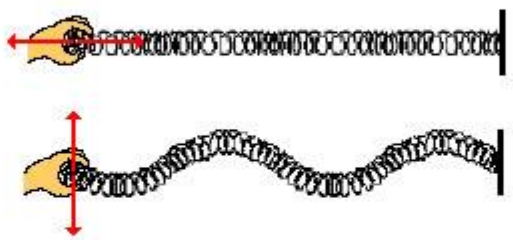
Waves in a Slinky

Introduction

In this laboratory, you will perform several experiments to help you better understand wave motion and properties of waves.

If a slinky is stretched out from end to end, a wave can be introduced into the slinky by either vibrating the first *coil up and down perpendicular to the slinky* or *back and forth along the slinky*. A wave will subsequently travel from one end of the slinky to the other. As the wave moves along the slinky, each individual coil is seen to move out of place and then return to its original position. The coils always move in the same direction (perpendicular to or along the slinky) that the first coil was vibrated. A continued vibration of the first coil results in a continued back and forth motion of the other coils. If looked at closely, one notices that the wave does not stop when it reaches the end of the slinky; rather it seems to bounce off the end and head back toward where it started.



Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

A wave can be described as a disturbance that travels from one location to another location. If the first coil of the slinky is given a single back-and-forth vibration, then we call the observed motion of the disturbance through the slinky a pulse. A pulse is a single disturbance moving through a medium from one location to another location. However, if the first coil of the slinky is continuously and periodically vibrated in a back-and-forth manner, we would observe a repeating disturbance moving within the slinky that endures over some prolonged period of time. The repeating and periodic disturbance that moves through a medium from one location to another is referred to as a wave.

When a slinky is stretched, the individual coils assume an equilibrium or rest position.

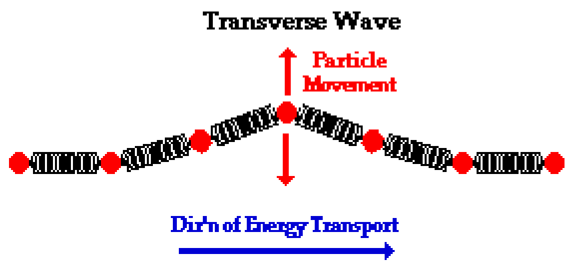
When the first coil of the slinky is repeatedly vibrated back and forth, a disturbance is created which travels through the slinky from one end to the other.

A Wave Transports Energy and not Matter

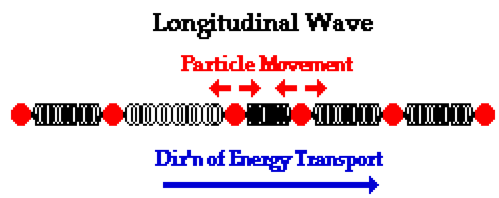
When a wave is present in a medium (that is, when there is a disturbance moving through a medium), the individual particles of the medium are only temporarily displaced from their rest position. There is always a force acting upon the particles that restores them to their original position. In a slinky wave, each coil of the slinky ultimately returns to its original position. It is for this reason, that *a wave* ***involves the movement of a disturbance without the movement of matter.***

Waves transport energy. As a disturbance moves through a medium from one particle to its adjacent particle, energy is being transported from one end of the medium to the other. In a slinky wave, a person imparts energy to the first coil by doing work upon it. The first coil receives a large amount of energy that it subsequently transfers to the second coil. When the first coil returns to its original position, it possesses the same amount of energy as it had before it was displaced. The first coil transferred its energy to the second coil. The second coil then has a large amount of energy that it subsequently transfers to the third coil. When the second coil returns to its original position, it possesses the same amount of energy as it had before it was displaced. The third coil has received the energy of the second coil. This process of energy transfer continues as each coil interacts with its neighbors. In this manner, energy is transported from one end of the slinky to the other, from its source to another location.

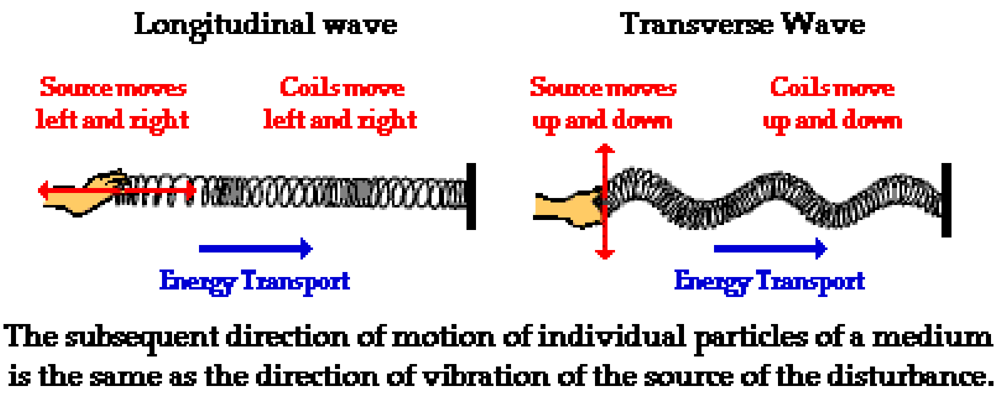
A transverse wave is a wave in which particles of the medium move in a direction perpendicular to the direction that the wave moves. Suppose that a slinky is stretched out in a horizontal direction across the room and that a pulse is introduced into the slinky on the left end by vibrating the first coil up and down. Energy will begin to be transported through the slinky from left to right. As the energy is transported from left to right, the individual coils of the medium will be displaced upwards and downwards. In this case, the particles of the medium move perpendicular to the direction that the pulse moves.



A longitudinal wave is a wave in which particles of the medium move in a direction parallel to the direction that the wave moves. Suppose that a slinky is stretched out in a horizontal direction across a table and that a pulse is introduced into the slinky on one end by vibrating the first coil forward and backward. Energy will begin to be transported through the slinky from one end to the other. As the energy is transported, the individual coils of the medium will be displaced forward and backward. In this case, the particles of the medium move parallel to the direction that the pulse moves.

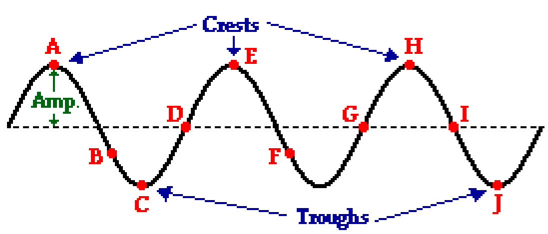


Any wave moving through a medium has a source. Somewhere along the medium, there was an initial displacement of one of the particles. For a slinky wave, it is usually the first coil that becomes displaced by the hand of a person. So if you wish to create a transverse wave in a slinky, then the first coil of the slinky must be displaced in a direction perpendicular to the entire slinky. Similarly, if you wish to create a longitudinal wave in a slinky, then the first coil of the slinky must be displaced in a direction parallel to the entire slinky.



The Anatomy of a Wave

If a snapshot of a **transverse wave** is taken, then it would look like the following diagram.

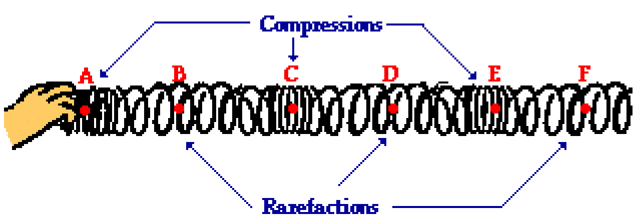


The dashed line drawn through the center of the diagram represents the initial or resting position of the slinky. This is the position that the string would assume if there were no disturbance moving through it. Once a disturbance is introduced into the slinky, the particles of the string begin to vibrate upwards and downwards. At any given moment in time, a particle on the medium could be above or below the initial position. Points A, E and H on the diagram represent the crests of this wave. The crest of a wave is the point on the medium that exhibits the maximum amount of positive or upward displacement from the initial position. Points C and J on the diagram represent the troughs of this wave. The trough of a wave is the point on the medium that exhibits the maximum amount of negative or downward displacement from the initial position.

The wave shown above can be described by a variety of properties. One such property is amplitude. The amplitude of a wave refers to the maximum amount of displacement of a particle on the medium from its rest position. In a sense, the amplitude is the distance from equilibrium to crest.

The wavelength is another property of a wave that is portrayed in the diagram above. The wavelength (λ) of a wave is simply the length of one complete wave cycle. If you were to trace your finger across the wave in the diagram above, you would notice that your finger repeats its path. A wave is a repeating pattern. It repeats itself in a periodic and regular fashion over both time and space. And the length of one such spatial repetition (known as a wave cycle) is the wavelength. The wavelength can be measured as the distance from crest to crest or from trough to trough. In the diagram above, the wavelength is the horizontal distance from A to E, or the horizontal distance from B to F, or the horizontal distance from D to G, or the horizontal distance from E to H.

If a snapshot of a **longitudinal wave** is taken, then it would look like the following diagram.



Because the coils of the slinky are vibrating longitudinally, there are regions where they become pressed together and other regions where they are spread apart. A region where the coils are pressed together in a small amount of space is known as a compression. A region where the coils are spread apart, thus maximizing the distance between coils, is known as a rarefaction. Points A, C and E on the diagram above represent compressions and points B, D, and F represent rarefactions. *While a transverse wave has an alternating pattern of crests and troughs, a longitudinal wave has an alternating pattern of compressions and rarefactions*.

For a transverse wave, the wavelength is determined by measuring from crest to crest. In the case of a longitudinal wave, a wavelength measurement is made by measuring the distance from a compression to the next compression or from a rarefaction to the next rarefaction. On the diagram above, the distance from point A to point C or from point B to point D would be representative of the wavelength.

Frequency and Period of a Wave

A single back-and-forth vibration of the first coil of a slinky introduces a pulse into the slinky. But the act of continually vibrating the first coil with a back-and-forth motion in periodic fashion introduces a wave into the slinky. Suppose that a hand holding the first coil of a slinky is moved back-and-forth two complete cycles in one second. The rate of the hand's motion would be 2 cycles/second. In turn, every coil of the slinky would vibrate at this rate of 2 cycles/second. This rate of 2 cycles/second is referred to as the frequency (f) of the wave. The unit for frequency is the Hertz (abbreviated Hz) where 1 Hz is equivalent to 1 cycle/second. If a coil of slinky makes 2 vibrational cycles in one second, then the frequency is 2 Hz.

The quantity frequency is often confused with the quantity period. Period refers to the time that it takes to do something. The period (T) of a wave is the time for a particle on a medium to make one complete vibrational cycle. Period, being a time, is measured in units of seconds. So, frequency is the number of cycles per second, and the period is the number of seconds per cycle. They are inverses of each other.

$f = 1/T$ and $T = 1/f$

The Velocity of a Wave

The velocity of an object refers to how fast an object is moving and is usually expressed as the distance traveled per time of travel. In the case of a wave, the speed is the distance traveled by a wave crest in a given interval of time. In equation form,

$v = d/t$

If the crest of a slinky wave moves a distance of 20 meters in 10 seconds, then the speed of the slinky wave is 2 m/s.
Because wavelength (λ) and period (T) are units of distance and time, the above equation may be written as follows:

$v = \lambda f$

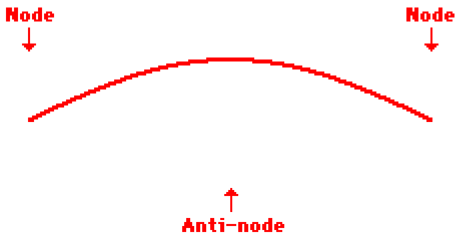
By this, you can see the wavelength and frequency are inverses of each other. For a given velocity, if you increase the frequency, the wavelength will be shortened.

The velocity of the wave is dependent on several factors, including the tension in the slinky (FT) and the linear mass density (μ) of the slinky, where μ is found by dividing the mass by the length.. This relationship is as follows: $v = \sqrt{\frac{FT}{\mu}}$

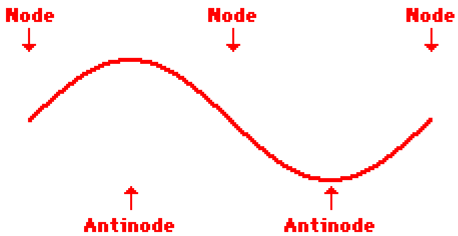
Standing Waves

Standing wave patterns are wave patterns produced in a medium when two waves of identical frequencies (such as a slinky wave and its bounce-back reflection) interfere in such a manner to produce points along the medium that always appear to be standing still. These points that have the appearance of standing still are referred to as nodes. The points of maximum displacement are called antinodes.

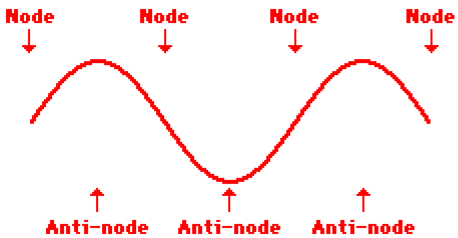
The simplest standing wave pattern that could be produced within a slinky is one that has nodes at the two ends of the slinky and one antinode in the middle. The animation below depicts the vibrational pattern observed when the medium is seen vibrating in this manner.



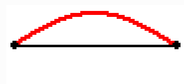
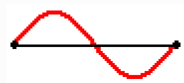
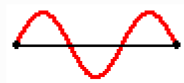
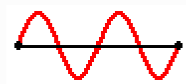
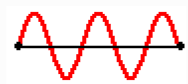
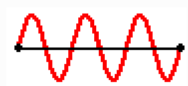
The above pattern is called the first harmonic. Other wave patterns can be observed within the slinky when it is vibrated at greater frequencies. For instance, if you vibrate the end with twice the frequency as that associated with the first harmonic, then a second standing wave pattern can be achieved. This standing wave pattern is characterized by nodes on the two ends of the slinky and an additional node in the exact center of the slinky. As in all standing wave patterns, every node is separated by an antinode. This pattern with three nodes and two antinodes is referred to as the second harmonic and is depicted in the animation shown below.



If the slinky frequency is increased even more, then the third harmonic wave pattern can be produced within the slinky. The standing wave pattern for the third harmonic has an additional node and antinode between the ends of the slinky. The pattern is depicted in the image shown below.



Observe that each consecutive harmonic is characterized by having one additional node and antinode compared to the previous one. The table below summarizes the features of the standing wave patterns for the first several harmonics.

HARMONIC	# OF NODES	# OF ANTINODES	PATTERN
1st	2	1	
2nd	3	2	
3rd	4	3	
4th	5	4	
5th	6	5	
6th	7	6	
nth	n + 1	n	--

Materials

- Slinkys
- Styrofoam cup
- Stop Watch
- Spring Scale
- Meter Stick
- Double-pan balance

Activity 1: Wave Pulses

In this section of the lab you will create different types of waves in order to discuss the differences and similarities between them.

1. Stretch the slinky out on the table. Shake the slinky sharply to the right or left one time to produce a transverse wave pulse. Make three sketches of what the slinky looked like at three different times to show the progression of the wave.

2. With the slinky still stretched, sharply push the slinky inward one time. Make three sketches of what the slinky looked like at three different times to show the progression of the wave.

3. In what ways are these two waves different and in what ways are they the same?

Place an empty Styrofoam cup beside the slinky near one end. Create a transverse wave pulse from the other end that causes the cup to move.

4. The object was initially at rest, and then began to move. What type of energy did the cup gain?

5. The initial source of energy is your hand. Explain how the energy went from your hand to the cup

Activity 2: Continuous Waves and Standing Waves

Instead of just producing wave pulses, you will now produce continuous waves which travel down the slinky. You will also produce continuous waves which appear to be standing still. These are called standing waves and are a special case of a continuous wave. They can be produced at only certain frequencies. It may take some practice to properly produce different numbers of standing waves. In this section you will be determining the frequency of different standing waves and coming up with a general equation that can be used for all standing waves.

1. Produce a transvers continuous continuing traveling wave. Sketch the wave at 3 different times to show the wave motion.

2. Now produce a transverse continuous standing wave and sketch how the slinky appears.

3. Explain the difference between continuous traveling waves and continuous standing waves.

4. You will want to determine the frequency of various standing waves. (Be sure to keep your slinky stretched to the length of one meter stick.) What is a good method for determining the frequency? (Be sure to think of ways to minimize error and list these ways.)

5. Using your method, determine the frequency (1/s) for a single standing wave (1 antinode and 2 nodes). Be sure to show your data and include proper units in your answer.

6. What is the wavelength (m) of this wave? (Be sure to explain where your result came from.) Include proper units in your answer.

7. What is the velocity (m/s) of this wave? Write down your model relating wavelength, frequency and the number of nodes to velocity. Be sure to include proper units in your answer.

8. With the slinky stretched the same amount as above, create a double standing wave (2 antinodes and 3 nodes). Using the same method, determine the frequency of this wave.

9. How does the frequency compare to that of the single standing wave? What do you think the frequency of a triple standing wave would be?

10. Write down the model (equation) relating the number of standing waves (antinodes) to the frequency.

11. What is the wavelength of the double standing wave and how does it compare to that of the single standing wave? What do you think the wavelength of a triple standing wave would be using your model above?

12. Write down the model (equation) relating the number of standing waves (antinodes) to the wavelength.

13. As above, calculate the velocity of the double standing wave. What do you observe about the difference in velocities of the single and double waves?

14. Write down the model (equation) relating the velocity to frequency, wavelength and the number of standing waves.

Activity 3: Tension in a Slinky

In this section you will be directly measuring the tension (FT) in the slinky when it is pulled to different lengths by using a spring scale. You will also be using the equation above to mathematically determine the tension in your slinky from your measured values of the speed of a wave traveling down your slinky and the mass per unit length, $\mu = m/L$ of your slinky. When plugging values into your equation remember that FT should be in Newtons (kg m/s^2), v should be in m/s, and μ should be in kg/m.

1. Measure and record the mass of your slinky.

2. Stretch your slinky out to the longest length that still allows you to produce a decent standing wave. Measure and record this length and calculate your mass per unit length (μ).

3. Using your spring scale, measure and record the tension force in Newton required to pull the slinky to this length.

4. While your slinky is stretched to this length, but not attached to the scale, create a double standing wave and determine its velocity using the methods in Activity 2.

5. Calculate the tension in the slinky using the velocity in number 4 and the model: $v = \sqrt{\frac{FT}{\mu}}$.

6. How do your measured and calculated values for tension agree? Calculate the % error between these values.

   % error = 100 × (difference between the two tensions) / (tension measured by the spring scale)

7. In your lab report, describe sources of error that might account for the difference between your tension forces.