Homework #2

PHYS 1240: Sound and Music
Summer 2019

due Monday, July 22, 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. (6 points) Suppose you have a string of length $L = 0.5$ m on which waves travel at speed $v_t = 150$ m/s. If standing waves are produced, what is the wavelength λ_5 of the fifth harmonic? What is the frequency f_5? How many nodes and antinodes are contained on this mode of vibration?

Problem 2. (4 points) If the amplitude of a sound wave is doubled, by what factor will the intensity increase? By how many dB will the sound intensity level (SIL) increase?

Problem 3. (4 points) Suppose we're in class with a SIL decibel meter up front, and everyone is screaming at the top of their lungs, hooting and shouting and pounding on their desks, shooting off firecrackers, its PHYS 1240 gone wild... and the meter is reading a reasonably steady sound intensity level of 110 dB. If there are 20 people, and each person is producing roughly the same intensity of sound, then what sound intensity level (in dB) would the meter show if everyone except one person suddenly got totally quiet?

Problem 4. (2 points) The often-quoted ideal range of human hearing is 20 Hz to 20 kHz. How many octaves is this?

Problem 5. (4 points) A vocalist starts singing a note at 250 Hz, goes up a perfect 4th, then up another perfect 4th, then down an octave, then up a major second (using only justly-tuned intervals). What frequency does the vocalist end on? Show all your work.

Problem 6. (6 points) Consider the interval of a major third. First, in a justly-tuned scale (based on the low end of the harmonic series), what is this frequency ratio (give your answer as a decimal)? Second, in a Pythagorean tuning (moving from the lower note up by fifths and down by octaves until reaching the upper note), what is this ratio (again, as a decimal)? And third, in an equal-tempered scale, what is the frequency ratio for a major third? Make sure you include enough digits in your answers to distinguish the three decimals.

Problem 7. (6 points) Using headphones, listen to Deutsch's Cambiata Illusion. From which side (if any) do you hear high notes, and from which ear do you hear low notes? Does this change if you reverse earphone positions? Are the high notes migrating to the other side when you reverse earphone positions, or do both earphones play both high and low notes? Might this relate to which hand is your dominant one?

Problem 8. (12 points) Think about all the physical variables we have discussed that can characterize a single tone: intensity, frequency, duration, and waveform. For each pair of sounds described below, find one variable that is roughly the same for both sounds, and find two variables that differ between the two sounds. Be sure to explain how and why you think each of the variables you choose might differ. For example, if the sounds are a tuba and a flute both playing *forte*, you might write, "Same intensity, different frequency (tuba has lower pitch), different waveform (timbres different for different instruments)."

a) Two steady sines waves A and B with the same wave velocity, where A has twice the amplitude and twice the wavelength of B.

b) An oboe player playing the A_4 tuning note for an orchestra and a violinist plucking the A-string (at 440 Hz).

c) A person whispering the two words "no kidding."

d) A dog barking once and a person cracking their knuckles.

e) A pianist plays a C-major chord (with the notes C_4, E_4, G_4) with the dynamic marking *fortissimo*, then plays a *fortissimo* d-minor chord (with the notes D_4, F_4, A_4).

f) You're standing near a straight railroad track, and a train traveling towards you at 100 feet per second gives a short toot of its whistle when it's 100 feet away from you, then gives the same toot 3 seconds later.

Problem 9. (6 points) Identify which part of the human ear fits for each of the following descriptions. For each description, your choices are: ossicles, Eustachian tube, oval window, pinna, hair cells, basilar membrane.

a) Allows normal air pressure on both sides of the tympanic membrane.

b) Transmit and amplify the motion of the tympanic membrane to the cochlea.

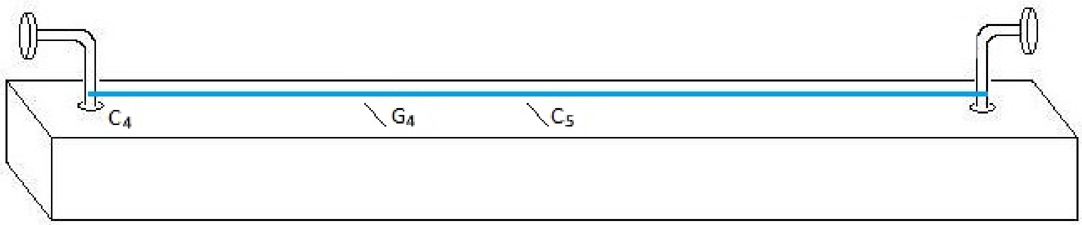
c) Their stimulation sends neural impulses to the brain.

d) Collects sound and directs it into the auditory canal.

e) Performs a frequency analysis of sound where location along it is correlated with the sound frequency.

f) Allows the stapes to transmit vibrations into the cochlea.

Homelab 2. (50 points) (underlined portions indicate what you need to submit on paper for this homelab)



This week, you will build a monochord (a musical instrument with only one string) and measure the different fundamental and harmonic frequencies that can be played on a steel string.

The materials you will need will be handed out in class. They are: a piece of wood with two holes in it, two bent nails, and a steel guitar string. The string we will give you has a diameter of 0.010 inch. You will also need a ruler and some kind of adhesive tape for when you put the string on the monochord. As soon as you can, you should put a piece of tape on the end of the string—the end is sharp and the tape will keep you from hurting your fingers.

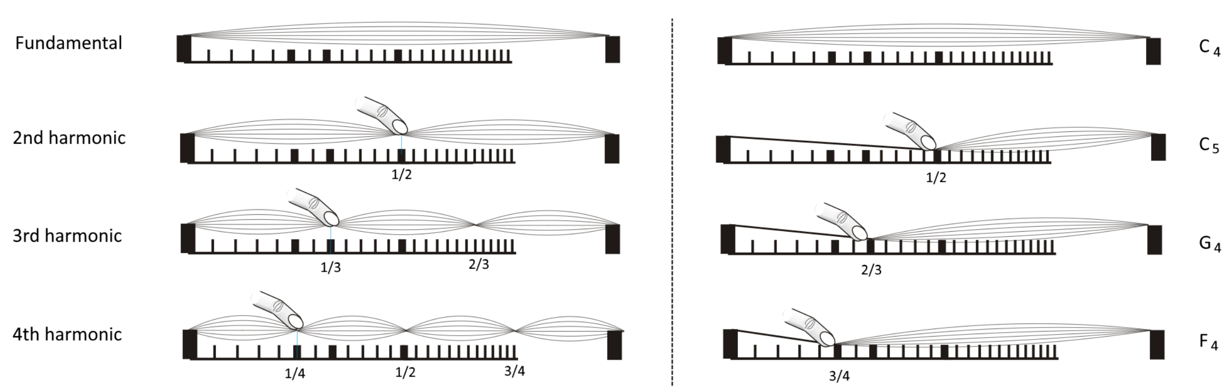
Step 1: Push the nails into the holes as shown above. They should go almost, but not quite, all the way through the board. If you push them too far in they will stick out the bottom, the board will not rest flat, and you might scratch yourself on them. You won't need a hammer to put the nails in because the holes are already big enough. You might need to use a book or some other solid object to push them in, or it might help to twist them while you push. The nails we are using are called "coated sinkers." They have a sticky coating that will keep them from turning in the holes when you don't want them to.

Step 2: Now put the wire on the monochord. First, put two pieces of tape within reach so you will be able to get them while you are trying to keep the wire from unwinding. Loop the end of your string with the little brass ring around one of the nails, close to where it goes into the board. Slip the other end of the string through the brass ring and pull it tight. This will hold the brass ring end on the first nail. Now, pull the other end of the wire down to the other nail until there is a straight section of wire running from one nail to the other, about 1/4" or less above the board. Wrap the wire about 10 times around vertical part of the second nail, ending with a few turns around the horizontal part of the second nail, and tape it down. You will probably still have a foot or so of wire left. Just coil it up and tape it out of the way. If you turn the second nail you will now see that you can tighten and tune the string. Before you bring it up to pitch it is important to arrange the coils on the vertical parts of the second nail so that the last few turns of the wire (before it heads for the other nail) are on top of a few other turns. This way, as you increase the tension on the wire it will pinch the turns underneath and this will keep it from slipping. If your wire slips, the pitch will not hold steady and you will not be able to make good frequency measurements.

Step 3: It's time to tune your monochord. Your goal is to tune the string up to a frequency of about 300 Hz, or around D_4. The exact pitch is not important. You should bring the pitch up slowly from below to avoid breaking the string. To tune, tighten the string and match the pitch using either the Frequency Tone Generator on our website's Additional Links page or by recording and measuring the frequency with Raven Lite. (If you use an instrument, tone generator, or guitar tuner, be careful that you are tuning to the right octave—if you try to tune it a whole octave too high it will break.) When you look at the spectrogram with Raven Lite you will see a whole series of frequencies (the harmonics of the string), but the frequency you are trying to tune is just the lowest one, which corresponds to the musical pitch. Once the string is tuned, check and see if the pitch is stable. It may drift downwards for the first few minutes, but then it should soon become very stable, as long as you pluck it gently. If the pitch keeps drifting downwards the string may be slipping on one or both of the the nails. Check to see that the turns overlap, as discussed above.

Step 4: Now, you will play your monochord much like the Vietnamese đàn bầu, which relies on the string's harmonics to produce different pitches (though the đàn bầu also has a pitch lever to change the string tension). The goal is to measure the frequency of vibration of the first five natural modes (a.k.a. "harmonics" or "partials") of the string. (Sometimes the lowest mode is called the "fundamental," and the ones above it are called "overtones." In this language we want to measure the frequency of the fundamental and the first four overtones.) The first few modes we are looking for are pictured on the left side of the diagram below. To excite the first mode, simply pluck the string gently near the center. For the first overtone (second harmonic), pluck the string near one end while lightly touching it with a finger tip exactly at the midpoint. This creates a node at the center of the string. You will have to experiment to find the best spot to touch the string. Once you find it, use a pencil to mark the spot on the board so you can easily find it again. To excite the next mode, touch the string 1/3 of the way from one nail while plucking it near the other nail. In general, to excite mode N, you must touch the string at a point that is $1/N$ of the total length from one end. Experiment until you have all of these points marked for the first five modes and you can clearly hear the sound of each mode. It may take some patience.

Step 5: Make a recording of the sound of each of the first five modes with Raven Lite. It will be easiest to identify them in the spectrogram if you put them all on a single recording, one after another. Notice that, for each mode, besides the lowest frequency, the spectrogram will also contain higher frequencies. This is unavoidable because more than one mode has a node at the position where you put your finger. (For example, the second and fourth modes both have nodes at the center of the string. So, when you are exciting the second mode you will probably excite some fourth mode as well.)



Step 6: Using your spectrogram recording, carefully measure and record the frequencies of the first five modes. Since your tones will last at least a second, you can set the sharpness control to a large number of samples for better frequency resolution. With care, you can measure each of the five frequencies with an accuracy of about 1 Hz. What frequencies should you get ideally for the first five harmonics? If any are not close to your measured values, resolve any discrepancies.

Step 7: Now, you will play the string the way a slide guitarist does, by placing a hard object against the string so that it is divided into two sections. The part of the string that is plucked will be called the sounding length, and the other side will be damped by a finger. A small metal object like a pair of scissors or a spoon makes a good slide.

The goal is the play and record six notes from the diatonic scale. We will use the justly-tuned intervals of the Ptolemy scale. With the monochord still tuned to about 300 Hz, we will call this pitch C_4 (even though it's not the standard pitch for C_4), and we will figure out how to shorten the string (as in the right side of the figure on the previous page) to make the higher-pitched notes shown in the first column of the table below. In the second column we have listed the frequency ratios for the Ptolemy scale. The fundamental frequency of a vibrating string varies as the reciprocal of the sounding length, so the length ratios we need to get the desired frequencies are the reciprocals of the frequency ratios. Reproduce the table below and fill in the third column of the table with the reciprocals of the values in the second column (for example, the entry for C_5 should be 1/2). To find the desired sounding lengths, we must multiply the full length of the string by these length ratios. Carefully measure the full length of your string and enter your result in the C_4 row of the sounding length column, including units (e.g. if your ruler measures centimeters, write "cm" in parentheses under "Sounding Length") and enough digits to represent your true measurement precision. Now fill in the rest of the sounding length column by multiplying your full length by the length ratios in column 3. (For example, the sounding length for C_5 should be 1/2 the full string length.) Now mark the locations of your target sounding lengths for each note on your monochord, and label each mark with the note name. The marks for C_5 and G_4 are shown in the figure at the start of this problem. If you orient your monochord so that your sounding lengths are to the right, all of the marks should be under the left half of the string. With care, you can place the marks with an accuracy of about 1/32 inch or 0.5 mm.

Step 8: Next, play each note and record the frequencies using Raven Lite. To do this, carefully place your slide above the mark for a note and pluck the sounding length while damping the other side of the string with a finger. Apply only gentle pressure to the slide so that you don't change the pitch by stretching the string. With Raven Lite you will see a harmonic series for each note you play, but here we are interested only in the lowest (the fundamental) frequency, which corresponds to the perceived pitch. Record the measured frequencies in the 5th column. You should be able to measure the frequencies with an accuracy of a few Hz.

Step 9: Now we want to see how close our measured frequencies are to the desired Ptolemy scale. To do so, calculate a percent error for each measured frequency. The percent error shows how different your measurements are from the theoretical or predicted values. To calculate it, take each measured frequency and divide it by the frequency you would expect, which we will take to be your measured fundamental frequency for C_4 multiplied by the frequency ratio in column 2. Then, subtract 1, and multiply by 100 to convert to a percent. Thus, the percent error for C_4 should be exactly 0, and in general it is given by the formula

$$\%\ \text{error} = \left(\frac{\text{measured frequency}}{\text{C}_4\ \text{frequency}\ \times\ \text{frequency ratio}} - 1\right) \times 100\%$$

With this formula, fill in the last column of your table

Step 10: Play Row, Row, Row Your Boat:
C C C D E, E D E F G, C_5 C_5 C_5, G G G, E E E, C C C, G F E D C

Note	Frequency Ratio	Length Ratio	Sounding Length ( )	Measured Frequency (Hz)	Percent Error (%)
C_5	2/1				
G_4	3/2				
F_4	4/3				
E_4	5/4				
D_4	9/8				
C_4	1/1				