Homework #3

PHYS 1240: Sound and Music
Summer 2019

due Monday, July 29, 2019

Instructions: Answer the following questions on a separate sheet of paper (no need to turn in this question sheet). Be sure to show all your work (show *how* you get your answers), since physics isn't just about getting the right answers, but rather about the process of reasoning through problems.
A stapled hard copy of your work is due at the beginning of class on the due date listed above.

Problem 1. (8 points) What does ADSR stand for? Draw an example sound envelope and label each of the letters on your drawing. Then, draw sound envelopes for a cymbal played three different ways (you can reference sound samples from the UK's Philharmonia Orchestra): a crash cymbal, a rolled cymbal, and a damped cymbal.

Problem 2. (4 points) If you double the tension applied to a string, how much is its fundamental frequency increased? How many semitones ($\sqrt[12]{2}$) does this raise the pitch?

Problem 3. (4 points) Where would you pluck a guitar string to most effectively excite the third mode? Where would you touch it lightly with your finger to kill modes 1 and 2 but leave 3 vibrating? If you do this, how much higher is the pitch of this harmonic than the pitch you ordinarily hear from that string?

Problem 4. (2 points) During the fast slip-grip motion of a bowed string, which is the longer part of the cycle—the slip or the grip?

Problem 5. (4 points) For a tube 8 feet long at room temperature, open at both ends, what is the frequency of the fundamental mode? If this tube is an organ pipe and a $2\frac{2}{3}$' organ stop is played alongside it, which harmonic is reinforced?

Problem 6. (6 points) Draw the second harmonic for a pipe open at both ends, plotting air velocity as a function of length along the pipe. Where could a large hole be placed to emphasize this harmonic? Then, if they exist, draw the air velocity standing waves of the second harmonic for a pipe closed at one end and for a cone open at one end. (*Hint: for the cone (e.g. saxophone), is there more pressure buildup (faster air) near the tip (mouthpiece) or the open end (bell)?*)

Problem 7. (22 points) Go to the Phet simulation titled "Fourier: Making Waves" (the link is on the Additional Links page of our website). Download and open the .jar file, and once the application is open, do some exploring. On the Discrete tab, you should see three graphs: the top one (Amplitudes) allows you to adjust the relative amplitudes of the Fourier coefficients (i.e. the intensities of a note's harmonics), the middle one (Harmonics) shows the wave of each harmonic, and the bottom one (Sum) shows the resulting complex waveform produced.

a) (8 points) First, drag the amplitude of A_1 to 0.00 and the amplitude of A_8 to 1.00, and look at the Sum plot. What is the wavelength of the wave (in meters)? What about the amplitude (no units needed)? On the right under *Graph controls*, click the drop-down menu to change from a function of space (x) to a function of time (t). What is the period of the wave (in milliseconds)? Convert this to seconds and calculate the frequency (in Hz)

b) (4 points) Now, drag A_8 to 0.00 and A_9 to 1.00, and measure the period and frequency of this new wave. Theoretically, what should the ratio between the frequencies of these two harmonics be? Is this what you get?

c) (4 points) Now, drag both A_8 and A_9 to 1.00, and change the horizontal and vertical scales to the right of the Sum plot to zoom out until you can see the full waveform. What phenomenon can you see occurring? What is the frequency associated with this phenomenon? (First you'll have to measure the period, of course.) Figure out which coefficient A_i has this same frequency by changing different amplitudes and looking at the resulting periods on the Harmonics plot.

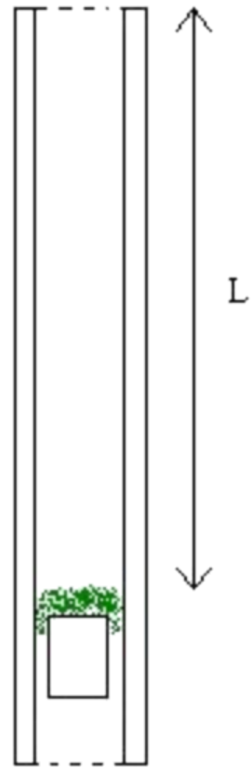
d) (2 points) When you click the Sound checkbox at the bottom right, how does this sound (the two pure tones mixed) compare to the sounds produced from parts a) and b)?

e) (4 points) In his work *Sensations of Tone* from 1863, Helmholtz gives the following information about the intensities of the harmonics for two different instruments (using musical dynamic markings: from loudest to quietest, these are f, mf, mp, p, pp, ppp):

Instrument	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
#1	f	ppp	f	p	mf	—	mf	pp
#2	f	mp	—	mf	—	p	—	p

Reproduce these two configurations using the Amplitudes plot, and listen to what they sound like. One of the instruments is a clarinet, and the other is an organ. Which do you think is which? Why might this not be a perfect representation of the actual instrument?

Homelab 3. (50 points) (underlined portions indicate what you need to submit on paper for this homelab)



In this homelab you will make a panpipe tube and measure its fundamental resonant frequency for several values of the length L. We will make a graph of the period versus the length, and use our data to measure the speed of sound. If you do everything carefully, you can measure the speed of sound this way with a precision of a few percent.

The materials you will need will be handed out in class. They are: a piece of plastic pipe (made of CPVC, with a length of 20 cm and an inside diameter of 1.2 cm), a small ball of clay, and a wooden plug that fits loosely inside the pipe. It will also help to have one or two unsharpened pencils on hand (or something of a similar shape), as well as a ruler.

Step 1: First, assemble your panpipe tube. To do so, make a ball of clay with a diameter a little less than the inside diameter of your tube. Then slip the ball of clay into the bottom of the tube, and put the wood plug in the same side after it. Hold the tube upright (as shown in the diagram—the clay is the green blob), and use a pencil or other tool to keep the plug from slipping out. Put the square end or eraser end of a pencil in from the top, and pack the clay in so it makes a flat floor that completely seals the tube. To check that the tube is sealed, put your lips around the top and blow gently. Carefully measure the inside length L of the tube. This can be done by putting a pencil into the tube (square end first) until it touches the clay, marking the depth on the side of the pencil, and then removing the pencil and measuring it with a ruler. If you only have an inch ruler you should measure the length in inches and then convert to centimeters, using 1 inch = 2.54 cm. Measure as accurately as you can. For L to be well-defined, it is important that the floor of the tube should be flat.

Step 2: Learn how to play your panpipe tube by watching this brief video segment. When you can produce a steady tone, you will notice that the pitch can be lowered by covering more of the tube with your lower lip, or by blowing more directly into the tube. For this lab, try to get the highest pitch you can from the fundamental mode.

Step 3: Measure the frequency of the fundamental mode using Raven Lite. As in the previous assignments, make a recording and then adjust the sharpness and other controls so you can make the most accurate measurement possible. (It is difficult to "overblow" the tube and excite the second or higher modes, so you probably won't have any trouble getting the right mode.) Measure the frequency f for three different values of the length L ranging from something close to the full length of the tube to about half the full length. (Be careful you don't blow into the wrong end of the tube.) It does not matter exactly what lengths you use as long as you measure them accurately. Find the periods T in milliseconds that correspond to each frequency f, and record your three values for L (in cm), f (in Hz), and T (in ms).

Step 4: Make a graph of your results, either using your own graph paper or printing out the last page of this assignment. Plot the tube length in centimeters on the x-axis and the period T in milliseconds on the y-axis. Start both axes at the point (0 cm, 0 ms) at the lower left corner of the graph, and choose an appropriate division marker size so that the range of your data spreads across most of the graph area (for example, if your longest length is $\sim$19 cm, you might place a tick mark every five units along the x-axis, labelled "5 cm," "10 cm," "15 cm," and "20 cm"). Label both axes clearly.

Step 5: The wavelength of the fundamental mode of a pipe closed at one end is $\lambda = 4L$. Using the relationship between a sound wave's wavelength, period T, and velocity v, we can rewrite this equation as

$$T = \frac{4L}{v}.$$

This equation predicts a linear relationship between L and T. Draw the best straight line you can through your three data points, but do not force your line to go through the point (0,0). The effective acoustic length of your tube is a bit longer than the length you measured because of the "end correction" at the open end. Because of this effect, your line should cross the y-axis at a small, positive value of y.

Step 6: Now you will use your measurements to find the sound velocity. If we put the above equation into the form $y = mx + b$, where $x \leftrightarrow L$ and $y \leftrightarrow T$, it becomes clear that the slope of the line you drew is equal to the quantity $4/v$. Thus, with a little bit of algebra, you can calculate the velocity as 4 divided by the slope, or

$$v = 4/\frac{\delta T}{\delta L},$$

where $\delta T = T_3 - T_1$ is the difference between your longest period and your shortest period, and $\delta L = L_3 - L_1$ is the difference between your longest length and your shortest length. Use this method to measure the sound velocity, convert to meters/second, and write your result clearly near your graph.

Extra credit: As discussed earlier, due to the "end correction," the data should not precisely follow the formula for T above that passes through the origin. A more accurate formula for the relationship between T and L would replace L with an *effective length* $L+\Delta L$:

$$T = \frac{4}{v}(L + \Delta L),$$

where ΔL is the end correction. This represents the extra distance beyond the actual tube length where the sound wave's pressure node actually occurs, caused by the pipe not being infinitely thin. Musically, this correction can change the predicted frequency often by more than a semitone, so it must be taken into account when designing organ pipes or other wind instruments. Let's find this end correction. On your graph, find the point at which your line intersects the y-axis. Looking at the above equation, we see that the y-intercept (the constant b in the equation $y = mx + b$) is $T(0) = 4\Delta L/v$, where $T(0)$ is the value of T where the data would intersect the y-axis. Using the value for v you found in the previous part, rearrange this equation to solve for ΔL and calculate the end correction, recording your value for ΔL (be careful with units!). Theory predicts that this end correction is related to the pipe's diameter D by the formula $\Delta L = xD$, where x is some dimensionless number. What do you find for the value of x?

Name: ____

Homelab 3.

Length L (cm)	Frequency f (Hz)	Period T (ms)