

Slinky Wave Speeds

A matter wave is different from a moving particle because it is a temporary disturbance that moves through a medium such as a spring, water, or a metal bar. The disturbance can move between two locations without the matter between the locations.

Transverse and Longitudinal Waves: In this activity you'll be considering disturbances that move along a Slinky that is stretched and then fixed at each end. There are two types of disturbances that can travel along a stretched Slinky: [1] A few coils at one end can be pulled quickly in a direction that is perpendicular or **transverse** to the line of stretched coils and released; or [2] A few coils at one end can be bunched together in a **longitudinal** direction along the line of stretched coils and released. Video frames of each type of disturbance are shown in Figures 1a and 1b and Figures 2a and 2b.

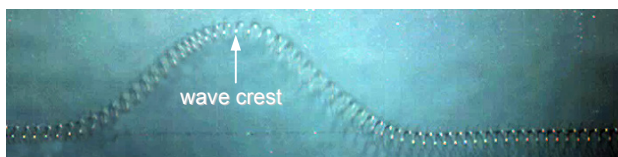


Figure 1a: A single frame showing a transverse disturbance moving along a stretched Slinky.



Figure 1b: A single frame showing that the transverse disturbance has moved about $\frac{1}{2}$ meter in $\frac{1}{8}$ th of a second.

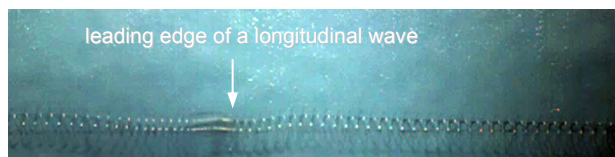


Figure 2a: A single frame showing a longitudinal disturbance moving along a stretched Slinky.



Figure 2b: A single frame showing that the longitudinal disturbance has moved about $\frac{1}{2}$ meter in $\frac{1}{8}$ th of a second.

Your task in this assignment is to study movies that show transverse and longitudinal disturbances moving along a stretched Slinky lying on a very slick (low friction) floor. What happens when just a few coils are disturbed in a deliberate manner and released? You'll be asked to think about the process by which the disturbances propagate along the Slinky, measure the wave speeds, and consider what properties of the Slinky will affect the speed of the waves.

Before starting this activity, you should view the "slow-mo" versions of the transverse and longitudinal QuickTime movies entitled <SlinkyWave_T01(slow-mo).mov> and <SlinkyWave_L10(slow-mo).mov>.

Notes about the Movies: The waves on this Slinky are moving at a rate of over 4 m/s, so we used a high speed video camera to record the motion at 125 frames per second (fps). We have created two sets of movies to enable you to observe and analyze Slinky waves. One set of movies shows the frames being replayed in "slow-mo" at only 15 fps so you can observe the motion. The other set can be used for analysis using the *Logger Pro* software. They are labeled "hi-speed".

1. Preliminary Questions

Note: You will receive **full credit for each prediction** made in this preliminary section whether or not it matches conclusions you reach in the next section. As part of the learning process it is important to compare your predictions with your results. **Do not change your predictions!**

- (a) **Examine how a coil moves as a transverse wave passes along the spring:** Open the Logger Pro file <CoilMotion.cmb>, which has the movie <SlinkyWave_T01(hi-speed).mov> inserted. In frame 14 of the movie, the y-axis is set to pass through a spring coil that is not yet disturbed. Please examine how this coil moves in the x-and y-directions, if at all, at various times as the wave travels along the spring. Please put an X in each box that describes the motion of the coil during the frames listed in the column.

Frames	Little or no motion in the x-direction	Not moving in the y-direction	Moving up or down in the y-direction
13–15 (before)			
21–23 (during)			
28–30 (crest)			
34–35 (during)			
42–44 (after)			

- (b) Does the coil you are watching ever seem to move any distance in the x-direction? Ignore wobbling. Explain.

- (c) How do you think the speed of the transverse disturbance, v_w , would change, if at all, if the spring were stretched further so that it has a greater tension, T , and smaller mass per unit length, μ ? Explain the reason(s) for your answer.

v_w would: Increase _____ Decrease _____ Stay the Same _____

- (d) How do you think the speed of the transverse disturbance would change, if at all, if another spring is used that has the same tension but thicker, more massive coils so that its mass per unit length, μ , is increased? Explain the reason(s) for your answer.

v_w would: Increase _____ Decrease _____ Stay the Same _____

2. Activity-Based Questions

In the activities that follow we would like you to determine the speed of the transverse wave and compare it to the theoretical prediction of the wave speed as a function of the Slinky tension, T , and its mass per unit length (or linear density), μ . Finally you will measure the speed of the longitudinal wave.

- (a) Open the Logger *Pro* file <WaveSpeed_T.cml> and use video analysis to determine the speed of propagation of the transverse wave crest in m/s using the <SlinkyWave_T10(hi-speed).mov>. Explain your procedure and report your results rounded up to 3 significant figures along with the uncertainty (**RSME**). **Note:** Don't forget to scale the movie very carefully using the **Set Scale** tool (you can repeat the scaling until the green line looks just right). Then move ahead to the first frame that shows the wave crest. You may want to use either the **Curve Fit** or **Model. . .** feature in the **Analysis** menu to determine the velocity.

Measured Transverse wave speed: $v_w =$ _____ m/s

- (b) **Calculate the theoretical speed of a transverse wave:** A derivation in most introductory physics texts predicts that the equation for the wave speed of a small amplitude transverse wave on a spring or string of should be $v_w = \sqrt{T/\mu}$ where T is the tension in the spring and μ is its mass per unit length (or linear density). **Note:** If you predicted in 1(b) and 1(c) that speed should increase with tension and decrease with mass per unit length (i.e., linear density), then the equation for speed is consistent with that prediction.

The T and μ data for the Slinky, as shown on the title screen of the transverse wave movie entitled <SlinkyWave_T01(hi-speed).mov>, is given as $T = 1.7 \text{ N}$ & $\mu = 0.081 \text{ kg/m}$

Determine the theoretical value of the wave speed for the transverse wave to three significant figures and show your calculations.

- (c) **Measure the longitudinal wave speed:** Open the Logger *Pro* file entitled <WaveSpeed_L.cml> and determine the propagation speed of the longitudinal wave in meters/second shown in <SlinkyWave_T01(hi-speed).mov>. Explain your procedure. Did you use modeling or curve fitting? Then record your results to three significant figures along with its uncertainty (RSME). **Note:** Once again don't forget to use the Set Scale tool to scale the movie very carefully.

Measured Longitudinal wave speed: $v_w =$ _____ m/s

3. Reflections on Your Findings

- (a) **Compare results of measured with theoretical values for the transverse wave speed:** Calculate the % difference between the theoretical and measured values. If you did not set scale or select wave locations carefully, we expect that there might be up to a 5% discrepancy between the theoretical and measured values of the transverse wave speed for each type of wave. Calculate the % difference between the theoretical and measured values and comment on your results.
- (b) **Compare results of measured values for the transverse and longitudinal wave speeds:** How much do your values differ from each other? **Notes:** (1) If you look at the title screen of the two movies you analyzed in the last section you'll see that the Slinky tension was very slightly less and mass per unit length very slightly more for the longitudinal wave than for the transverse wave. (2) The similarity between the two results suggests that the theoretical equations for both types of waves are identical. It is interesting to note that even though most introductory physics texts derive the expression $v_w = \sqrt{T/\mu}$ for transverse waves, we've not seen it done for longitudinal waves.

Measured Transverse Wave Speed: $v_w =$ _____ m/s

Measured Longitudinal Wave Speed: $v_w =$ _____ m/s

- (c) What did you learn from this Activity about wave propagation on a Slinky or Logger *Pro* video or equation analysis that you didn't already know?