# Waves and Oscillations

This is the outline of exercises that we want you to do in lab. This is a complement to the material in the lab manual. Please read the manual to learn about the tools and techniques; use this document to guide your experiments and calculations in the lab.

**You should complete at least the first three problems below in any order.** In the remaining time, continue onto a fourth or more. We encourage you to download the [Physics Toolbox Sensor Suite](), a similar app [PhyPhox]() , or your own preferred app for use this week.

## Problem #1: Waves on a Cord

**The question to answer: How do the waves on an elastic cord relate to frequency, length, and tension?**

First, pluck your cord in the center - this forms the first standing wave shape (The Fundamental) which you'll want to replicate. Turn on the signal generator, set the Voltage to **3V**, and then the frequency to 5 Hz - 5 cycles per second. You can press the "Stand By" button to pause the output voltage, and and press it again to restart it as necessary. Make use of the "ten's place" buttons to change frequencies.

- Note the length of your string.
- Note the weight of the mass and hanger hanging off the pulley at the end.

Now, slowly turn up the frequency until you see that fundamental wave shape. This is a resonance phenomena, and so it should stand out quite a bit - if you are unsure, you likely haven't hit it yet, keep turning up the frequency!

- What frequency does your fundamental occur at?

This is the frequency of your first wave! The string goes up and down that many times each second.

- Given that, how long does it take to go through one complete cycle? This is your wave's period! For example: My dog Yuvi wags her tail 10 times in 4.1 seconds. Her tail's period is 0.41 seconds per wag, a frequency of about 2.4 Hz.

Now, let's do a calculation: A wave's velocity can be found by multiplying its frequency and wavelength (m * 1/s = m/s ). Your plucked cord only had one "bump" which is only half of a full wave, so the wavelength is twice the length of your stretched cord.

- What is your cord's wave velocity? Note: This is not how fast your cord is moving up and down, it is how fast the vibration from your pluck travels along the cord!

Next, make some changes:

- Increase the frequency until you see a full wave on the string (not the half-wave of the fundamental), and note the value you get. Continue on until you see a wave and a half, two, etc...
  - Determine the relationship between "number of half-waves" and the frequency you wiggle your string at.
- If you pinch the cord, say somewhere in the middle of the left half, you will change the wavelengths available.
  - Explain why this is true.
  - How will the wavelengths change, and how will that affect the new fundamental frequency?
  - Find the fundamental frequency for this shortened string. Remember: you are simply pinching the cord, not stretching it out!
    - How does the frequency and period of the wave change when the cord shortened? Does this match your expectations?
    - Do a quick calculation: How did the wave velocity change? Why might you have expected that?
- Now, let go of the string and remove a little bit of mass from your hanger - or add some, both are fun.
  - Find the fundamental frequency for this slightly looser (or tighter) string. Remember: the string is a bit looser (or tighter), but still the same overall length!
    - How does the frequency and period of the wave change with the new tension? Does this match your expectations?
    - How did the wave velocity change?
- Discuss your results: Where might you have seen these effect in your day-to-day life (or in your major!)?

## Problem #2: Waves in the Air

**The question to answer: What waves do sounds make?**

For this activity you will want a musical instrument of some variety. You can use your own vocal tract and make vowel sounds, or **if you have a musical instrument, you should totally bring it into lab**!

We also have, in the center of the lab, Electrolarynx Units. These are medical devices designed to accommodate people who have, through various routes, lost their vocal folds. You might watch a brief instructional video here: https://www.youtube.com/watch?v=R1fclIP-g50 .

In addition to the applets found in the Physics Toolbox linked to above, there are many sound-visualization apps or websites (https://academo.org/demos/virtual-oscilloscope/ ) and ones that show the frequencies you make (https://borismus.github.io/spectrogram/ , https://aguaviva.github.io/GuitarTuner/GuitarTuner.html, ) out there. We will be using a paid app called **SignalScopeBasic2020** for our purposes. Find the oscilloscope page, click on the graph icon, and make sure the Autoscale setting is set to **“Auto”**. This graph will display how much the pressure of the air changes as time passes. Now:

- Make an “aah” sound, and note what the shape of the wave looks like.
  - How does the wave’s shape change (or stay the same) when you change pitch - going higher and lower?
- Now, keep the same pitch, and change your vowel sounds - “aah”, “ooh”, “eee”, “aye”, “ou”, etc...
  - Here again, note what changes and what stays the same.
  - Note: The loudness, or volume, of your noises is cool, but the amplitude of your wave is ignorable - we know how that works. The physics that we want you to focus on is the shape of the wave, and the frequencies that make it up!
- Let’s get physics-ey: Make a good, repeatable “aah” sound, and sketch out / screenshot a picture of the sound wave you are creating.
  - The wave you make repeats every several milliseconds, or 'ms' - what is that period? (My “aah” had a period of 10.4 ms, or 0.0104 seconds)
  - Given that, how many cycles does it go through in one second (the frequency)? (For me, I’d calculate 1 / 0.0104 s , 100ish hz)
  - Let’s try the same calculation we did above, in a different manner: Your vocal folds are about 2cm long, and can (very) roughly be modeled as a string. Given your measured fundamental frequency, what is the wave speed along your vocal folds? How does that compare to the elastic cord we used before? How about the speed of sound in air?
    - Would you (again, making a rough model) describe your vocal folds as "loose strings", or "tight strings"?

Now, let’s look at the waves that make up that funky sound. Go to the next page of the app - the FFT. Again, we’ll want to check several settings. On the graph settings, we suggest you set the Autoscale to **“Auto”**, the Vertical Axis and Horizontal Axis to **“Lin”**. In the Gear Settings, change your Frequency Resolution to “**2 Hz”**, change the Max Frequency to **“5000.0 Hz”**, scroll down to Averaging and set it to **“Off”** and the Averages to **“0”**. Make sure any Peak Tracking is set to **"Off"** - this will let you click on the screen to measure frequencies and amplitudes!

“FFT” stands for Fast Fourier Transform - the app looks at the sound you make, and figures out what frequencies make up the sound, and how loud each frequency is. The graph updates live, and will show you what frequencies you are making (low ones on the left, higher ones on the right) and how loud they are (quiet ones are tiny, loud ones are tall).

- As you did before make a good “aah” sound, and note what the graph shows you now.
  - How does the graph's shape change (or stay the same) when you change pitch - going higher and lower?
  - Now, keep the same pitch, and change your vowel sounds - “aah”, “ooh”, “eee”, “aye”, “ou”, etc...

Let’s get physics-ey again! Repeat that same “aah” sound you made before, and and sketch out / screenshot a picture of the graph you are creating.

- What frequencies are you making? You can pinch and zoom in if you want, but note the first several substantial peaks.
  - How are these peaks related?
- There’s clearly a pattern here. What is the frequency of your lowest substantial peak in this pattern?
  - How does that relate to the period you measured above? Why might you expect that?

As you can see, your vocal folds act much like the elastic cord - they wave very well at a range of predicable frequencies. You control which of those frequencies are loud or quiet by changing the shape of your vocal tract - your throat, mouth, nasal cavity, etc... - to resonate well with some of those particular frequencies, and poorly with others.

- Thinking back to the string model, what are you doing to your vocal folds (vocal cords) when you increase or decrease your pitch?

## Problem #3: How Much Louder?

**The questions to answer: What is the increase in emitted "noise" due to one click of the volume control?**

First steps:

- You need the “Physics Toolbox Sensor Suite” on a second iPad or your own smart device. You will want to have one member use the “Tone Generator” tool to create a tone. The rest of the you will use the FFT in the SignalScope app to measure this frequency's amplitude. Put the microphone of your smart device very close to your group's iPad - you might ask the room for a minute of silence while you do this (or, do it as a whole class!).

Now, measure:

- Set the sound generating device at a low volume, and start the tone. What sound intensity level do you measure? (The speaker and microphone should be close so ambient sound doesn’t create confounding data. Move them closer if needed, but don't change the positions of anything nearby after you start taking data - your hands included!)
- Increase the volume on your device by one “click”, and measure the change in detected sound intensity level. Repeat, and take a number of data points, enough to establish a clear trend in your results.

The question to answer:

- Are you measuring the amplitude in Decibels, dB, Pascals, Pa, or in millivolts, mV?
- By how much does the sound level increase when you increase the output by one click?
- By what percentage does this increase in sound intensity level correspond to?
- Do you see the same increase at low volumes and high volumes?
- Discuss the trend you see as you go from quiet to quite loud. What does "one click" do to the sound?

## Problem #4: Making Waves

**And now its your turn: run an experiment to show us something cool!**

You've got a number of tools at your disposal, and a lot of cool physics under your belt to play with. Remember that for your own experiment you should:

- Ask an exam-style question
- Briefly explain why it's an interesting/worthwhile experiment
- Sketch out all relevant motion and force diagrams
- List out and record the required measurements
  - Explain why you need these measurements, and how will you make them.
  - Show all calculations
- Discuss the results

There's a lot you could do for this - and there's waves pretty much everywhere you look. You could calculate the size of a couple dogs, find hot-spots in our microwave, explore Tuvan Throat singing or other polyphonic overtone styles, and more. If you wanted to aim more for oscillators you would be welcome to explore masses on a string or spring - even though we haven't directly experimented on them in lab yet, they totally fall into this category and are just about everywhere!

## Report

You'll be recording your work on the whiteboard tables as you go, and so be clear when summing up your process and your conclusions. Keep your discussions short, sweet, and to the point, please. Be sure to indicate what work you did on the report (as opposed to what your lab partners did).

Remember: The point of the report is to show your TA how well each of you understand the material, how well you designed and performed experiments, how well you can discuss your results, and how much of a scientist you were - not to show them you can parrot the textbook, always get the "right" answer, or do everything. The process, your reasoning, and your improvement are the key to earning full credit.

Be sure that each of your group members submit this assignment as soon as possible (ideally at the end o your lab), and take some time to consider how lab went for you and your peers, and how you can improve the experience next week.

## Looking Ahead: Gasses Ahoy

This isn't something to calculate today, but something to think about: We'll be jumping topics once more after next week's break (it's exciting, isn't it?!) to discuss gasses, and thermodynamics in general. There's a lot of cool things to play with on this topic, especially now that the temperatures outside are dropping pretty fast. We've talked a lot about waves this week, and so here's the thing to think about until we meet again: what determines how fast sound waves travel through the air? Would you expect them to move faster or slower when it is cold out?