

Lab 02 - Mathematics of Waves

NAME: _____

Time spent on Lab 02 = approximately 3 hours, does not need to be done at one sitting

Materials needed = Access to computer and high speed internet, smartphone or tablet, plastic or metal slinky or spring, 0.3 meters or longer.

Learning Objectives:

- Experiment with springs and applying mathematical and graphical models to spring data
- Experiment with sound software
- Utilize sound software to analyze the structure of the human voice

Virtual Lab:

In Lab 02, you will begin to formalize the mathematical description of sound and waves. To do so, first please navigate to [Late Nite Labs](#) to perform the “Standing Waves” experiment.

Experiment:

Now that you have completed a physical example of wave on a string, and fit mathematical models to it, let's try to have some fun experimenting at home! Each time you take data for the rest of the lab, it would be helpful to be in a quiet room, or to keep trying until you reach a lull in background noise. Each trial you run will only take a few seconds.

To begin this portion of the lab, please use a smartphone or tablet to download a frequency analyzer app. Many of them are free, but you may have to listen/watch an advertisement before using it. Some that have been tested are:

iOS: Spectrum Analyzer:

<http://spectrumanalyzerapp.com/>

Android: FFT Spectrum Analyzer:

<https://play.google.com/store/apps/details?id=com.xyz.fft&hl=en>

Windows Mobile: Spectrum Analyzer: <https://www.microsoft.com/en-us/store/p/spectrum-analyzer/9wzdncrfjc8c>

These apps will take sound input from the microphone on your tablet or phone and create what is called a Fast Fourier Transform of the sound it hears. Put simply, this a graph of amplitude versus frequency that covers the majority of the spectrum of human hearing. These apps are free, so they will NOT measure the frequencies very precisely, but you can measure them within 100 Hz or so. If you have any troubles finding these apps or another free spectrum analyzer, please consult your instructor for advice.

Open up the app and it should begin displaying data immediately. Try talking into your mic and then hum a tune and hold it for second.

1. Make a note of which approximate frequencies are most prominent in your hum, i.e. which frequencies have the highest peaks in the live readout.

206 and 412

2. Do you think your hum SHOULD have ONE definite frequency? Explain why or why not.

Yes because the hum is a monotone.

Now let's go through some activities to help us understand whether or not we SHOULD see only one frequency.

3. Start making an "ahhh" sound, like when visiting a doctor to have your throat checked. What frequencies are strong in your "ahhh" sound?

272, 1088, 1905, 2723

4. Start humming the "ahhh" sound again and watch the app readout. Without changing the volume of your voice, change the sound from "ahhh" to "eee". What happens to the frequencies shown in the app.

Many of the frequencies disappeared while others had reduced values.

We have two problems to study related to the experiments you just did. The first problem is to understand why the vocal folds produced a series of almost equally spaced frequencies. The second problem is to understand why many of the produced frequencies disappear or have reduced intensities once the sound wave interacts with the oral/nasal cavity.

The two problems are related and can be at least partially understood in terms of a concept called standing waves, like the ones reviewed in the Late Nite Labs.

Bust out your slinky and "fix" one of the ends so it cannot move. You can do this by either taping it to a chair leg, or having someone hold it. Stretch your whole Slinky to its full length so it will not bump anything when you start to move it, fixed at one end and in your hand at the other end.

Shake the non-fixed end of the slinky to create a standing wave. If you do this on the floor, it would be best to have a hard surface, so the slinky is not sliding against carpet. Practice until you are able to produce standing waves with two [nodes](#) (at the two ends), three nodes (two at the ends and one in the middle), and four nodes (two at the ends and two between the ends). There are some sample pictures below to guide your work.

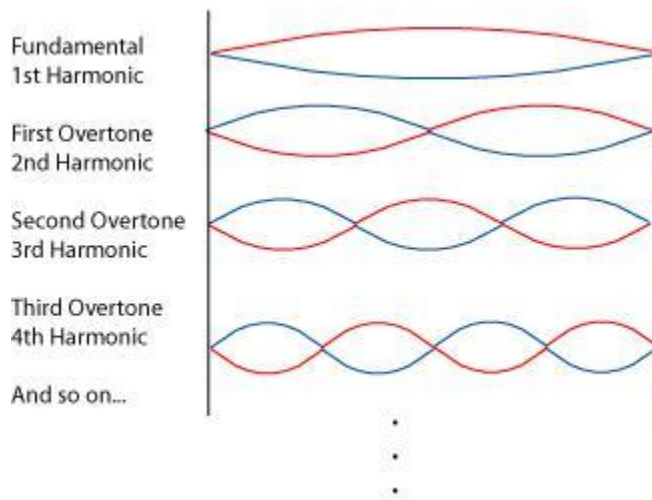


Figure #1

5. Determine the frequency of the side to side (or up and down) oscillations necessary to create each of the following three standing waves:

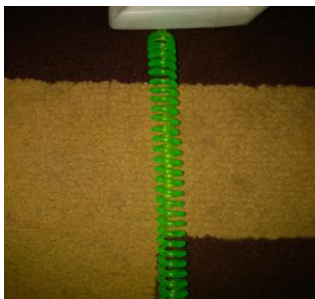
- 2 nodes (one at each end); find frequency = f_1
- 3 nodes (at the ends and one in the middle); find frequency = f_2
- 4 nodes (at the ends and two between the ends); find frequency = f_3

$f = v/\lambda$,
for f_1 $\lambda = 2L$ so $f_1 = v/2L$

for f_2 $\lambda = L$ so $f_2 = v/L$

for f_3 $\lambda = 2/3L$ so $f_3 = 3v/2L$

6. Take a photo of your experimental setup and insert it here.



7. Write the mathematical relationship between the frequencies you found above. What would you expect for the frequency of f_n ?

$$f_n = nV/2L = nf_1$$

where n is the number of the harmonics.

8. Grab your slinky at the halfway point, and then stretch it to the same length you were using in previous questions. What is now different from the activity you did above? How would you expect that to change the behavior of the system? Explain.

Tension or force that is applied to the slinky is doubled and this will affect the frequency of the system. The amplitude is also reduced and the velocity (V) will be $\sqrt{T/\mu}$

9. After having stretched your half Slinky to the appropriate length and keeping one end fixed, determine and record the frequency of the oscillations necessary to create a standing wave with:

a. 2 nodes (one at each end); find frequency = f_1

b. 3 nodes (at the ends and one in the middle); find frequency = f_2

$$f_1 = V/2L \text{ but } v = \sqrt{T/\mu} \text{ new } f_1 = \sqrt{(T/\mu)}/2L$$
$$f_2 = \sqrt{(T/\mu)}/L$$

10. Write the mathematical relationship between the frequencies you found in question #9. What would you expect for the frequency of f_n ?

$$f_n = nf_1 = n(\sqrt{T/\mu})/2L$$

11. Compare the answers to #7 and #10.

Equation #7 shows the relationship between frequency and harmonics while #10 shows the same relationship when the spring tension is doubled.

12. Given that the endpoints of the slinky must remain still (nodes), why is it not possible to place a wave with any arbitrary wavelength on the string?

Because standing waves only occur when a wave with the correct wavelength meets its reflection

13. What is the simplest standing wave pattern that could be fit on the slinky?

Fundamental or 1st harmonic

14. What is the relationship between the slinky length L and the wavelength for this case?

$$L = \left(\frac{1}{2}\right) \lambda$$

15. What is the next simplest standing wave pattern that can be fit on the slinky?

The 2nd harmonic

16. What is the relationship between the slinky length L and the wavelength in this case?

$$L = \lambda$$

17. Try to develop a general formula for the allowed wavelengths for standing waves on the slinky with both ends fixed.

Since $L = \left(\frac{n}{2}\right) \lambda$ then $\lambda = 2L/n$

18. Use your result from question #17 to write down a formula relating the allowed frequencies for a standing wave and the length for a slinky with both ends fixed.

$$f = v/\lambda$$

from #17 $\lambda = 2L/n$

$$f_n = nV/2L$$

Knowing that equally spaced frequencies are likely a result of standing waves, reopen the spectrum analyzer app and make humm or “ahhh” sound into the microphone.

19. If you see multiple, evenly spaced frequencies which are prominent in your hum or “ahh” sound, why might that be? Think about resonance!

In the process of humming, sound waves are produced at many different frequencies which are created by resonance of air that is produced during breathing.

20. If you are able to roughly guess the three major frequencies in your voice, try to backwards calculate the length of your vocal cords. Assume that the loudest frequency is the fundamental mode, the second loudest is the first overtone, etc. You might find your result from #18 to be helpful!

$$f_n = nV/2L$$

$$206 = nV/2L$$

$$412L = v$$

$$L = v/412 \text{ ----- } 1^{\text{st}} \text{ harmonic}$$

$$624 = 2V/2L$$

$$L = V/624 \dots \dots \dots 2^{\text{nd}} \text{ harmonic}$$

Once you have completed all lab questions, please download this document as a PDF only! Then upload this PDF to Blackboard under the assignment “Lab 02”, for grading.

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