Physics of Music - Final Exam Review

The final exam will take place in PSCB 120 on Friday Dec 13 10:30-12:30. The final exam format will be similar to that of the midterm, with a multiple choice section followed by free-form questions. The duration of the exam will be 90 minutes.

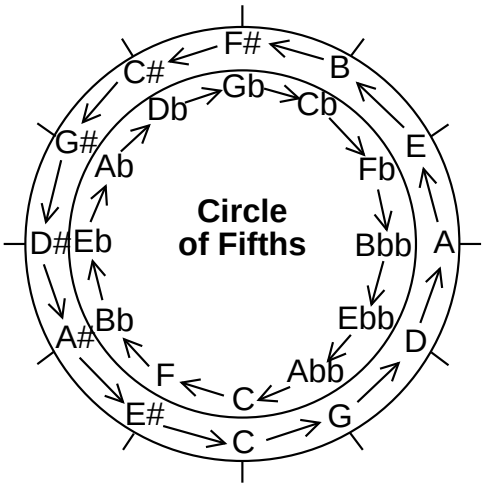
The exam will test materials from the whole course: Lecture 1–18 and Problem Sets 1–7. Lecture notes and problem sets are linked to the course web site. Examples of possible free-form questions are given below.

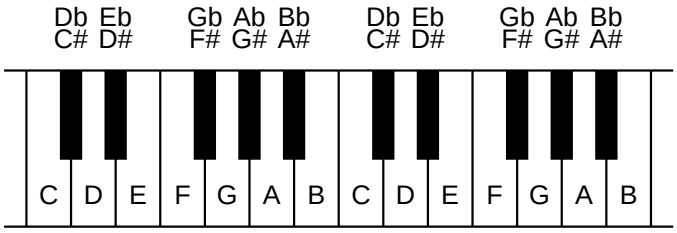
The key formulas and facts given below will be provided with the exam. No other aids are permitted in the exam. In particular, calculators are not required and not permitted.

Bring a Scantron 8000 form, a #2 pencil, and your student ID.

Formulas and Facts

- Frequency and period: $f = 1/T$
- Wave velocity, frequency and wavelength: $v = f\lambda$
- Harmonic series ($n = 1$ is first harmonic, $n = 2$ is first overtone): $f_n = nf_1$
- Boundary conditions: node at fixed end of a rope or closed end of an air column, anti-node at free end of a rope or open end of an air column.
- Musical intervals: octave (2:1), perfect fifth (3:2), perfect fourth (4:3), major third (5:4).
- Sampling limit is $f < 1/(2T)$.





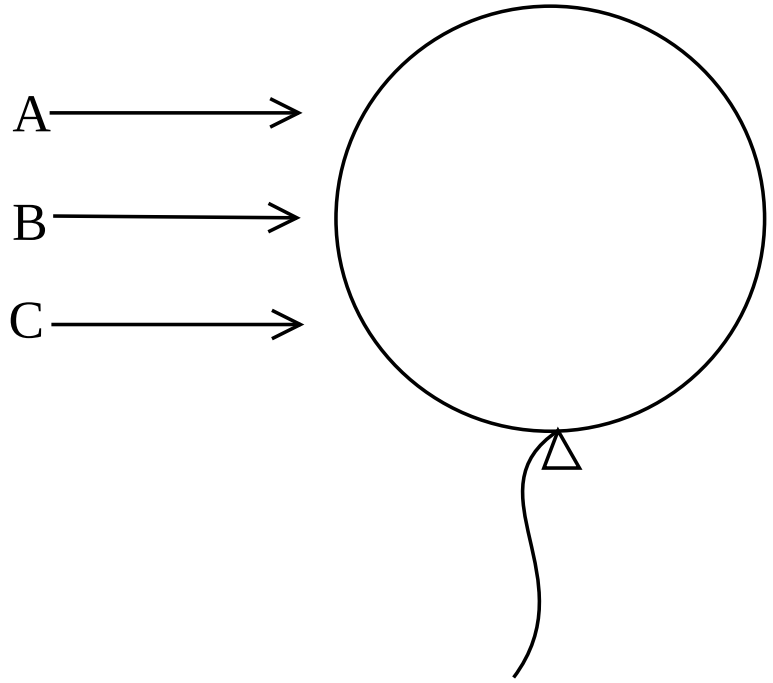
Sample Free-Form Questions

1. Suppose that a plane wave of sound is travelling towards a ballooon as shown in the diagram below. Paths A,B,C on the diagram show the directions of the sound wave front, before reaching the balloon, at three different locations.

   (a) Sketch the paths for the wave fronts A, B, C as they pass through the balloon. Assume that the ballon is filled with Helium gas in which the speed of sound is about three times faster than in air. I do not expect you to get the angles exactly right, but the general features should be correct.

   (b) Repeat the previous question but now assume that the balloon is filled with exhaled air in which some of the Oxygen has been replaced with Carbon Dioxide, giving a speed of sound that is slightly slower than in atmospheric air.

   (c) Will a person listening on the other side of the balloon hear a louder sound when it is filled with Helium or exhaled air?



2. Imagine a string of length L that is fixed at both ends, for example, on a violin or a guitar.

   (a) Sketch the five lowest-frequency standing waves of the string.

   (b) Give the wavelengths of each standing wave. Express your answer in terms of the unknown string length L.

(c) Give the frequencies of each standing wave. Express your answer in terms of the unknown speed v of transverse waves along the string.

3. Adjaceant pairs of strings on a guitar are usually tuned so that their fundamental frequencies are in the ratio 4:3 (a perfect fourth interval). Pressing down on a string with your finger creates a new node and changes the effective length of the string for vibrations.

   (a) Where should you position your finger along a string's length to raise its fundamental resonant frequency by a factor of two (one octave)?

   (b) Where should you position your finger along a string's length to raise its fundamental resonant frequency by a major third?

4. Assume that the distance between your ears is D and that the speed of sound is v.

   (a) Calculate the frequency f at which the wavelength equals the distance between your ears. Express your answer in terms of the unknowns D and v.

   (b) Calculate the time delay T between the left and right ears for sound that approaches directly from your left side. Express your answer in terms of the unknown D and v.

5. In this problem, you will calculate the frequencies of the note (E) that is a major third above C in the Pythagorean and Equal Temperament scales.

   (a) Using the circle of fifths, count how many steps up by a fifth are required to take you from C to E. What is the corresponding frequency ratio for these steps?

   (b) How many whole octaves can you shift this E down by and still be above the original C? What is the ratio between the frequency of this shifted-down E and the original C? This ratio measures the size of a major third in the Pythagorean scale.

   (c) How many semitones above C is E? What is the corresponding frequency ratio (E/C – a major third) in the equal temperament scale?

6. How does the reverberation time of a rectangular room change if all its dimensions (height,length,width) are doubled? The reverberation time RT is related to the room's volume V and effective area A by the formula

$$RT = 0.161 \frac{V}{A} \qquad (V \text{ in } m^3;\ A \text{ in } m^2)$$

7. Suppose the air column in a trombone has an effective length of L when its slide is fully retracted (at its shortest). Assume that the speed of sound is v.

(a) Calculate the fundamental frequency for a cylindrical air column of the same length that is closed and one end and open at the other end (without a bell or mouthpiece). Express your answer in terms of the unknown L and v.

(b) Suppose the slide is extended by a distance d. What is the new fundamental frequency of the trombone's air column? Express your answer in terms of L, v, and d.

(c) How far should the slide be extended to lower the note by a perfect fourth? Express your answer in terms of L.

8. A piano string receives energy from being struck by a hammer. The point along the string at which the hammer strikes influences the resulting timbre. The amount of time that the hammer makes contact with the string also influences the timbre: to a good approximation, frequencies above $2/T$ will be missing where T is the contact time.

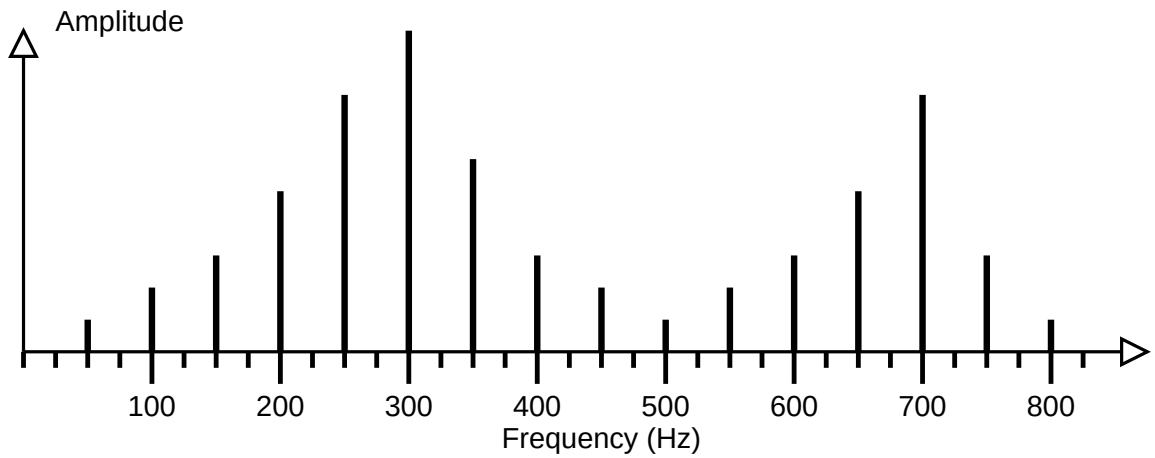
   (a) Suppose that the hammer hits the string at a point located one third of the way along its length. Which harmonics will be *missing* from the timbre?

   (b) Suppose that a note is played so that the hammer remains in contact for a time T. How long should the hammer remain in contact in order to play a note one octave higher with the same timbre?

9. The frequency spectrum below shows the timbre of a sung tone.

   (a) What frequency are the vocal chords vibrating at to produce this tone?

   (b) What are the central frequencies of the first two formants of this tone?



10. Suppose that the notes on an analog piano recording range from 50–1000 Hz. What is the minimum sampling frequency of a digital recording that will capture at least 10 harmonics of every note?