UVA's Hands-on Introduction to Nanoscience

Introduction to Waves

(revision 28 Jan 2013)

Student Name (printed):________________________________

Signature:________________________________

Introduction:

One of the more useful toys in the Physics arsenal is the lowly Slinky®. The Slinky® can be used to demonstrate both kinds of waves: longitudinal and transverse. The Slinky® can also be used to investigate pulses, echoes, and interference. Finally the Slinky® can be used to investigate the effect of tension on pulse speed. In this lab you will gather a lot of descriptive data on wave phenomenon. But remember what Professor Bean said about "a wave is wave is wave." That is, because all types of wave act similarly, you should be able to extrapolate this lab's spring wave results to the behavior of light waves, sound waves, and even electron waves!

Lab Preparation:

a) Prior to lab you should study this webpage "Review of Waves" (upon which you will be quizzed at the start of the lab):

http://www.virlab.virginia.edu/Nanoscience_class/labs/Review_of_Waves.htm

b) You should also print out a copy of this lab guide and bring it with you to the lab.

Lab Materials:

String
Slinky® (~ 7 cm diameter spring)
Coil (~2cm diameter spring)
Stopwatch

Acknowledgement: This lab manual was inspired by a laboratory guide written by Thomas O'Neil of the Shenandoah Valley Governor's School, Fishersville, Virginia

=== 0) TRANSVERSE and LONGITUDINAL PULSES (using the slinky) ===

Continuous waves are fun and easy to produce. But single sharp pulses make it easier to observe what is really going on. So this experiment provides practice at making really good single pulses:

Part 0a) Transverse (or shear) pulses: Stretch the Slinky® out on the floor approximately 5-6 meters with one person sitting at each end (note: three floor tiles = slightly less than 1 meter). Do not overstretch the Slinky® (because it is easily damaged). But DO stretch enough that the Slinky® lies in an essentially straight line.

One of the holders should then transmit a SINGLE transverse pulse by rapidly moving the end of the Slinky® ON THE FLOOR. The pulse should be formed by moving the Slinky® rapidly out to the right of the person forming the pulse and back to the starting point (i.e. using a ~1/3 meter flick of the wrist). This will be called a 'right' pulse.

RELEVANCE: Electromagnetic waves (light) are transverse waves. Water waves and seismic waves are part transverse and part longitudinal.

Part 0b) Longitudinal (or pressure) waves: Maintain the position of Slinky® and team members as above.

One of the holders should very rapidly compress (push) in the end of the Slinky® (by 15-30 cm) and then rapidly draw it back to its original position. If you do this really well, adjacent turns of the Slinky® will actually collide with one another, making a metallic clinking sound.

RELEVANCE: Sound waves are longitudinal waves. Water waves and seismic waves are part transverse and part longitudinal.

=== 1) TRANSVERSE vs. LONGITUDINAL PULSES (using the slinky) ===

Same setup as experiment 0: Stretch the Slinky® out on the floor approximately 5-6 meters with one person sitting at each end (note: three floor tiles = slightly less than 1 meter). Do not overstretch the Slinky® (because it is easily damaged). But DO stretch enough that the Slinky® lies in an essentially straight line.

Part 1a) Transverse vs. Longitudinal Waves: Alternate transverse pulses with longitudinal pulses. Does one type of wave move faster than the other?

RELEVANCE/CHALLENGE: Geologists use this phenomenon to calculate the distance between a seismograph and an earthquake's epicenter. Can you explain how this might be done?

RELEVANCE/CHALLENGE: Taking this farther, how might you pin down the exact location of the earthquake epicenter?

Part 1b) Transverse Pulse + Longitudinal pulse: Simultaneously send a transverse and a longitudinal pulse from opposite ends of the Slinky®. How is the transverse pulse affected by the longitudinal pulse?

Part 1c) Transverse wave + Longitudinal pulses: Send a continuous transverse wave from one end (by waving that end side to side) and repeated longitudinal pulses from the other end. How are the transverse pulses affected by the longitudinal wave?

============= 2) SIMPLE REFLECTIONS (using the slinky) ============

Same setup as experiment 0: Stretch the Slinky® out on the floor approximately 5-6 meters with one person sitting at each end (note: three floor tiles = slightly less than 1 meter). Do not overstretch the Slinky® (because it is easily damaged). But DO stretch enough that the Slinky® lies in an essentially straight line.

PART 2a) One of the holders should transmit a SINGLE transverse pulse by rapidly moving the end of the Slinky® ON THE FLOOR. The pulse should be formed by moving the Slinky® rapidly out to the right of the person forming the pulse and back to the starting point (i.e. using a ~1/3 meter flick of the wrist). This will be called a 'right' pulse.

Describe/sketch what happens when the pulse reaches the far end (this is called a closed reflection). Does it come back as a 'right' or 'left' pulse?

Description/sketch:

Part 2b) Tie about 1 meter of string to one end of the Slinky®. Stretch the Slinky® out on the floor approximately 5-6 meters with one person at each end sitting down holding onto the appropriate free end. Have the person with the string end hold the Slinky® by pulling lightly on the string and moving away so that the Slinky® is stretched the same 5-6 meters as in #1. The OTHER holder should transmit a SINGLE transverse pulse. The pulse should be formed by moving the Slinky® rapidly out to the right of the person forming the pulse and back to the starting point (i.e. again using a ~1/3 meter flick of the wrist).. This will be called a 'right' pulse.

Describe/sketch what happens when the pulse reaches the far end (this is called an open reflection). Does it come back as a 'right' or 'left' pulse?

Description/sketch:

======== 3) REFLECTION + TRANSMISSION (using the slinky + coil) ========

Part 3a) Tie the Slinky® together with a Coil using a short piece of string. On the floor, pull back the end of the Slinky until the smaller coil JUST BARELY straightens out. (If you pull any harder, beginning to stretch out the smaller coil, you will damage the flimsy Slinky). The person holding the Slinky® should transmit a SINGLE transverse pulse. The pulse should be formed by moving the Slinky® rapidly out to the right, then back to the starting point to make a 'right' pulse.

Describe/sketch what happens when the pulse encounters the boundary between the two springs. Note: Two pulses should be observed and both phases recorded! Take care to note the speed of the pulse in the large Slinky® and the long coil.

Description/sketch:

Part 3b) Repeat the experiment with a right pulse that starts in the Coil and traverses down the spring to the Slinky®

Describe/sketch what happens when the pulse encounters the boundary between the two coils (this is called refraction and reflection). Note: Two pulses should be observed and both of their phases recorded! Also compare the size of the pulse in the large Slinky® and the long coil.

Description/sketch:

RELEVANCE/CHALLENGE: Powders of transparent materials appear white rather than clear. Can you explain why?

RELEVANCE/CHALLENGE: Light can be trapped inside simple glass fibers, providing the basis for "information highway" (a.k.a. Internet). Can you explain why?

================ 4) INTERFERENCE (using the slinky) ==============

Part 4a) Stretch the Slinky® out on the floor approximately 5-6 meters with one person at each end sitting down holding onto the appropriate free end. Both holders should simultaneously start a SINGLE transverse pulse ON THE FLOOR. The pulses should be formed by moving the Slinky® rapidly out to the SAME side (one person's right and the other's left) and back to the starting point.

When your pulses meet in the **middle**, do they reflect back or pass through one another? To test: One of you make a small pulse, the other a large pulse (so that you can tell them apart).

Describe/sketch what happens when the two pulses meet in the middle (This is called constructive interference). Do they make a larger or smaller pulse at the moment of meeting? Note: it is sometimes easier to see by tying a small ribbon/string/tape exactly in the middle and observing how the ribbon moves (or doesn't move) when the pulses meet.

Description/sketch:

Part 4b) Stretch the Slinky® out on the floor approximately 5-6 meters with one person at each end sitting down holding onto the appropriate free end. Both holders should simultaneously start a SINGLE transverse pulse ON THE FLOOR. The pulse should be formed by moving the Slinky® rapidly out to OPPOSITE sides (one person's right and the other's right) and back to the starting point.

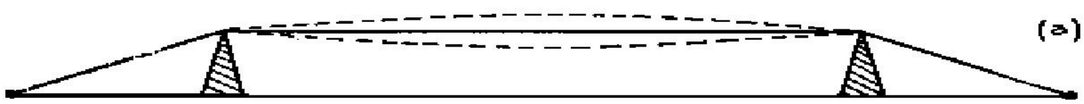
Describe/sketch what happens when the two pulses meet in the middle (This is called destructive interference). Do they make a larger or smaller pulse at the moment of meeting? Note: it is sometimes easier to see by tying a small ribbon/string/tape exactly in the middle an observing how the ribbon/center point moves (or doesn't move) when the pulses meet

Description/sketch:

RELEVANCE/CHALLENGE: It is really important not to transpose the two wires when hooking up stereo speakers. Can you explain why?

================= 5) STANDING WAVES (using the coil) ===============

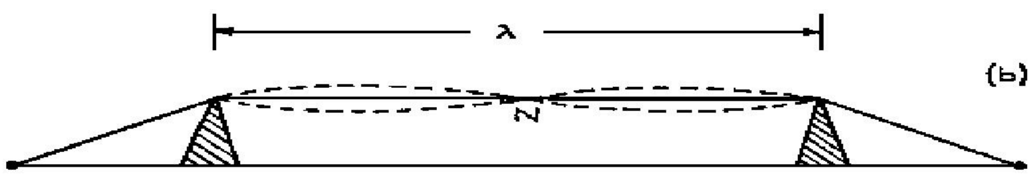
Part 5a) Stretch the Coil out on the floor approximately 5-6 meters with one person at each end sitting down holding onto the appropriate free end. One or both holders should then begin transmitting a CONTINUOUS WAVE ON THE FLOOR. It is easier to get a large wave if both holders wave. But it also works with only one person, and this removes the need to synchronize your motions. TRY BOTH WAYS. The desired waveform will have a single "hump" which moves out to the right and then out the left. Some adjustment in timing will be necessary until the wave is formed. This is called a "standing wave" because it does not seem to move along the length of the spring. It may be helpful to gather half the Coil at one end to shorten the overall coil for this wave.



Describe the number of points on the wave that move the maximum distance (antinodes). Describe the number of points on the wave that do not move at all (nodes).
How many "wavelengths" are there between the ends of the spring?

Description:

Part 5b) Start by doing exactly the same thing you did in experiment 6 to set up a single "hump" sanding wave. But then gradually increase the frequency of your exciting motion. Your single hump wave should initially dissolve into confusion. But when your frequency gets high enough, a new double hump standing wave should emerge.



Describe the number of points on the wave that move the maximum distance (antinodes). Describe the number of points on the wave that do not move at all (nodes).
How many "wavelengths" are there between the ends of the spring?

Description:

(still using the coil)

Part 5c) Continue the process you began in experiments 4a & 4b by further increasing the frequency of your exciting motion. As you increase the frequency you should go through a sequence of confused motion => 1 hump => confused motion => 2 humps => confused motion => 3 humps. Does it make any difference if only ONE of the holders moves his/her end?

FOR BRAGGING RIGHTS: Moving the ends (or end) of your Coil even faster, what is the *maximum* number of anti-nodes your group can set up on your standing wave (and hold them stable long enough for the TA to count them)?

RELEVANCE: This is where the "quantum" in QUANTUM MECHANICS comes from: Waves that can have all sorts of energies when free, are instead restricted to only discrete energies when trapped in a "box" (because only certain energies will give waves of the right size to fit into that box).

Part 5d) Standing waves in variably sized boxes: Above you saw how you can only set up strong waves of certain frequencies on springs of a certain length (and tension). But what would happen if you could change the length of a spring while maintaining its tension? Would the frequency of the half wave (experiment 5a) be independent of the spring's length? Here is a way to see:

- Start by basically repeating experiment 5a: Coil, 5-6 meters long, find the frequency of standing half wave:

- Leave the spring exactly as is, but now have your third team member hold the spring at its middle point. On one half of the spring (the end now to either side) again set up a standing half wave. How does the frequency of this new half standing wave compare to the half wave on the full-length spring?

RELEVANCE: This experiment demonstrates the QUANTUM SIZE EFFECT ("QSE"): When an object gets smaller (even though you change nothing else about it), electronic energy levels (and their separations) increase. That is because the electron waves must shrink to maintain their standing waves fits (smaller wavelength = higher frequency = higher energy). Manifestation: gold nanoparticles have non-golden pastel colors, which change with their size.

============= 6) VELOCITY vs. TENSION (using the coil ============

Stretch the coil out on the floor 5 meters with one person sitting down holding onto each free end. One of the holders should transmit a SINGLE transverse pulse ON THE FLOOR. The pulse should be formed by moving the Coil rapidly out to the right of the person forming the pulse and back to the starting point. Using the stopwatch, determine the time for a single pulse to travel from the originating end, down to the other end and return back to the originating end. Repeat this twice more and get an average time. Measure the length of stretch and determine the velocity. Then plot in the grid below.

Stretch Distance (m)	First Time (s)	Second Time (s)	Third Time (s)	Average (s)	Velocity (m/s)
5m					
5.5m					
6m					
6.5m					
7m					

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