Waves in a Spring
Observing the Characteristics of Waves

PURPOSE
In this activity you will observe and investigate important wave properties. What you observe about waves in a spring can be applied to other kinds of waves, including sound waves, water waves, and light waves.

MATERIALS

meter stick or metric tape measure	spring
string, 2 meters in length	stopwatch

Safety Alert
Coiled springs are social creatures. Avoid releasing either end of the stretched spring; the untangling process can be quite difficult.

PROCEDURE
LONGITUDINAL AND TRANSVERSE WAVES

1. Answer the questions as you perform this activity. You and your lab partner should hold opposite ends of a spring and stretch it out on the floor to an appropriate length. Experiment to determine the best stretch distance for your spring but be careful not to exceed the elastic limit of the spring. Pinch a clump of coils together with your free hand and release the clump of coils. Do not let go of the end of the spring. Observe the pulse that travels back and forth through the spring. Why is it called a longitudinal pulse? Sketch the wave pulse on your student answer page.

2. Give one end of the spring a few vigorous sideways (transverse) shakes. How is this wave different from the longitudinal wave? Sketch the transverse wave pulse on your student answer page.

3. The stretched spring is the medium through which the pulse travels. Send a short transverse pulse down the spring. Observe the shape of the pulse as it moves along the spring.
   a. How does the shape change? Can you suggest a reason for this?
   b. Upon what does the initial amplitude of the pulse depend?
   c. Does the speed of the pulse appear to change with its shape?
   d. Generate single pulses of various amplitudes (small, medium, and large). Does the pulse speed appear to depend on the size of the pulse?
   e. What could you do to produce wave pulses that travel faster in the spring? Can it be done by shaking the spring harder? How about shaking the spring faster?

f. Measure the length of the stretched spring (do not change this length) and the travel time of a pulse generated at one end. Use a stopwatch to time how long a wave takes to travel up and down the spring. Calculate the speed of the traveling wave pulse for pulse sizes that are small, medium, and large. Record your values in Data Table 1. Is the speed of the wave pulse affected by the amplitude of the pulse?

g. Change the length of the stretched spring and determine the pulse speed as before. Is the speed of the wave pulse affected by the tension? Does the stretched spring, under different tensions, represent the same or different media?

INTERFERENCE

4. Have your partner generate a wave pulse toward you on the same side of the spring that you sent a pulse toward your partner. This interaction between the two wave pulses is called interference.
   a. Describe the interference of the two wave pulses. How does the pulse amplitude during interference compare with the individual amplitudes before and after this interaction.
   b. Repeat the experiment, but with the two pulses traveling on opposite sides of the spring. Compare the interference with that of the previous interaction. When the two pulses meet, does the displacement of the spring at that instant get larger or smaller?
   c. Did the two pulses pass through each other or bounce off each other? If you are not sure, then have your partner send a transverse wave pulse down the spring at the same time you send a longitudinal wave pulse. Now what can you say about the interaction of these two wave pulses: do the wave pulses bounce off each other or do they pass through each other?
   d. What conclusions can you draw about the displacement of the medium at a point where two pulses interfere? (This is called the *Principle of Superposition*.)

REFLECTION

5. With one far end of the spring held firmly in place by your lab partner (fixed-end), send a single pulse down one side of the spring. Observe the reflected pulse.
   a. Compare its amplitude with that of the transmitted pulse just before reflection. What is the orientation of the reflected pulse relative to the transmitted pulse?
   b. Attach a light string about 2 m long to the far end of the spring and maintain the tension on the spring by holding the end of the string. This is called a free-end termination for the spring. Send a pulse down one side of the spring as before and observe the pulse reflected from the "free" end. Compare the reflected pulse from the "free" end of the spring with the reflected pulse from the fixed end.

PERIODIC AND STANDING WAVES

6. By moving your hand steadily back and forth, you can produce a series of pulses called a periodic wave. The distance between any two adjacent crests or troughs on a periodic wave is called the wavelength. The rate at which you move your hand back and forth determines the frequency. Generate a periodic wave and take a "snapshot" of the wave. Sketch the picture on the diagram provided. On your diagram, show the amplitude of the periodic wave. Sketch one wavelength, and using the total length of the spring, determine the wavelength. How does the wavelength depend on the frequency?

7. Have your partner generate a continuous periodic wave while you try and match it. You have produced a *standing wave*. While your partner holds the end of the spring steady, you will form transverse standing waves having first one, two, three, and then four loops. Find the frequency needed to produce each standing wave pattern. The frequency is the number of times your hand moves through a complete cycle (back and forth) every second. It will be easier to find the frequency if you time 10 cycles of your hand. After you find the frequency, you will be able to find the speed of the waves just created, since $v = f\lambda$.
   a. What are the loops called?
   b. What are the places called where the spring does not appear to move?
   c. What is the general relationship between the number of loops and the frequency of the wave?

Name ______________________________

Period ______________________________

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DATA AND OBSERVATIONS

LONGITUDINAL AND TRANSVERSE WAVES

1. Observe the pulse that travels back and forth through the spring. Why is it called a longitudinal pulse? Sketch the wave pulse below.

2. Give one end of the spring a few vigorous sideways (transverse) shakes. How is this wave different from the longitudinal wave? Sketch the transverse wave pulse below.

3. The stretched spring is the medium through which the pulse travels. Send a short transverse pulse down the spring. Observe the shape of the pulse as it moves along the spring.
   a. How does the shape change? Can you suggest a reason for this?

b. Upon what does the initial amplitude of the pulse depend?

c. Does the speed of the pulse appear to change with its shape?

d. Generate single pulses of various (small, medium, and large) amplitudes. Does the pulse speed appear to depend on the size of the pulse?

e. What could you do to produce wave pulses that travel faster in the spring? Can this be done by shaking the spring harder? How about shaking the spring faster?

f. Measure the length of the stretched spring (do not change this length) and the travel time of a pulse generated at one end. Use a stopwatch to time how long a wave takes to travel up and down the spring. Calculate the speed of the traveling wave pulse for pulse sizes that are small, medium, and large. Record your values in Data Table 1. Is the speed of the wave pulse affected by the amplitude of the pulse? Use your data and $d = vt$ to answer this question.

Data Table 1: Longitudinal and Transverse Waves							
Pulse Type	**Pulse Size**	**Distance (m)**	**Trial 1 (s)**	**Trial 2 (s)**	**Trial 3 (s)**	**Avg. Time (s)**	**Speed (m/s)**
Transverse	Small						
Transverse	Medium						
Transverse	Large						
Longitudinal							

g. Change the length of the stretched spring and determine the pulse speed as before. Examine three different lengths for the stretched spring. Is the speed of the wave pulse affected by the length of the stretched spring (the tension)? Does the stretched spring, under different tensions, represent the same or different media?

Data Table 2: Spring Length						
Trial	**Distance (m)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg. Time (s)**	**Speed (m/s)**
1						
2						
3						

INTERFERENCE

4. Have your partner generate a wave pulse toward you on the same side of the spring that you sent a pulse toward your partner. This interaction between the two wave pulses is called *interference*.
   a. Describe the interference of the two wave pulses. How does the pulse amplitude during interference compare with the individual amplitudes before and after this interaction.

b. Repeat the experiment, but with the two pulses traveling on opposite sides of the spring. Compare the interference with that of the previous interaction. When the two pulses meet, does the displacement of the spring at that instant get larger or smaller?

c. Did the two pulses pass through each other or bounce off each other? If you are not sure, then have your partner send a transverse wave pulse down the spring at the same time you send a longitudinal wave pulse. Now what can you say about the interaction of these two wave pulses: do the wave pulses bounce off each other or do they pass through each other?

d. What conclusions can you draw about the displacement of the medium at a point where two pulses interfere? (This is called the *Principle of Superposition*.)

REFLECTION

5. With the far end of the spring held firmly in place by your lab partner (fixed-end), send a single pulse down one side of the spring. Observe the reflected pulse.
   a. Compare its amplitude with that of the transmitted pulse just before reflection. What is the orientation of the reflected pulse relative to the transmitted pulse?

   b. Attach a light string about 2 m long to the far end of the spring and maintain the tension on the spring by holding the end of the string. This is called a free-end for the spring. Send a pulse down one side of the spring as before and observe the pulse reflected from the "free" end. Compare the reflected pulse from the "free" end of the spring with the reflected pulse from the fixed end.

PERIODIC AND STANDING WAVES

6. By moving your hand steadily back and forth, you can produce a series of pulses called a periodic wave. The distance between any two adjacent crests or troughs on a periodic wave is called the wavelength. The rate at which you move your hand back and forth determines the frequency. Generate a periodic wave and take a “snapshot” of the wave. Sketch the picture on the diagram below. On your diagram, show the amplitude of the periodic wave, show one wavelength and from the total distance of the wave determine the value for the wavelength. How does the wavelength depend on the frequency?

7. Have your partner generate a continuous periodic wave while you try and match it. You have produced a *standing wave*. While your partner holds the end of the spring steady, you will form transverse standing waves having first one, two, three, and then four loops. Find the frequency needed to produce each standing wave pattern. The frequency is the number of times your hand moves through a complete cycle (back and forth) every second. It will be easier to find the frequency if you time 10 cycles of your hand. After you find the frequency, you will be able to find the speed of the waves just created, since $v = f\lambda$.

Data Table 3: Standing Waves

Loops	Wavelength (m)	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)	Avg. Time (s)	Frequency (Hz)	Speed (m/s)
1	$\lambda = 2L =$						
2	$\lambda = \ \ L =$						
3	$\lambda = \frac{2}{3}L =$						
4	$\lambda = \frac{1}{2}L =$						

Where L = the distance between both lab partners holding either end of the spring.

a. What are the loops called?

b. What are the places called where the spring does not appear to move?

c. What is the general relationship between the number of loops and the frequency of the wave?

ANALYSIS

1. How does the product of frequency and wavelength ($f\lambda$) for the various standing wave patterns compare with one another?

2. How do these values compare with the speeds of the pulses calculated in Data Table 1 for the transverse wave?

3. How are speed, frequency, and wavelength of a transverse wave related to one another?

4. Consider the *power* (number of Joules of work per second) you are expending as you sweep your hand back and forth to create transverse standing waves. Does the power you expend to create waves depend on the frequency of the waves?

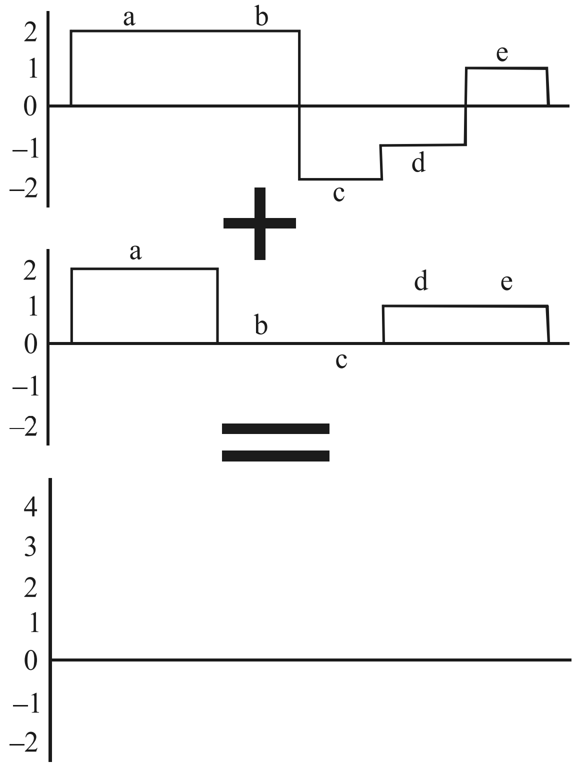
5. Does the power required depend on the amplitude of the waves?

CONCLUSION QUESTIONS

1. Suppose a flute player and a tuba player start playing at the same time, from equally far away. Whom will you hear first? Why?

2. Which travels faster: red light or blue light? (Blue light has a higher frequency.)

3. For the waves shown in the following picture, sketch the sum of the two waves.



4. What happens to the displacement when the two waves meet in phase (crest on crest)?

5. What happens to the displacement when the two waves meet out of phase (crest on trough)?

6. What happens to the pulses after they pass through each other?

7. Explain how the reflection of a wave from a rigid barrier (a fixed end) and a less rigid barrier (a free end) affect the wave's phase.

8. What happens to the speed, wavelength, and frequency of a wave when it reaches the boundary between two media?

9. A string is attached to a vibrating machine which has a frequency of 120 Hz as shown in Figure 1. The other end of the string is passed over a pulley of negligible mass and friction and is attached to a weight hanger which holds a mass m = 0.5 kg.

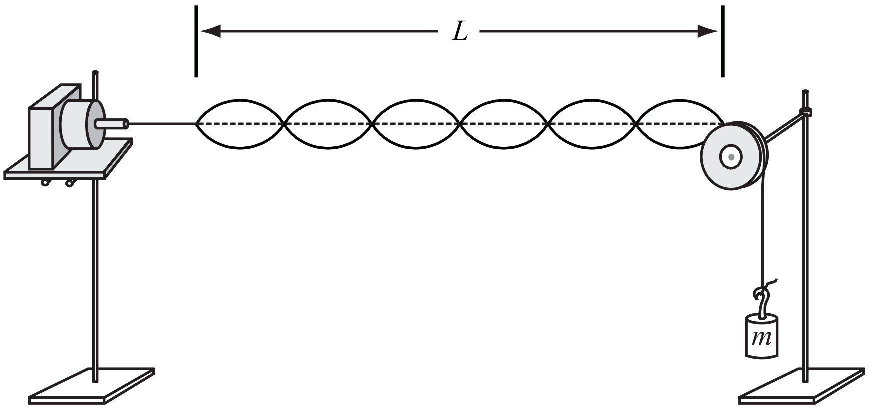


Figure 1

a. Determine the tension in the string.

b. The speed of the wave in the string is related to the tension by the equation $v = \sqrt{\frac{F_T}{\mu}}$, where F_T is the tension in the string and μ is the linear density of the string. If the linear density of this string is 0.05 kg/m, determine the speed of the wave in the string.

c. Determine the wavelength of the wave in the string.

d. Determine the length of the string from the point of attachment on the vibrating machine to the pulley.

e. Would you need to increase or decrease the mass on the hanger to produce a lower number of loops? Explain.