Name: _____

Giant Slinky:
Quantitative Exhibit Activity

Materials: Tape Measure, Stopwatch, & Calculator.

In this activity, we will explore wave properties using the Giant Slinky. Let's start by describing the two types of waves: transverse and longitudinal.

Transverse and Longitudinal Waves

A *transverse wave* moves side-to-side orthogonal (at a right angle; perpendicular) to the direction the wave is moving. These waves can be created on the Slinky by shaking the end of it left and right.

A *longitudinal wave* is a pressure wave alternating between high and low pressure. These waves can be created on the Slinky by gathering a few (about 5 or so) Slinky rings, compressing them with your hands and letting go. The area of high pressure is where the Slinky rings are bunched up and the area of low pressure is where the Slinky rings are spread apart.

Transverse Waves

Before we can do any math with our Slinky, we need to know a little more about its properties. Begin by measuring the length (**L**) of the Slinky (attachment disk to attachment disk). If your tape measure only measures in feet and inches, convert feet into meters using 1 ft = 0.3048 m.

Length of Slinky: L = _____ m

We must also know how long it takes a wave to travel the length of the Slinky so that we can calculate the speed of a wave. For now, we are going to investigate transverse waves, so make a single pulse by jerking the Slinky sharply to the left and right ONCE (very quickly) and then return the Slinky to the original center position. Time how long it takes the pulse to make it to the other end of the Slinky. Do this several times and average the trials together for a more accurate result. Be sure to stop any remaining waves in the Slinky in between measurements. (Table on next page.)

	Time
Trial 1	sec
Trial 2	sec
Trial 3	sec
Average time ($\bar{t}$)	sec

Now, we can calculate the speed (**v**) of a *transverse* wave in this Slinky:

$$v = \frac{L}{\bar{t}}$$

v = _____m/s

With this information, we can now calculate wavelengths and frequencies of a wave.

Wavelength, Amplitude and Frequency

Wavelength (λ) is the distance along the direction of motion between successive peaks or valleys (maxima and minima) of a wave; note that wavelength is not the distance between a peak and the next valley, but the peak-to-peak or valley-to-valley distance. Since this is a measure of distance, wavelength will be in units of meters.

Amplitude (**y**) is the maximum displacement a wave makes from the rest position (in the side-to-side direction that the wave is vibrating). Note that this is half the full peak to valley distance. Amplitude is measure of distance and will have units of meters.

λ = *wavelength*
y = *amplitude*
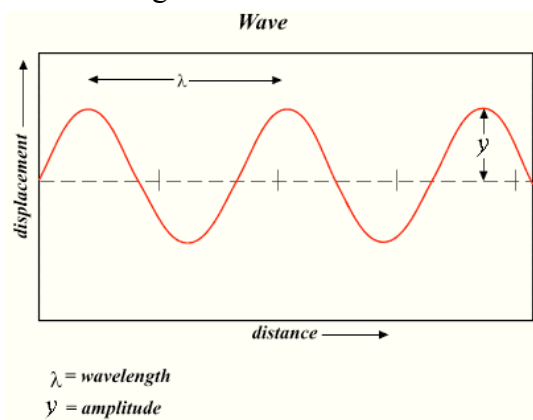
Frequency (**f**) is the count of how many wavelengths pass by a point every second. If 5 waves go by every second, then the frequency would be 5/sec. The 1/sec unit is also called a *Hertz* (Hz) and is the standard unit of frequency. The wave in the example given above then has a frequency of 5 Hz. *Period* (**T**) is how long it takes a wave to travel past a point and is simply the inverse of frequency (**T**=1/**f**) and has units of seconds.

Given the equation for speed above, derive the relationship between wavelength, frequency and wave speed.

> (*Hint:* Wave speed will simply be **v** and has units of m/sec. What combination of wavelength and frequency will produce the correct units for speed? Determine this by multiplying or dividing the units of the variables for frequency and wavelength just like you would if you were substituting numbers for the variables.)

$$v = \underline{\hspace{3cm}}$$

Does the speed, frequency or wavelength of a wave depend on its amplitude?

Yes   *No*

Use this relationship between wave speed, wavelength and frequency to determine what the frequency of a *transverse* wave in this Slinky would need to be in order to fit *a **single** wavelength along the length of the Slinky*.

$$f = \underline{\hspace{3cm}} Hz$$

Try and make a wave with this frequency in the Slinky. As you continue to pump waves with this frequency into the Slinky, you may notice that a special pattern is starting to develop in the wave. Specifically, that there is one point in the middle of the Slinky that appears to not move at all while other parts of the wave oscillate largely. This special wave is called a *standing wave*.

Longitudinal Waves:

All of the wave properties discussed for transverse waves also apply to longitudinal waves. However, the maximum and minimum of a wave have special names: the area of high pressure (corresponding to the transverse wave's maximum) is called the *compression* and the area of low pressure (corresponding to the transverse wave's minimum) is called the *rarefaction*.
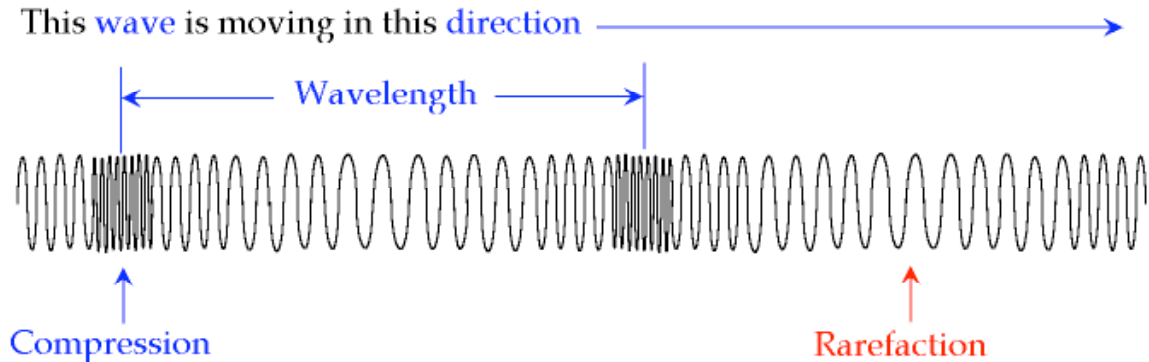
Now calculate the speed of a *longitudinal* wave in the Slinky. Gather several (about 5 or so) rings of the Slinky together. When you let go, you will see the compression travel the length of the Slinky. Time how long it takes the compression to travel the whole length (you will here the compression 'clink' against the attachment disk when it arrives at the end):

	Time
Trial 1	sec
Trial 2	sec
Trial 3	sec
Average time ($\bar{t}$)	sec

Now, we can calculate the speed (**v**) of a *longitudinal* wave in this Slinky: $\left(v = \dfrac{L}{t} \right)$

v = _____m/s

Use this relationship between wave speed, wavelength and frequency to determine what the frequency of a *longitudinal* wave in this Slinky would need to be in order to fit **_two wavelengths along the length of the Slinky_**. (Be careful, this is a slightly different question than the similar one asked for transverse waves!)

f = _____Hz

Sound

Sound waves are good examples of longitudinal waves in air. The figure below shows how molecules of air (the individual dots) are affected by sound waves. The compressions of the sound wave are areas in the air that have higher air pressure (density) and the rarefactions are areas with lower pressure (density). These alternating densities will cause our eardrums to vibrate and this is how we sense sound.

Compression   **Rarefaction**
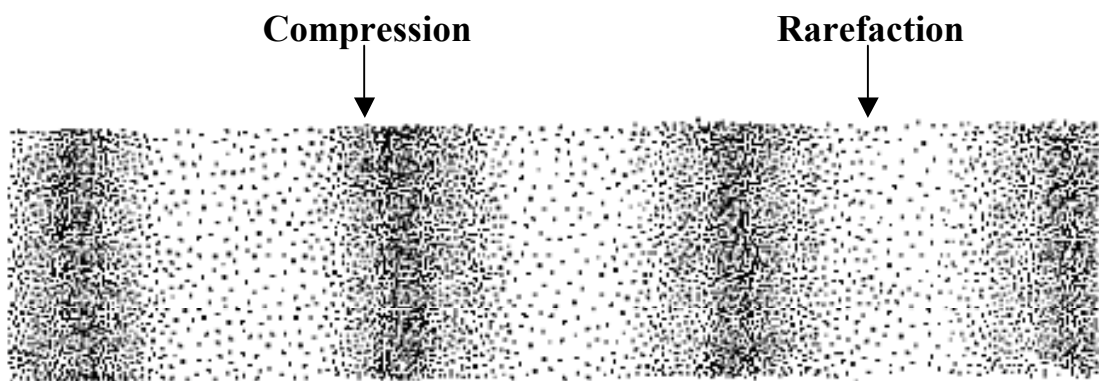
Standing Waves Extension:

Interference and Standing *Transverse* Waves

Interference occurs when two waves overlap each other. In the Giant Slinky, these waves are caused by the newly produced waves traveling towards one end of the Slinky and older waves that have been reflected back to the other end. When these two waves overlap, they add up to make larger and smaller amplitude waves.
- *Constructive interference* occurs when two peaks (maxima) of a wave (or two valleys/minima) overlap and add together to create a larger wave than either of the original waves.
- *Destructive interference* occurs when a peak (maximum) and a valley (minimum) overlap and add to either partially or completely cancel out the waves.

Constructive: **Destructive:**

Combined waves ⟶

Wave 1 ⟶

Wave 2 ⟶
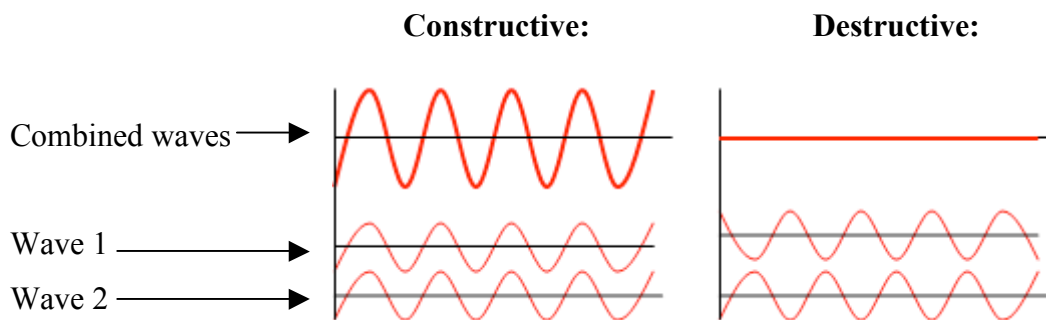
Standing waves are the result of continuous interference of waves with specific frequencies that allow for certain points of the waves to have no movement while other parts of the wave undergo all of the movement.
- *Nodes* are the places in a standing wave where there appears to be no movement.
- *Anti-nodes* are the places in a standing wave where the maximum amount of movement (full amplitude) appears to take place.

The criteria to form a standing wave is that integer (whole) multiples of half a wavelength be within the length of the Slinky. When a standing wave is produced with exactly half a wavelength along the length of the Slinky, the resulting wave is called the *fundamental* and the nodes are at the endpoints of the wave. When a full wavelength is used, the resulting wave is called the *first harmonic* (B on the illustration on the next page) and a node also appears at the midpoint of the Slinky length. (If you were able to produce a standing wave with the frequency determined above, you were seeing the first harmonic wave for this Slinky.).

Label the frequencies needed to produce each of the standing waves below; the positions of the nodes are labeled according to what fraction of the Slinky length the first node that is not an end point appears. (Table on next page.)

A: 0   1

B: 1/2

C: 1/3

D: 1/4

E: 1/5

F: 1/6

G: 1/7
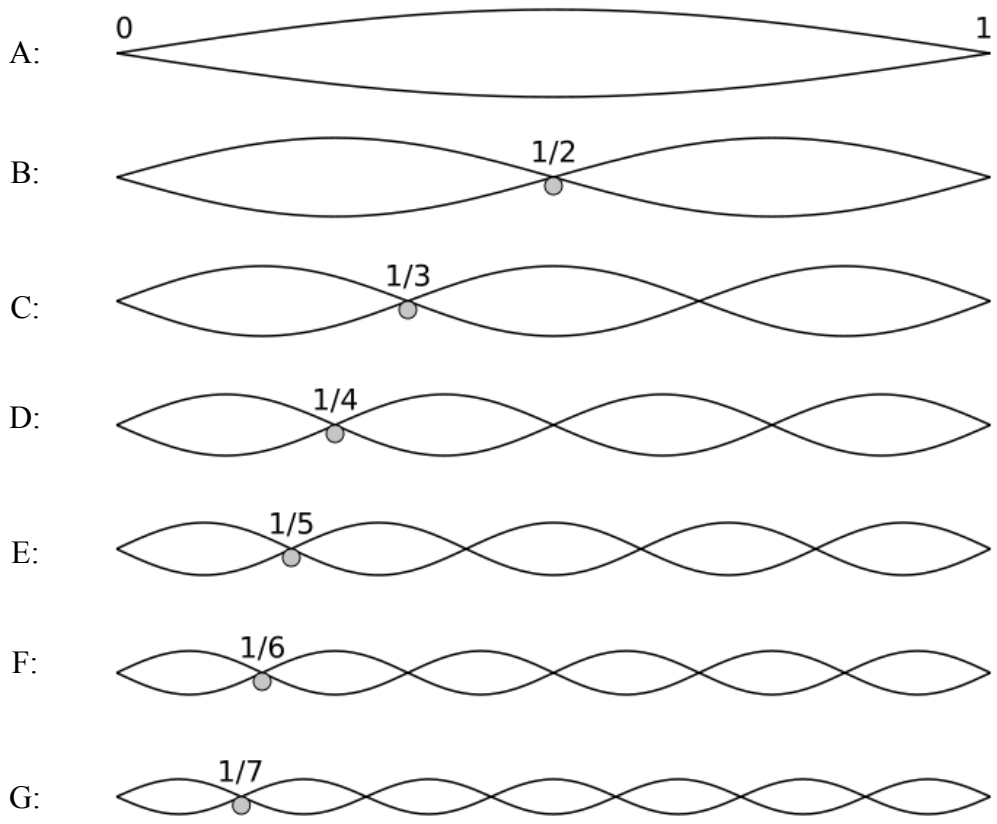
		Frequency	
A	Fundamental		Hz
B	1st Harmonic	(same frequency as found on page 3)	Hz
C	2nd Harmonic		Hz
D	3rd Harmonic		Hz
E	4th Harmonic		Hz
F	5th Harmonic		Hz
G	6th Harmonic		Hz

(*Hint:* If λ_B is $2\lambda_A$, then $f_a = 0.5f_b$. If λ_C is $3\lambda_A$, then $f_c = 3f_a$, etc.)

Try this:

Start waving the end of the Slinky back and forth until you create a standing wave. Don't try to produce any specific frequency, just find one that is comfortable for you. Have a partner count the number of nodes and identify which harmonic is being produced. Then count how many complete back-and-forth oscillations (swings) of the Slinky you make in 10 seconds (have your partner time the 10 seconds while you count your oscillations). The frequency you are creating is then:

$$f = \frac{\text{number of oscilations}}{\text{time}}$$

where time would be 10 sec. See if the frequency you measured compares well to the frequency of your identified harmonic.

Harmonic: _____   Oscillations per 10 seconds: _____

Frequency: f = _____Hz

_____

Image Credit: