Homework 5, HONS 280 (Physics of Sound and Music)
Spring 2020
Due Date – Wednesday, February 5th at the beginning of class

As always, turn your legible and complete answers in on separate paper. Remember, I can't give partial credit unless I can follow what you've done. Including words is usually a good thing for you.

Unless specified otherwise, assume the speed of sound in air is 343 m/s.

1. In class, you saw me struggle to use a 2-Liter bottle as a Helmholtz resonator. Let's play with my struggles a little bit. Assume a 2-Liter bottle has a volume of 2 Liters (obviously). (2 Liters is 2×10^{-3} m^3). Also assume the top has an area of about 4.15×10^{-4} m^2 and the depth of the opening is about 0.027 m (all accurate to the best of my ability). Note that we can lower the effective volume of the bottle by partially filling it with water (which effectively diminishes the volume of the resonator by the volume of the water included).

   a) What is the fundamental resonant frequency of the bottle when it is completely empty?

   b) The formula for the resonant frequency of a Helmholtz resonator assumes that the "air piston" composing the oscillating air in the bottle opening area has a small volume compared to the bulk of the resonating cavity. Assume that we need at least 10 times the volume in the bottle as we find in the opening to use the equation; if that's the case, what is the highest frequency we can get out of the bottle by putting liquid inside without modifying the bottle-cap area?

   c) If I did my math right, your answer to the above two questions should be accessible is the tuning note A-440 (440 Hz). How much *water* would you need to put in the bottle to obtain that frequency from the 2-Liter?

   d) All of this is interesting to some degree, but I highly doubt that if I were to put the amount of water in that we calculated in part (c) we would actually get A-440. What sorts of assumptions have we made that might negatively affect our analysis here?

2. Describe, in detail, the difference between harmonics, overtones, and partials.

3. A system has the following resonant frequencies (in Hz): 50, 222, 111, 82, 333, 267, 360, 420, 135, 37, 147. (By the way, if you combine these frequencies and listen to it – say in Audacity – it sounds horrible).

   a) What is the fundamental frequency?
   b) Identify all of the overtones.
   c) Identify all of the partials.
   d) Identify all of the harmonics.

4. What is a sympathetic vibration?

5. Our department has some meter-sticks that are hollow and take the shape of a square pipe. (If you look at them end-on, you see a square, not a circle). The side-length of the square is about 1.6 cm.

   a) What is the fundamental resonant frequency of this meter-stick (open on both ends)? (Since the end correction is not given in your text for a square cross-section, assume that for an open square cross section the total end correction (for both ends combined) is approximately 1.22 multiplied by the side length).
   b) What are the first two overtones?

6. At one point I had 4 circular pipes made of various materials in my office. (Really. We Physics folks have stuff like that sometimes). Here are their properties:

Pipe Number	Pipe Length (cm)	Pipe inner diameter (cm)
1	153	2.0
2	153	2.2
3	76	3.5
4	61	2.5

   a) Calculate the fundamental frequency of each of the four pipes (assume both ends are open to the atmosphere).
   b) Calculate the first two overtones of pipe 1 (again, assume both ends are open to the atmosphere).
   c) Calculate the fundamental frequency of pipe 3 (if one end is plugged).
   d) What would your answer to part (c) above have been if you had forgotten the end correction?
   e) Calculate the first two overtones of pipe 3 (if one end is plugged) (with the proper end correction).

7. One of the reasons that we're focusing so much on pipe resonance is that all of the wind instruments use these resonances in different ways. There's another reason we're studying them, too. Your ear can be reasonably well modeled as a pipe. Assume that the outer ear canal is a cylindrical pipe 3 cm long, closed at one end (by the eardrum). Calculate the fundamental resonant frequency of this pipe.

8. Examine Figure 5.1 in your text and comment on it, giving particular attention to the frequency you found in the previous problem. Does this make sense? Why or why not?