic frequencies create different standing wave patterns, three of which are shown below.



Similar patterns of waves are used to create sound waves from the strings of a guitar, violin, or piano. Standing waves also develop in mechanical systems such as cables, airplane wings, and even bridges. The collapse of the Tacoma Narrows Bridge (see Internet resources) is a dramatic example of the destructive results of uncontrollable standing waves.

PROCEDURES

All procedures should be experienced by all team members. Don't just watch – participate! Each student should take notes of observations during the work of the lab activity. From these notes, write descriptions of observations that were made, and answer the Procedure Questions ("Qs") and Review Questions.

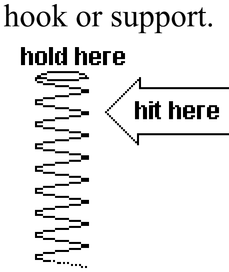
DO NOT OVERSTRETCH THE SUPER SPRING!!!!

The Super Spring works fine stretched to a limit of 12 meters (39 feet). Beyond that, the Super Spring may become permanently distorted.

PROCEDURE A - WAVE PULSES

1. Set up the Super Spring for use.
   Stretch the Super Spring along a smooth bench top or on a smooth section of floor.
   (Use on a rug is not advised since the rug will restrict the motion of the Super Spring.)
   CAUTION! Do not stretch the Super Spring too long or you may damage it!

Anchor the far end by attaching the Super Spring to a C-clamp or any other solid hook or support. The end that is clamped to a support is called a *fixed end*.



2. Send a transverse pulse down the Super Spring®.
   Do this by holding your end of the Super Spring and quickly hitting or slapping the Super Spring sideways just in front of your hand. (If you try to send a pulse down the Super Spring by shaking the end side-to-side, you must

use a quick, single shake of the end of the Super Spring, otherwise the entire Super Spring moves instead of sending a pulse. Whichever method is most effective for your group, practice making pulses until you become comfortable with the method and make consistent pulses.)

You should be able to send a pulse that travels down the Super Spring then reflects back from the fixed end.

Q1. Describe the wave pulse that travels down the Super Spring. Make a sketch of its shape.

Take a small piece of masking tape or white label tape and attach it to the Super Spring at some point near the middle. Send several wave pulses down the Super Spring. Watch the small piece of tape.

Q2. Describe the motion of the point in the Super Spring marked by the piece of tape as a wave pulse passes through.

Q3. Taken as a whole, what is the motion of the Super Spring as a transverse wave passes down its length?

Q4. What is actually moving from your end to the fixed end of the Super Spring?

3. Energy

All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves. Potential energy is stored in a spring by stretching or compressing the spring with a force (see also Hooke's Law and elastic potential energy). Any object that moves has kinetic energy as a result of both the mass and the speed of the object.

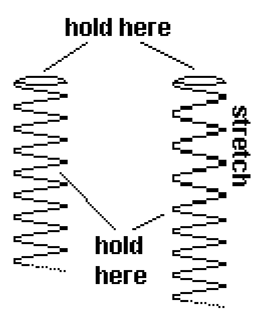
Q5. In what way does a wave pulse show the presence of potential energy?

Q6. In what way does a wave pulse show the presence of kinetic energy?

Q7. What is the source of this kinetic and potential energy in the Super Spring?

4. Send a longitudinal pulse down the Super Spring.

Do this by holding your end of the Super Springand also holding one of the coils a short distance from the end. Stretch the Super Spring about twice the relaxed length of that section, then let go.



You can also send a pulse by compressing the end section of the Super Spring, but this usually sends a weaker pulse and tends to move the entire length of the Super Spring. Try to send a pulse by both methods to see how this works. Also try out any other methods that you can think of the start a longitudinal pulse. (If you find another method that works well, report on this with a description.)

You should be able to send a pulse that travels down the Super Spring, then reflects back from the fixed end.

Q8. Describe the wave pulse that travels down the Super Spring. Try to make a sketch of its shape in the Super Spring.

As before, have a small piece of masking tape or white label tape attached to the Super Spring at some point near the middle. Send several wave pulses down the Super Spring. Watch the small piece of tape.

Q9. Describe the motion of the point in the Super Spring marked by the piece of tape as a longitudinal wave pulse propagates?

Q10. Taken as a whole, what is the motion of the Super Spring as a longitudinal wave passes down its length?

Q11. What is actually moving from your end to the fixed end of the Super Spring?

Q12. In what way does a longitudinal wave pulse show the presence of potential energy?

Q13. In what way does a longitudinal wave pulse show the presence of kinetic energy?

Procedure B - Reflection and Refraction

1. Reflection of a Transverse Wave Pulse- Part 1

Attach the Super Spring to a wall. (This can be done by stretching the Super Spring, and having a student hold the Super Spring to the wall.) Send a transverse wave pulse down the Super Spring by either hitting the Super Spring or a quick, violent shake, but now pay close attention to the wave that reflects back from the wall.

Q1. Is the reflected wave on the same side of the Super Spring or on the opposite side as compared to the original wave pulse?

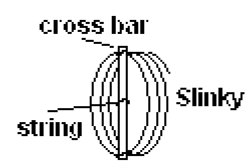
Q2. Describe any other changes that you see in the shape or size of the reflected wave pulse.

Q3. Is this situation a fixed end or a free end? How do you know?

2. Reflection of a longitudinal wave pulse

As in the first procedure, send a longitudinal wave pulse down the Super Spring, but now pay close attention to the wave that reflects back from the fixed end.

Q4. Describe any changes in the reflected wave pulse.



3. Reflection of a Transverse Wave Pulse- Part 2

Obtain a length of string that will be about the same length as the Super Spring when it is stretched for use. The best way to attach the string is by tying it to the middle of a cross-bar at the end of the Super Spring (see sketch). The cross-bar can be a wood splint, or a piece of string tied across the Super Spring and taped in place.

Attach the far end of the string to a clamp or other anchor. Stretch the Super Spring to about the same length as before.

As before, send a transverse wave pulse down the Super Spring, but now pay close attention to the wave that reflects back from the string. Do not watch the wave travel through the string or other spring at this time.

Q5. Is the reflected wave on the same side of the Super Spring or on the opposite side as compared to the original wave pulse?

Q6. Describe any other changes that you see in the shape or size of the reflected wave pulse.

Q7. Is this situation a fixed end or a free end? How do you know?

4. Refraction in a different medium

Replace the string with a different spring or heavier rope. Attach the new medium to an anchor as you did with the string in the previous procedure. A wave that continues to travel after crossing a boundary from one medium to another is said to be a transmitted wave.

As before, send a transverse wave pulse down the Super Spring, but now pay close attention to the wave that continues into the second medium. Do not pay attention to the reflected wave in the Super Spring at this time.

Q8. Is the transmitted wave on the same side of the Super Spring or on the opposite side as compared to the original wave pulse?

Q9. Describe any other changes that you see in the shape, size, or speed of the transmitted wave pulse.

Send a transverse wave down the Super Spring. Have one person observe what happens in the Super Spring, one person watch and observe what happens at the boundary, and one person observe what happens in the string or other spring.

Q10. To the extent that you are able, describe all of the wave behaviors that you observe in this system of two different materials carrying waves. (Hint: Have each person describe to the group what they saw in their portion, so that all possible detail gets included.)

PROCEDURE C - Wave Speed

1. Wave speeds in different media

In Procedure B, in addition to the Super Spring, you used a string and another material as different media for the wave propagation. If you have another medium available, you can also use it to replace the string or different medium that you have already used.

Send a transverse wave down the Super Spring that is attached to another medium.

Q1. How does the speed of the wave appear to change when it enters a new medium?

Now, send a transverse wave down the other medium.

Q2. How does the speed of the wave appear to change when it enters a new medium?

2. Wave speeds as media properties change

Remove the string or other medium from the Super Spring. Return to having the Super Spring attached to the original anchor. Change the properties of the Super Spring by stretching it tighter than before (changing the tension of the Super Spring). To do this, at the end that you hold, bunch-up the extra length that you do not need, rather than changing the length the Super Spring is stretched, since this can ruin the Super Spring.

Send a transverse wave through the tighter Super Spring.

Q3. Does the wave move down the Super Spring faster or slower than when the Super Spring was at its original tension?

Tighten the Super Spring a little more, and send another transverse wave down it.

Q4. Does the wave move down the Super Spring faster or slower than before?

Q5. What is the relationship between the tension in the Super Spring and the wave speed in the Super Spring?

3. Wave speeds as wave properties change

Return the Super Spring to the original set up, anchored as you had it in the first procedure. Create a transverse wave of small amplitude, then a transverse wave of larger amplitude. Continue to increase the amplitude of the wave, paying attention to the speed the wave travels at. (This works well on a tile floor, with the tiles as markers for height of the wave.)

Q6. As the amplitude increases, what happens to the speed of the wave?

PROCEDURE D - Superposition of Waves.

1. <u>Superposition of Transverse wave pulses</u>

Two team members are required to make things work. Remove the far end of the Super Spring from the anchor, and have it held by a second team member. (The best observations of the phenomena occur when the Super Spring is held on the floor and a piece of string or tape is at the middle of the Super Spring to give a point of reference for observations.)

CAUTION! With opposite ends of the Super Spring being held by different people, there is an unhealthy urge to release your end to surprise the other person. Don't do it! Two reasons: (1) Although a Super Spring is not very heavy, somebody can still get injured. (2) Even if nobody gets injured, letting the Super Spring fly across the bench is also a great way to destroy the Super Spring beyond usefulness. Please be careful, reasonable, and considerate!

Practice sending transverse waves down the Super Spring until you can both send a wave that meets in the middle of the Super Spring at the same time. Once you have practiced this technique, send a transverse wave of the same amplitude and on the same side from each end of the Super Spring.

Q1. What happens when the waves meet? After they have passed the middle point?

Now, send a transverse wave from each end of the Super Spring on the same side, but of different amplitudes.

Q2. What happens when the waves meet? After they have passed the middle point?

Q3. How does this situation compare the previous situation?

Now, send a transverse wave from each end of the Super Spring with the same amplitude, but on different sides of the Super Spring. (This may take a little practice.)

Q4. What happens when the waves meet? After they have passed the middle point?

Q5. How does this situation compare to the previous two situations? What is the same in both? What is different in both?

2. Standing waves- part 1

To create a standing wave, two people should hold the Super Spring by the end and create continuous transverse waves down the Super Spring at the same amplitude and frequency. Start with a large amplitude and a low frequency.

Q6. What does the Super Spring look like at this frequency? Draw a picture.

Repeat the procedure with the same amplitude, but higher frequency.

Q7. What does the Super Spring look like at this frequency? Draw a picture.

Q8. What is different about the two standing waves you have created?

Continue to create standing waves using the same amplitude and increasing frequency.

Q9. Compare each standing wave to the ones you have created before it. What is the same in each situation? What is different in each situation?

You may notice that some of these frequencies do not create a standing wave pattern. Increase the tension of the Super Spring and repeat the amplitude and frequency for each pattern that did not work before.

Q10. Do these frequencies create standing wave patterns now?

The frequencies that create standing wave patterns are the resonance frequencies for the Super Spring. Changing the tension of the Super Spring would change those frequencies in the same way that changing the tension of a guitar string tunes the guitar.

3. Standing Waves- Part 2 Uising the optional *Snakey*.

To answer Standing Waves- Part 1 more qualitatively, you should be able to determine the actual frequencies that you use. Measure the length of the stretched *Snake*y. Do not change the *Snakey* length during this experiment. Try this procedure:

(1) Have another team member use a stop watch.

(2) When you have a standing wave pattern established, count out loud the motion of your hand as… “Start” . . . “One” . . . “Two” . . . and continue to . . . “Nine” . . . “Ten”

(3) The other person times your counting with the stopwatch.

(4) The frequency of the standing wave will be 10 divided by the stopwatch time.

(5) The wavelength of the standing wave {} in the *Snakey* is equal to the total length of the *Snakey* divided by the number of wavelengths in the standing wave.

[□ = (length of *Snakey*)/(n)]

Using that timing method, complete the data for the following data table:

Number of wavelengths (n)	Stopwatch time (s)	Frequency (Hz)	Length of Wavelength (□)
½			
1			
1 ½			
2			
2 ½			
3			

Q1. Using the measured length of the stretched Spring, what is the wavelength (in meters or feet) of each number of wavelengths used in the experiment?

Q2. What is the frequency of each wavelength?

Q3. What is the relationship between the number of wavelengths and the frequency of the spring? Describe this relationship, or develop a formula relating number of wavelengths and frequency.

Summary & Review Questions: Answer questions clearly and concisely. Add any comments or ideas that seem useful.

1. Water waves are not exactly the same as the kinds of waves observed in the Super Spring. However, they are similar to one of the types of waves you have used. Are water waves more like transverse or longitudinal waves? Describes ways in which these waves are similar and ways in which they are different.

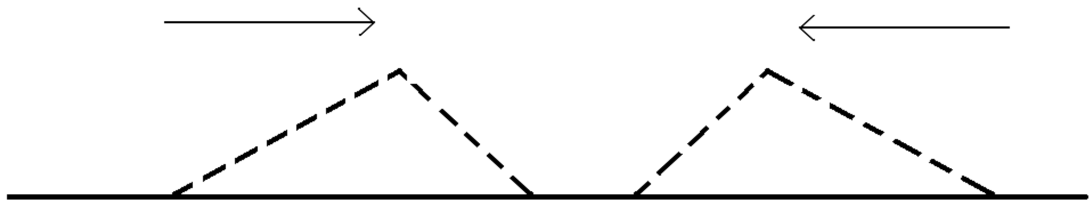
2. Sound waves are also not exactly the same as the kinds of waves observed in the Super Spring. However, they are similar to one of the types of waves you have used. Are sound waves more like transverse or longitudinal waves? Describes ways in which these waves are similar and ways in which they are different.

3. What properties of a medium may affect the wave speed of waves traveling through that medium? Also try to suggest how those properties affect the wave speed, making waves faster or slower.

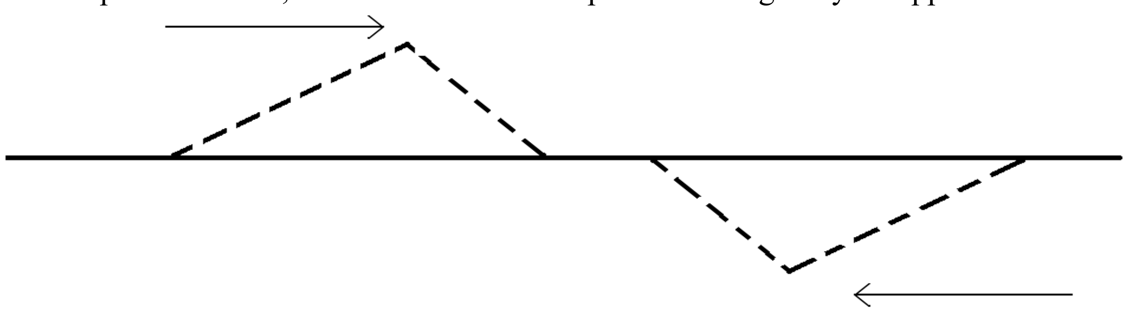
4. Considering your answers to the previous question, how might properties of different gases affect the speed of sound through those gases (as compared to the speed of sound in air)? Consider air at different pressure or different temperature. Also, consider different gases such as helium or carbon dioxide.

5. Similarly, how would the speed of sound be affected by the different properties of water or steel as opposed to sound traveling through air?

6. The sketch below shows two wave pulses approaching each other along a normally-straight medium. Make a sketch to show the shape of the medium when the two pulses have traveled to the point where the peak of each wave is at the same point.



7. Same problem as #6, but this time the wave pulses are originally on opposite sides of the medium.



8. The wave equation that applies to all types of waves is

$v = f * l$

where 'v' is wave speed (m/s)

'f' is frequency (Hz)

and 'l' is wavelength (m) (l is the Greek letter "lambda").

If wave speed is constant, what is the mathematical relationship between wavelength and frequency? Is this verified by your results in Q1 in part D3? Explain how. (Hint: what is the wave speed for each wavelength you timed?)

9. If a frequency of 3.0 Hz causes a standing wave pattern of exactly one wavelength in a Super Spring, what frequency would cause a standing wave pattern of 1.5 wavelengths? What other information do you need to determine the actual wave speed in the Super Spring?

10. Determine the wave speed for the different wavelengths measured in D3.

Wavelength	Frequency	Wave Speed