Homework #1

PHYS 1240: Sound and Music
Summer 2019

due Monday, July 15, 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) You're at a summer concert at the Red Rocks Amphitheatre, and the temperature is 86°F (30°C). How long does it take sound from the stage to reach you, seated 35 meters away? Could you notice this time delay? Why or why not?

Problem 2. (4 points) Suppose a xylophone mallet with a hard-rubber head remains in contact with the wooden bar for a few milliseconds, but during that short time it exerts a force of 500 N. If that force is concentrated in a contact area of only 5 mm^2, how much pressure is being exerted on that part of the bar? Express your answer both in N/m^2 and in atm. Does this suggest that the wood is deformed during impact? For reference, German U-boats couldn't dive more than 1,000 ft below sea level, at a max pressure of about 30 atm.

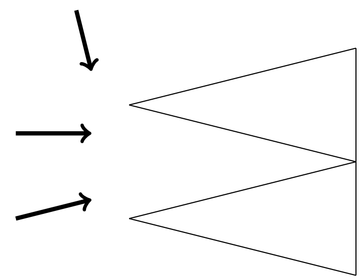
Problem 3. (4 points) What is the frequency in Hz of a human heart that pulses at a rate of 80 bpm (beats per minute)? What about the period? Is this a frequency within our audible range of hearing?

Problem 4. (4 points) Suppose you measured both frequency and wavelength of a sound wave, and found them to be 175 Hz and 2 m, respectively. What speed of sound does that imply? Think of at least two different reasons why the answer may not be 343 m/s.

Problem 5. (6 points) An empty jug or bottle is blown over the top to produce a sound with a certain pitch. Then, the container is partially filled with water and blown over the top again. Is the pitch (i.e. the natural frequency of oscillation) higher or lower than before? Check this yourself. Is the sound caused by vibrations of the container+water or of the air? Explain the change in pitch either as a change in the elasticity/stiffness of the oscillator (how much the air in the bottle is squeezed) or a change in oscillator's inertia/mass.

Problem 6. (4 points) A certain dog whistle operates at 22.75 kHz, while another (brand X) operates at an unknown frequency. If neither whistle can be heard by humans when played separately, but a shrill whine of frequency 6000 Hz occurs when they are played simultaneously, estimate the operating frequency of brand X, in kHz.

Problem 7. (6 points) An anechoic chamber has walls equipped with triangular wedges, as shown to the right (to see why this is and what can happen as a result, see our website's Additional Links page and click on the video on anechoic chambers). Assuming incident sound waves have a small enough wavelength that they can be treated as rays and reflect off any surface they hit, and assuming the sound waves will be completely absorbed after hitting 5 surfaces, draw what will happen to the three incoming rays shown (it may help to draw them on separate diagrams). How likely is it that incoming sound waves will echo back?



Problem 8. (4 points) A musician standing close beside a railroad track hears the whistle blowing while a train passes her. She reports that the pitch dropped by the musical interval called a major third. As we shall learn later, this means the received frequency must have been about 12% higher as the train approached (and 12% lower as it receded) than the f_0 that would have been heard with the train at rest. How fast in mph was the train going? Assume T=20°C.

Problem 9. (4 points) You are tuning a twelve-string guitar. The last pair of strings should play E_4 notes in unison, but when you play them together, you notice a "wah wah wah" sound occurring once every one and a half seconds. If one string has a frequency of 329.6 Hz (exactly at E_4), how far off in frequency is the second string? Next, you turn the tuning peg for the second string slightly and notice the beats occurring more frequently. To get the two strings in unison, should you keep turning in the same direction, or go the opposite way?

Problem 10. (10 points) Go to the Phet simulation titled "Wave Interference" (the link is on the Additional Links page of our website). Once you have it loaded, double-click on "Interference" and play around. Once you have a feel for what's going on, decide whether the following statements are true or false:

a) As a listener moves to different points, there is more than one physical location where constructive interference (loud spot) occurs (you can probe the amount of interference at two independent locations with the graph at the top right).

b) If the distance from the listener to the wave sources is different by exactly half of a wavelength, the waves cancel out (destructive interference) at this point (the tape measure will be helpful here).

c) If the distance from the listener to the wave sources is different by exactly one full wavelength, the waves cancel out (destructive interference) at this point.

d) The distance you need to move to get from one interference minimum to the next (one quiet spot to the next) is larger if the frequency of the sound is lower.

e) If you have stereo speakers set up in your room and one speaker dies while the other continues playing the same as before, both the loudest and softest spots in the room will get softer by the same amount.

Homelab 1. (50 points) (underlined portions indicate what you need to submit on paper for this problem)

This homelab is an introduction to Raven Lite, the software we will use to record and analyze sounds. Go to the Software page of our web site and read about Raven Lite. Following the instructions, download and install the program. Find the .pdf Quick Start and User's Guides that were installed. Open and play back some of the example sounds, and work through the Quick Start Guide. (On OS X installations it is possible that you will not be able to open the example files. That's okay! Just record some sounds of your own with the microphone instead. Use the Record To File menu item and click the little green triangle at the lower left of the window to start recording. See page 11 of the User's Guide.) Have a look at the Raven Lite User's Guide so you will know where to find more detailed information if you need it later.

Once you have opened an example file or have recorded a sound, examine the upper part of the sound window. You will see a graph of the sound pressure versus time. Zoom into this window until you can see individual oscillations of the pressure (see User's Guide pp. 7-9 for details). If you zoom in even more you will see dots representing the individual samples in the sound file. Raven Lite uses a 44.1 kHz sampling rate, the same as audio CDs. The program cannot display the sound pressure directly in Pascals because it does not know the sensitivity of your microphone or the gain of the amplifiers in your computer. It represents pressure in arbitrary units that are proportional to pressure. It calls these units U or kU, where $\text{kU} = 1000 \cdot \text{U}$.

The lower part of the window is a spectrogram representing the frequencies or pitches present in the sound and how they vary with time. The x-axis of the spectrogram is time measured in seconds, the same as for the upper graph of pressure versus time. The y-axis represents frequency in Hz or kHz. Dark regions in the spectrogram show at what times a particular frequency is present in the sound. There is a cursor readout at the lower left of the main window.

Use the controls in the Play tool bar to play the sound file LarkSparrow.aif, or a sound you record. Now set the Rate to 0.2 to play the sound more slowly. This will make it easier to see how features in the spectrogram correspond with the sounds you hear. Note how lines sloping downward in the spectrogram correspond to falling pitch and lines sloping upward to rising pitch.

When you explore your own sounds it will be critical to understand the function of the Sharpness Control, or Focus (Spectrogram Window Size), in the Spectrogram tool bar. The Focus determines the number of adjacent samples the program uses to calculate the frequencies displayed in the spectrogram. The default value is 512. Try sliding the control to the left to make the value less than 512. You will see that the spectrogram becomes broader in the y-direction (frequency). This is because the frequency of a very short section of the sound cannot be determined precisely. Now slide the control to the right and notice that the spectrogram becomes sharper in the frequency direction but broader in the x-direction (time). When we try to determine the frequencies present in a longer section of the sound we can do so more accurately, but only if the frequencies do not change with time. Sounds in music, like sounds made by birds, often vary rapidly in time, so we cannot increase the Focus value too much without smearing the spectrogram. Be sure to experiment with the Focus every time you study a sound using Raven Lite.

Next you will study four notes with Raven Lite and write down your results. On your sheet to turn in, you should label these notes “whistle,” “singing,” “high,” and “low.”

First, whistle any note for about two or three seconds and record it. If you cannot whistle, use the Frequency Tone Generator on our website’s Additional Links page and set it to about 1,000 Hz. You may have to play this tone on a separate device, depending on your laptop’s microphone settings. Observe the sound in the waveform (upper) window and in the spectrogram (lower) window. In the waveform window, zoom in until you can see individual oscillations, and draw what you see (a graph of pressure versus time for a duration of ~ 0.01 seconds). Then, measure the period of your note, using the cursor. You will probably get a result in the range 1 to 10 ms (milliseconds). The cursor resolution is only 1 ms, so instead of measuring the period of one cycle, it is better to measure the period of 10 cycles and then divide by 10. This way you can get an accuracy of 0.1 ms. Write down your measured period T, including units. Then calculate the frequency using f=1/T and record the result, being careful of units. Now go back to Raven Lite and measure the frequency of your note in the spectrogram window using the cursor. To do this, zoom the frequency scale so it covers the range 0 to ~ 1.5 kHz, set the focus to about 10,000, and adjust the brightness and contrast sliders until you see thin, dark, horizontal lines in the spectrogram. If you put your cursor over this line you can read its frequency in the cursor readout at the lower left of the window. Write down this “spectrogram” frequency and see how it compares to the calculated frequency above. (Note that we usually include error estimates, like “900 $\pm$ 20 Hz”, to indicate how fuzzy our measurements are, though this is not mandatory here.)

Now, record yourself singing a note into the microphone for about two or three seconds. In the waveform window, as before, zoom in until you can see individual oscillations, and draw what you see. Depending on your voice, these oscillations are probably a bit more complicated, so instead of calculating the period and frequency of the waves, we’ll work backwards. Go to the spectrogram window, where you should see a series of parallel, horizontal lines (if not, adjust the focus, brightness, and contrast sliders until they are clear). The lowest line should be the fundamental note you sang, and the higher lines are higher harmonics. Measure the frequencies of the fundamental note and of one higher harmonic of your choosing (the more prominent, the better), and write them down. Then calculate and record the period corresponding to each note. Finally, return to the waveform window and verify that both frequencies/periods correspond to some repeating pattern in the oscillations. Mark the length of both periods on your drawing.

Finally, try to sing the highest note you can and the lowest note you can, and record yourself doing so. Then, calculate the frequency of both notes (labelling them “high” and “low”) using either the waveform window (measuring T and f for the longest repeating pattern in the oscillations) or the spectrogram window (measuring the frequency of the lowest dark horizontal line), whichever method you prefer. Check your results with the frequency tone generator to verify which frequency you were actually singing, and write down the corresponding musical notes for both the highest and lowest notes you can sing (e.g. A_3, $E^{\flat}_5$). You can find this to the right of the frequency label on the Online Tone Generator, or alternatively, you can read off notes from the chart at the bottom of our website’s Additional Links page.