Homework #4

PHYS 1240: Sound and Music
Summer 2019

due Monday, August 5, 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. (4 points) What is the difference between a marimba and a xylophone? Why are marimba bars cut the way that they are?

Problem 2. (4 points) A wind chime, consisting of a set of cylindrical tubes striking against a suspended weight by the force of the wind, works best when vibrating as a uniform beam free at both ends, just like the bars of a xylophone. However, it must be attached to a string and hung in order for the hollow tubes to freely oscillate. In order to excite the first mode and get the clearest and loudest tone, how many different options do you have for the points at which you can attach the string? In addition, where should the suspended weight be placed to strike each tube?

Problem 3. (4 points) Guess and sketch the first two natural modes of the orchestral triangle, a metal rod bent into the shape of a triangle open at one corner. (*Hint*: how do we model the natural modes of a saxophone or a human vocal tract, which also contain bent corners?) Clearly indicate the location of all nodes.

Problem 4. (2 points) What happens to the distinction between voiced and unvoiced plosives when you whisper?

Problem 5. (6 points) Suppose you sing with your vocal tract filled with helium, in which the speed of sound is approximately 930 m/s. Does this change the frequency of vocal cord vibration? Does it change the formant frequencies? By how much?

Problem 6. (8 points) How are crickets able to make sound (what is the name of the process and how does it work)? Sketch a spectrogram (frequency versus time) of the cricket's song, zoomed in enough to see the details of a complete pattern. If you hear a cricket outside chirping twice every second, approximately what is the temperature outside, in °F?

Problem 7. (4 points) The average person speaks at a rate of about 5 syllables per second, or approximately a dozen phonemes per second. Suppose that the intelligibility of a spoken sentence requires that each syllable (or phoneme) that a person utters must drop at least 10 dB by the time the next one comes along; that is, that these time intervals should be at least 1/6 T_r. Use this criterion to make two estimates of the maximum acceptable T_r a room can have for speech to be understandable. Do you think it's more appropriate to apply such a criterion to syllables or to phonemes?

Problem 8. (2 points) Why do you think many movie theaters include decorative curtains and carpet on the side walls? Explain in terms of the quantities in Sabine's formula.

Problem 9. (16 points) Go to "Acoustics/Vibrations Animations by Dan Russell" (the link is on the Additional Links page of our website). Once you have reached the website, under "Vibrational Modes of Continuous Systems," go to "Rectangular Membrane" and have a look around. We will be concerned with the modes of a rectangle whose length is twice its width. This provides a good model for the front panel of a cajón (pronounced "ka-HONE"), a resonant wooden box used as a drum.

a) What spot on the panel should you hit it if you want to resonate the deepest frequency?

b) Draw a top-down view of the following six modes: (1,1), (1,2), (1,3), (2,1), (2,2), (3,1). Each sketch should only contain the rectangular boundary and any additional lines that represent nodes.

c) Determine what these modes sound like together by calculating the frequency of each of the six above modes. (Frequency ratios are listed to the left of each animation, and assume the (1,1) mode resonates at f_{11}=440 Hz.) Would this membrane sound harmonious? If it's helpful to you, feel free to find the corresponding musical notes to see how the frequencies fit together.

d) Go back to the main page, and under "Animations of Experimental Results," click on "Vibrational Mode Shapes of a Racquetball Racket." Compare the four membrane modes on the right side of the page with the rectangular membrane modes you already drew, identifying a specific rectangular mode for each racquetball racket membrane mode that has the same node pattern. These modes (and more so the frame modes on the left side) are what cause the "sweet spot" near the racket's center but away from major nodes.

Homelab 4. (50 points) (underlined portions indicate what you need to submit on paper for this homelab)

In this homelab, you will be a linguist and an ornithologist, measuring the acoustic properties of vocalizations of both humans and birds.

Step 1: Using Raven Lite, record yourself saying eeeeooooeeeeoooo. The eeee vowel sound should be like in the word "beet" and the oooo sound should should be like in "boot." Spend a few seconds on each vowel and vary your voice continuously from the eeee sound to the oooo sound. You should see a series of harmonics when the Focus is high enough, and if you turn the Focus down, you should see the larger-scale formant structure. Make a sketch of the formants you can see, on a plot of frequency (from 0 to about 5 kHz) versus time, and label the first formant as F1, the second as F2, and so on. As indicated in Figure 14.12 of Hall's *Musical Acoustics*, you should find that the first formant does not change much between eeee and oooo, but that there is a large change of the second formant frequency. Most vowels can be uniquely determined by the frequencies of the first two formants, so let's measure those. Below your sketch, record the frequencies of the first two formants for both eeee and oooo, labelling them with their IPA symbols as F1(i), F2(i) for eeee and F1(u), F2(u) for oooo.

Step 2: Use your recording to estimate the length of your vocal tract. Assume your tract is an ideal tube closed at one end (at the vocal cords) and open at the other (at the lips), and assume the speed v of sound travelling through the air in your throat corresponds to a temperature of 98.6°F (37°C). Thus, the frequencies of harmonics will be odd integer multiples of $v/4L$, where L is the length you wish to calculate. In the language of formants, this means that the length of the idealized vocal tract in terms of the frequency f_n of the nth formant should be given by the formula

$$L = \frac{v}{4f_n}(2n - 1).$$

On your recording, measure the highest formant from which you can still get a precise frequency measurement. Using this frequency and the formula above (making sure to show how you calculate the speed of sound), calculate the length of your vocal tract. Express your answer in centimeters. In addition, looking at the second formant in your recording, use the formula above to determine which vowel (eeee or oooo) corresponds to a longer vocal tract. What part of the vocal tract is responsible for this length increase?

Step 3: For this next part, make an audio recording of a bird's song/call, using your phone or another recording device. This can be any type of bird, as long as you are able to get a clear sample of at least one of its vocalizations in full. Try your best to isolate a single bird's call from others in the recording, and it may help to get away from traffic to reduce the noise. (Red-winged blackbirds, chickadees, and ducks often hang out around the Williams Village Field or the Kittredge pond, but all sorts of birds can really be found anywhere around campus or beyond.) Don't worry if you aren't able to identify the bird—we will only be concerned with analyzing the sounds it makes.

Once you have your recording, upload it to Raven Lite (if it's a video, it must first be converted to an audio file, which can easily be done online) and look at the spectrogram. Adjust the Focus, Contrast, etc. until you can clearly see what's going on in the recording, and either print out a copy of the spectrogram or reproduce the graph clearly on your answer sheet, with frequency on the y-axis and time on the x-axis (no colors necessary, but make sure all salient features are present).

Step 4: Next, analyze your spectrogram, including as much of the following information as you can (note that every recording will be different, so don't worry if some of the features below aren't present for your bird—just describe what you think would be most important to fully characterize the sound in your own words). First, as a scientist, it's good practice when making field recordings to include the time and location of your recording (not necessarily GPS coordinates, but just a short description of where you were, the time of day, etc.). If you could see the bird, include a visual description of what it looked like. Then, describe the quantitative features of the recording, giving the time duration of the bird's call/song (if it's a repeating pattern, what's the duration of one unit?) and finding the frequency range (highest frequency minus lowest). Finally, describe the recording qualitatively. Are there higher harmonics, is it a pure tone, or does it look more like rough noise? Do any lines go up, down, both, or stay steady? Would you describe the vocalization as a trill, a whistle, a chirp, or something else (or a combination)?

Step 5: Think about how your bird is able to produce the sound it does. Do you see any evidence of the syrinx being used in a way that's different from our larynx? This might be apparent if two lines occur at the same time running in different directions, or if a line suddenly switches direction without prior notice. Lastly, try to pick out a frequency from the recording that might represent the fundamental of a column of air closed at one end, and use this frequency to estimate the effective length of your bird's vocal tract (from syrinx to beak), using the same formula from Step 2 with $n=1$. For the velocity, use 355 m/s—birds have a higher metabolism than humans and therefore a higher body temperature, at about 105°F.