Name: ___________________________________

Partner(s): ________________________________

1114 section: _______

Desk # _____________

Date: _________________

Sound of Music

This lab is due at the end of the laboratory period.

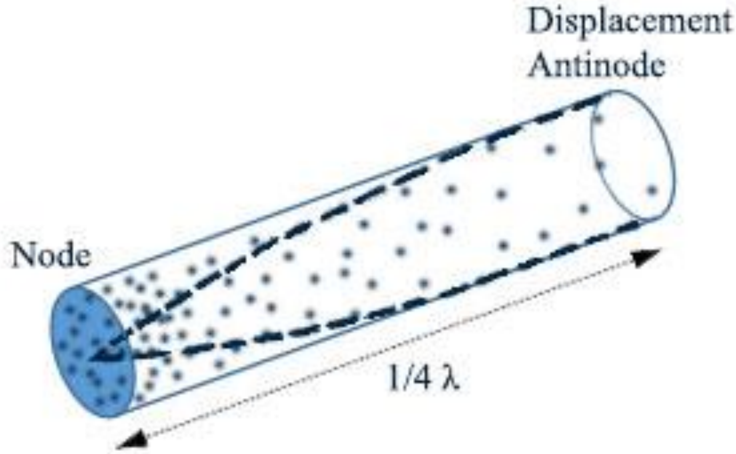
Purpose

To create and play musical notes using standing waves in a pipe closed at one end.

Introduction and Theory

From the physics point of view, different musical notes are sound waves with different frequencies. They travel from musical instruments to your ears and you hear music. As the speed of the wave is the product of the frequency and the wavelength ($v = f\lambda$), different notes will also have different wavelengths.

Musical instruments are built based on the resonance of sound: they magnify only sound waves with certain frequencies. These magnified sound waves are called standing waves and their frequencies are called the natural frequencies of the instruments. In this lab, we will hit one end of a plastic pipe with our own palm to create sound, thus we call them palm pipes. A few standing waves will be created in the pipe, where the one with the lowest frequency is called the fundamental. The fundamental standing wave has the largest amplitude and sets the tone of the sound. Its wavelength equals four times the length of the pipe as shown below.



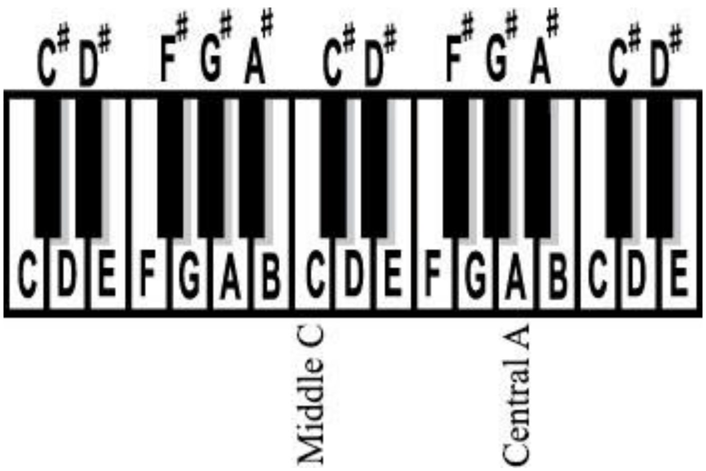
Apparatus

¾-inch PVC pipes with various lengths, ¾-inch PVC pipe connector, meter stick, computer with Logger Pro, Vernier microphone.

Activity 1: Finding the frequencies of musical notes.

Western music uses twelve musical notes:

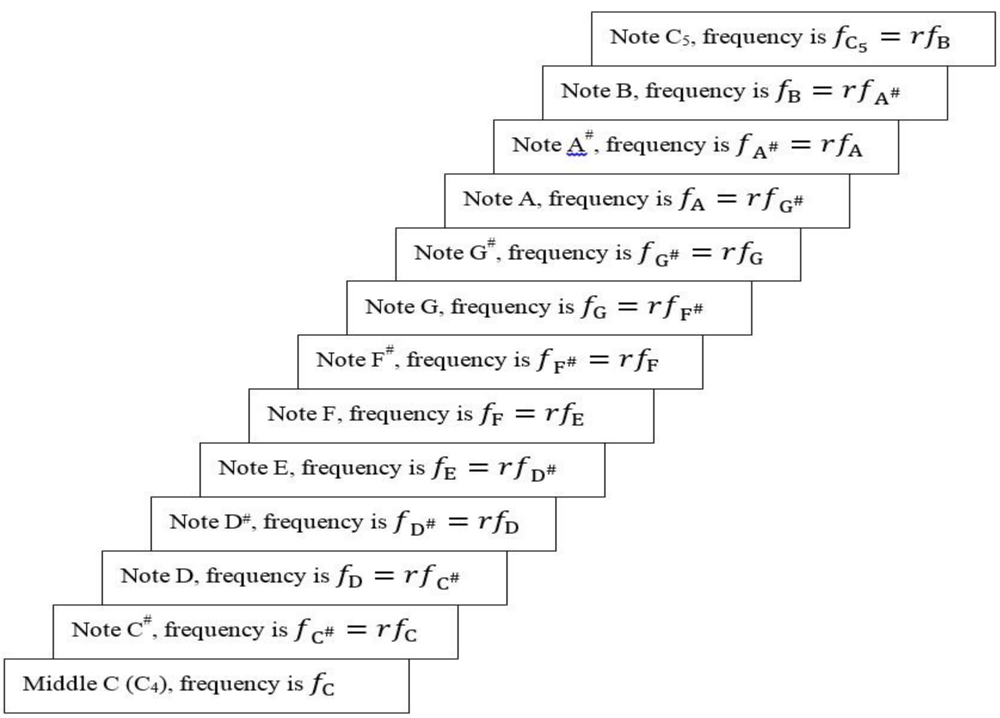
1	2	3	4	5	6	7	8	9	10	11	12
A	$A^{\#}$	B	C	$C^{\#}$	D	$D^{\#}$	E	F	$F^{\#}$	G	$G^{\#}$



https://commons.wikimedia.org/wiki/File:Note_names_keyboard.jpg (modified)

You probably know that as you move to the right side of the keyboard, the pitch or the frequency of the note is higher. But how much higher? There is a mathematical relationship between the frequencies of the 12 notes, which allows us to calculate all the frequencies from one basic frequency.

The mathematical relationship has two parts. First, every note is higher in frequency than its left-side neighbor (black or white) by the same ratio *r* (see figure below).



Secondly, after moving up 12 steps, the same note appears again, but its frequency is doubled: middle C (C_4) becomes C_5, whose frequency is twice of the frequency of middle C.

Combining the two parts of this relationship, we know the frequency of C_5 can be written as

$$2f_{\mathrm{C}} = f_{\mathrm{C}_5} = rf_{\mathrm{B}} = rrf_{\mathrm{A}^\#} = rrrf_{\mathrm{A}} = rrrrf_{\mathrm{G}^\#} = \cdots = r^{12}f_{\mathrm{C}}$$

Therefore, $2 = r^{12}$, or $r = 2^{1/12}$.

Now we have the ratio between adjacent notes. We also need to know the frequency of one standard note in order to calculate all frequencies. The general standard is that the central A has a frequency of 440 Hz.

The frequency of $A^\#$, the right-side neighbour of central A, is $440 \times 2^{1/12} = 466.16$ Hz. The left-side neighbour of central A, note G#, has a frequency of $440 \div 2^{1/12} = 415.305$ Hz. Following this method, use your calculator to calculate the frequencies of all 12 notes and fill the table below. Keep 5 or more non-zero digits for the frequencies. Check that the frequency of C_5 doubles the frequency of middle C.

Notes	Frequency (Hz)
Middle C	
C#	
D	
D#	
E	
F	
F#	
G	
G#	415.305
Central A	440
A#	466.16
B	
C (C_5)	

Activity 2: Using tuning forks with LoggerPro to explore pressure waves and FFTs.

Before making your own musical instrument, we will explore how to analyze sound waves, which are pressure waves, and their properties, like period and frequency.

Open file *_Physics with Vernier\35 Mathematics of Music.cmbl* in Logger Pro and plug the microphone into "CH1" of your interface box. Go to menu "Experiment—Data Collection" and change the data collection time to 1 second.

Hit the short tuning fork with the rubber hammer, bring the microphone close to the tuning fork, and then click the "Collect" button in Logger Pro. You will see that the pressure at the microphone changes in a sine wave fashion and the "FFT" graph on the bottom of the screen shows a single peak. (Note: FFT stands for fast Fourier transform and is a method of analyzing the frequencies in a wave.)

Sketch the pressure and FFT graphs below, labeling the Time and the Frequency axes. Make sure your pressure-time graph contains <u>at least 10 peaks</u>, to justify your answers to the questions that follow.

Pressure FFT

Let's determine the period from the Pressure graph and compare with the FFT graph.

Select 10 cycles from the Pressure-time graph and write down the Δt value here: _______________ s

The period of this sound wave is (show your calculation first):

T = ____________________ s

The frequency calculated from the period is (show your calculation first): $f = \frac{1}{T} = \cdots$

f = ___________________ Hz.

The peak on the FFT graph is ______________ Hz, which is _______ (close/not close) to the frequency calculated from the period.

Now, repeat for the long tuning fork and observe the graphs. The long tuning fork has a _____________ (higher/lower) frequency.

Activity 3: Calculating the length of the palm pipe that will create a musical note.

Now that we know the frequencies of each note, we will create notes using pipes! Get a letter from the instructor – that is the note you will create. Each partner will make a different note in your group, so your answers to Activity 2 and 3 will be different from your partner.

First you must find the length of the pipe that can produce the sound of your note: Knowing the frequency, one can calculate the wavelength using $v = f\lambda$ where the speed of sound in air at room temperature is v = 340 m/s. Then, you can calculate the length of the pipe because the fundamental standing wave will have a wavelength 4 times the length of the pipe (see the figure on the front page). Fill in the blanks below, keeping the final length to 0.1 cm precision:

The note I am going to create is _________ that has a frequency of ______________ Hz. So the wavelength is ____________ m, and the length of the palm pipe should be _____________ m, or ____________ cm.

Activity 4: Make the palm pipe and adjust its frequency.

Get two pipes of appropriate lengths and a connector from the instructor. Connect the two pipes with the connector so that the total length equals to the length you just calculated. Play the palm pipe by hitting one end of the pipe swiftly and it will make a musical sound. Practice a few times, making sure the length of the pipe does not change when you hit the pipe.

Now you will fine-tune your pipe using Logger Pro. Open file *_Physics with Vernier\35 Mathematics of Music.cmbl* in Logger Pro and plug the microphone into "CH1"of your interface box. Go to menu "Experiment—Data Collection" and change the data collection time to 1 second. Hit one end of the pipe continuously with your palm, and ask you partner to aim the microphone at the other end of the pipe and clicks the "Collect" button in Logger Pro. Logger Pro will listen to the sound and produce an FFT graph that tells you what frequencies are in the sound. Find the peak frequency using the mouse pointer.

Is the peak frequency the same as what you want? If not, adjust the length of the pipe based on:

In order to raise the frequency, we need to make the pipe ____________ (shorter/longer).

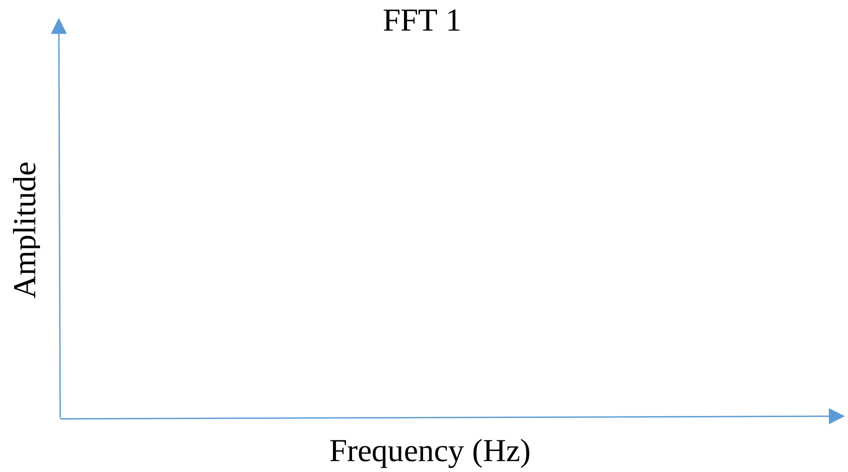
In order to lower the frequency, we need to make the pipe ____________ (shorter/longer).

After adjusting the length of the pipe, retest the peak frequency until it is within ± 1 Hz to the frequency of your note. You have created a musical instrument! Although it can only play one note, you can play songs together with your classmates. Record the final results below.

Pipe length (cm)	Peak frequency (Hz)

Activity 5: The overtones.

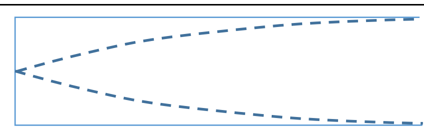
You may have noticed that there is more than one peak on the FFT graph: the first and the tallest is the fundamental frequency. The next peaks are called the overtones and they create the timbre for different instruments. In the space below, sketch the FFT graph given by Logger Pro from 0 to about 6 times the fundamental frequency, labeling all the peaks with their frequencies.



The frequencies of the peaks are mathematically related. Can you find the relationship?

The ratio of the peak frequencies roughly equals to:

These peaks are the frequencies of standing waves. Sketch the wave patterns of the first three standing waves below, noting that the actual movements of the air molecules are along the length of pipe instead of perpendicular to it. The even number harmonics are missing, which is a unique feature of closed-end wind instruments.

Fundamental:	
Third harmonic:	
Fifth harmonic	

Activity 6: Play songs with class.

After every student has made one palm pipe, we will play songs together. The lab instructor will be your conductor!

After this activity, hand in this handout, and return the pipes and the letters to the instructor.