**Longitudinal Waves on a Slinky** 

**Introduction**

Most of us are familiar with the slinky and its wave motions. The caterpillar-like ripples that move up and down the length of the slinky are in fact longitudinal waves that can be described by the 1D wave equation. Whereas the rope makes it easy to see transverse waves, the slinky, with its large open coils, makes it easy to see longitudinal waves. As a longitudinal wave passes down the length of the slinky, we see the coils compress (bunch up) and expand (spread out), and we see bunches travel along the slinky.

When we turn our attention to sound waves later in this course, we will remember the slinky. Sound waves are 3-dimensional longitudinal pressure waves in the air. As such, the waves are invisible. We can measure zones of compression and expansion with pressure sensors such as microphones, but we cannot see the zones. The slinky helps us in this regard. Having seen the coils of the slinky bunch together, we can more easily imagine air molecules doing the same. And having seen "bunch zone" travel along a slinky, we can more easily imagine a pressure zone traveling through the air.

In this lab, we place a slinky under tension and subject its ends to longitudinal oscillations in order to induce longitudinal waves. Through measurements we calculate the speed of the waves, and by choosing the right frequency and tension, we can even create standing longitudinal waves, in which we see zones of compressed coils, spaced at half-wave intervals, standing perfectly still!

**Informal Procedure**

Hold the ends of the slinky, one in each hand, and stretch the slinky, allowing it to rest on the smooth top of the lab bench. Lift the ends up a few centimeters above the bench top and keep them at this level (this reduces friction between the slinky and the bench and allows waves to travel more freely).

With one hand, "pop" one end of the slinky with a single, quick, longitudinal shove to create a pulse wave, and watch the pulse travel down the length of the slinky. You can increase (or decrease) the speed of the pulse by changing the tension in the slinky (lengthening or shortening the slinky). The pulse makes about two back-and-forth trips before dying. You can feel and see the pulse arriving at your hands with a rhythmic left and right "boom, boom". The time spanned by three consecutive "booms" marks one round trip of the pulse. This is the period of the wave.

**(1)** Estimate the period and slinky length and calculate the speed of the wave.

Now send a series of pulses (a wave train) along the slinky by oscillating your hand at a fixed frequency. While making the wave train, slowly lengthen (or shorten) the slinky until you see a standing wave form. You know you have a standing wave when the compression zones (places where the coils bunch together) cease traveling and stand still. You can also create standing waves by oscillating both hands in unison. This can be done in two ways, with the hands moving in the same or in opposite directions.

**(2)** How many normal modes are you able to create? Sketch them and indicate the number of nodes in each mode. Also sketch the range of displacements experienced by a point on the slinky.

**Formal Procedure**

We shall use several methods to determine wave speed and then compare the results. In one of your calculations you will need the mass of the slinky. Use $m = 0.19\ kg$.

<u>Determine Wave Speed, First Method</u>

Using your newly acquired technique for creating standing waves, establish a standing wave with a single displacement node at the center of the slinky. Use the two-hand method, with hands moving in unison but in opposite directions. Time a number of oscillation cycles to determine the wave frequency, and estimate the average length of the slinky extant while the wave existed.

**(3)** Record the node count, the time and number of oscillations, and the average length.
**(4)** Use the node count and length to determine the wavelength. Then use the wavelength and frequency to calculate the wave speed.

<u>Determine Wave Speed, Second Method</u>

Attach two force sensors to the Vernier, start Logger Pro, zero the sensors, <u>then</u> attach the ends of the slinky to the force sensors as shown in the figure. Adjust the length of the slinky to about 2 meters. This length corresponds to a tension of about 2N. Note that the slinky hangs in an arc. Align the force sensors to be tangent to the arc. Pick a point on the slinky about 1/3 the distance from one end (at $x = L/3$), pinch a group of coils together at that point, start data collection, and quickly release the coils. Longitudinal wave pulses will travel away from the point of release in both directions along the slinky. Shortly after release the pulses will arrive at the force sensors, reflect and continue in the opposite direction. The arrivals of pulses at the force sensors correspond to force peaks. Make note of the arrival times of the first four peaks.

**(5)** Record the arrival times, and the value slinky length $L$.
**(6)** Use the times, along with the value $L$ to calculate the wave speed.
**(7)** Record the slinky equilibrium tension $F$ (for use in the third determination below).

<u>Determine Wave Speed, Third Method</u>

In lecture, we guessed that the formula $v = \sqrt{F/\mu}$ for the speed of transverse waves on a rope might also be the correct formula for longitudinal waves on a slinky.

**(8)** Determine the wave speed using this formula. Use the slinky length and tension recorded above.
**(9)** How well do the second and third determinations of wave speed agree?