Midterm Exam

Physics of Music, Spring 2018

- This exam consists of multiple choice questions, a spectrogram matching question, several short answer questions, and a short discussion.
- Questions that require more thought to answer are worth more points.
- You may use your textbook, any of the materials posted on the course website, or any notes you have written yourself.
- You may use a calculator. If you do not have a calculator other than the one on your cellphone, you may use your cellphone to do arithmetic.
- If you want to test anything using the spectrum analyzer on your cellphone, you may do so, but please step out into the hall in order to do this. (You will need to produce any sounds with your own voice, of course!)
- You may *not* use your cellphones for anything other than:
  - Accessing the course website
  - Testing things using your spectrum analyzer
  - Doing mathematics (using the calculator app)
- Using your cellphones for anything else will be considered a violation of the Code of Academic Integrity.

1. Suppose that, from a given seat in a concert hall, the sound of a single violin player playing *forte* has an intensity of 60 dB. What would the intensity of twenty violin players playing with the same volume be?

   (a) About 70 dB
   (b) About 73 dB
   (c) About 80 dB
   (d) About 120 dB
   (e) About 1200 dB

2. A listener hears a tone of around 500 Hz that appears to fade in and out twice each second. What could produce this sound? *(There may be more than one correct answer; indicate all of them.)*

   (a) Two tones of frequencies 499 Hz and 501 Hz, one played in her left ear and one played in her right ear over headphones
   (b) Two tones of frequencies 499 Hz and 501 Hz, played on a speaker
   (c) Two tones of frequencies 500 Hz and 2 Hz, played on a speaker
   (d) A single tone of 500 Hz, whose amplitude is increased and decreased by turning up and down the volume twice per second

3. A person listens to a high-fidelity speaker system playing pure tones of 1000 Hz and 1200 Hz at high volume. Which of the following frequencies will *not* be recorded by the listener's ears?

   (a) 200 Hz
   (b) 1000 Hz
   (c) 1200 Hz
   (d) 2000 Hz
   (e) 2200 Hz
   (f) 2400 Hz
   (g) All of the above will be heard by the listener.

4. In the previous problem, why does the listener hear frequencies other than 1000 and 1200 Hz?

   (a) They are generated by the heterodyne mechanism from the nonlinear response of the mechanical parts of the human ear itself.
   (b) They are generated by the heterodyne mechanism from the nonlinear response of the speaker system.
   (c) They are an auditory illusion generated by the listener's brain.
   (d) Pure tones of a single frequency do not exist in nature.

5. Violin bows are made of very particular materials: horse hair from the tails of special horses, covered with rosin. Why is this done?

   (a) If they were made of other materials, the strings of the instrument would produce frequencies not in the harmonic series
   (b) If they were made of other materials, the instrument would not play in tune
   (c) These materials cause the bow to alternately stick and slip when drawn over the strings
   (d) This is done for historical reasons; there is no modern need for this

6. Suppose that a concert hall is partially filled with helium, so that the speed of sound is twice as fast as it is normally. What happens to the violins and flutes in the orchestra?

   (a) Nothing about the pitches that they play will change.

   (b) The flutes will sound an octave higher, but the violins will sound the same.

   (c) The flutes will sound an octave lower, but the violins will sound the same.

   (d) The violins will sound an octave higher, but the flutes will sound the same.

   (e) The violins will sound an octave lower, but the flutes will sound the same.

   (f) All of the instruments will sound an octave higher than they did before.

7. For a sound to appear to us as a musical tone, what must be true?

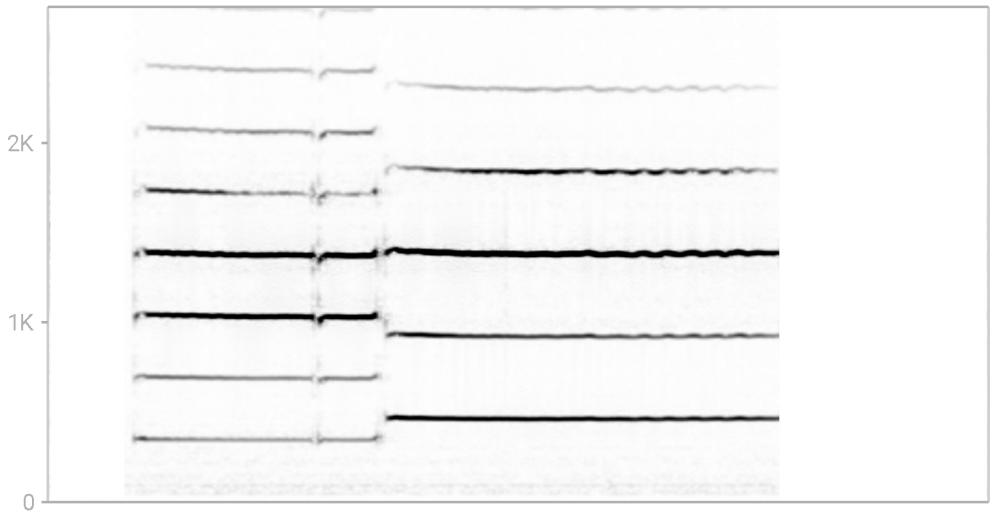
   (a) All of its frequencies must be integer multiples of the lowest frequency present.

   (b) All of its frequencies must be integer multiples of the same fundamental, whether or not that fundamental is present itself

   (c) All of its frequencies must be of the form $f = 440 \times 2^{N/12}$ Hz, where N is an integer.

   (d) None of the above

8. Here is a spectrogram showing two notes being played on a bugle, one after another.



   What is the musical interval (octave, fifth, etc.) between these two notes? Explain how you came to your conclusion.

9. Here are some spectrograms. (I have removed extra bits using a photo editor and reversed the colors from what you are used to seeing for ease of printing.) The sounds are:

   (a) A large choir of both men and women, singing a chord with many different notes in it

   (b) A man singing a solo in an operatic style, with significant vibrato, accompanied by a quiet orchestra.

   (c) The (un-musical) clanging of a church's bell

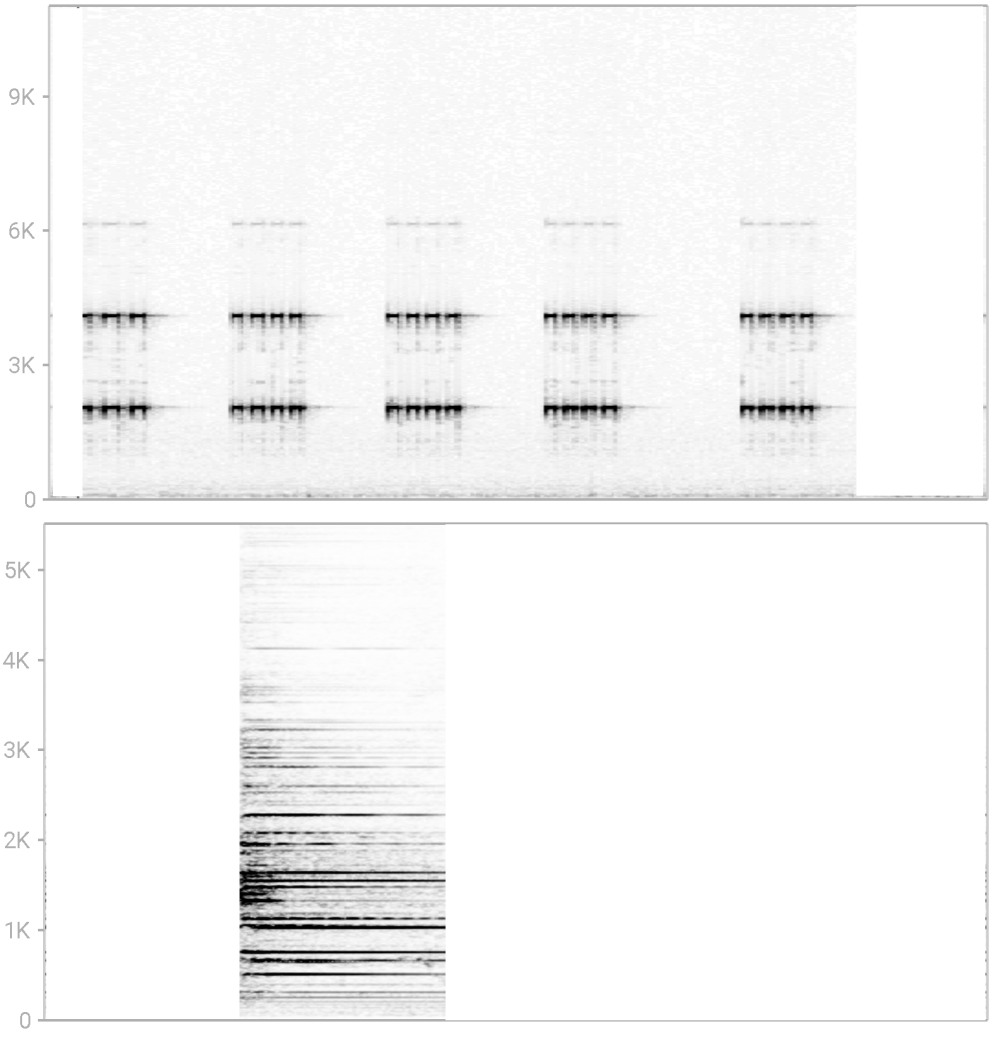
   (d) A cat meowing

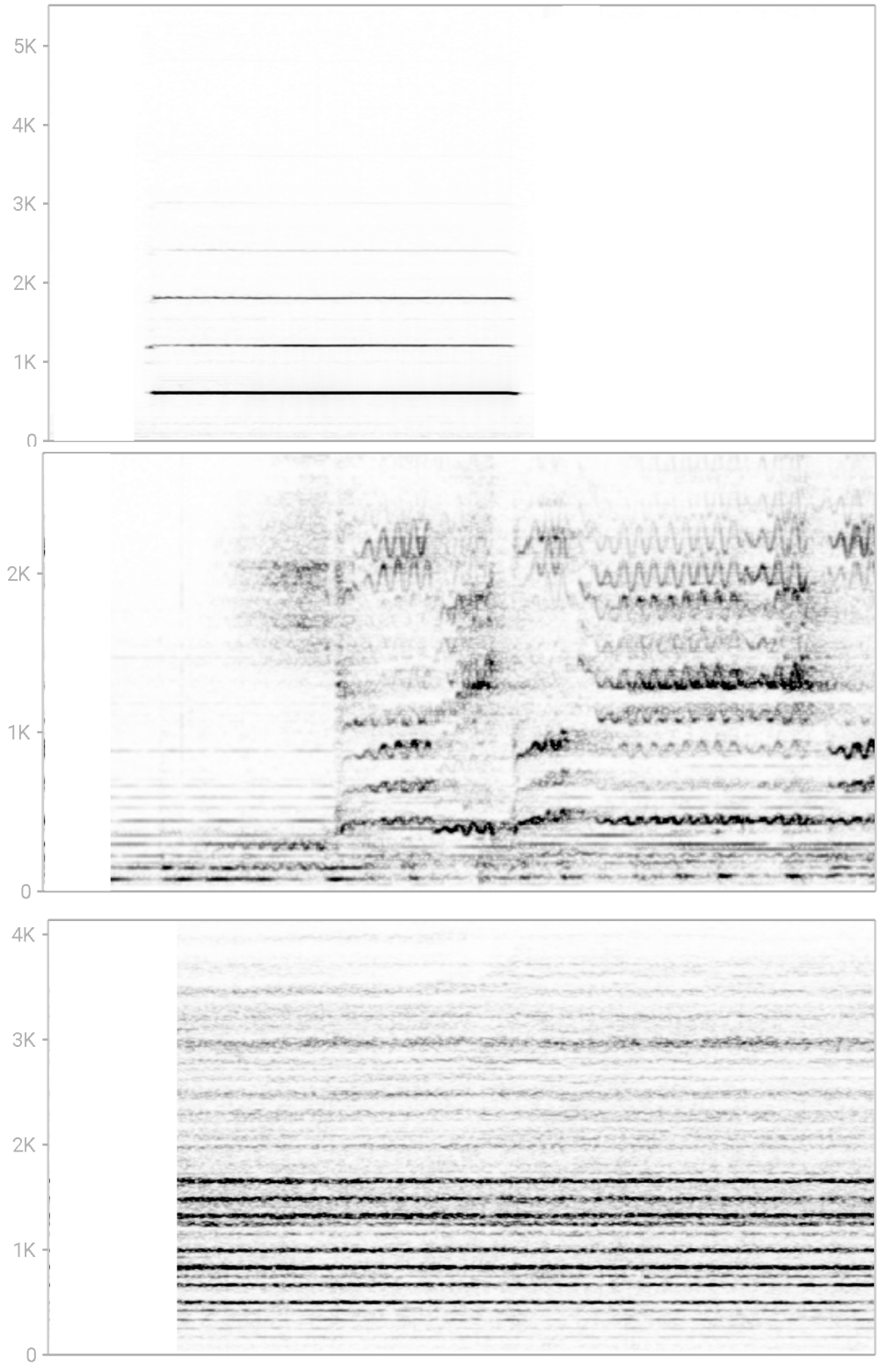
   (e) The beeping of an alarm clock

   (f) A single note being played on a flute

   (g) A single note being played on a trumpet

   Indicate which spectrogram goes with which sound. (Note that, upon consideration, I've decided not to play the sounds in class. This would not be that useful and would be logistically difficult.)

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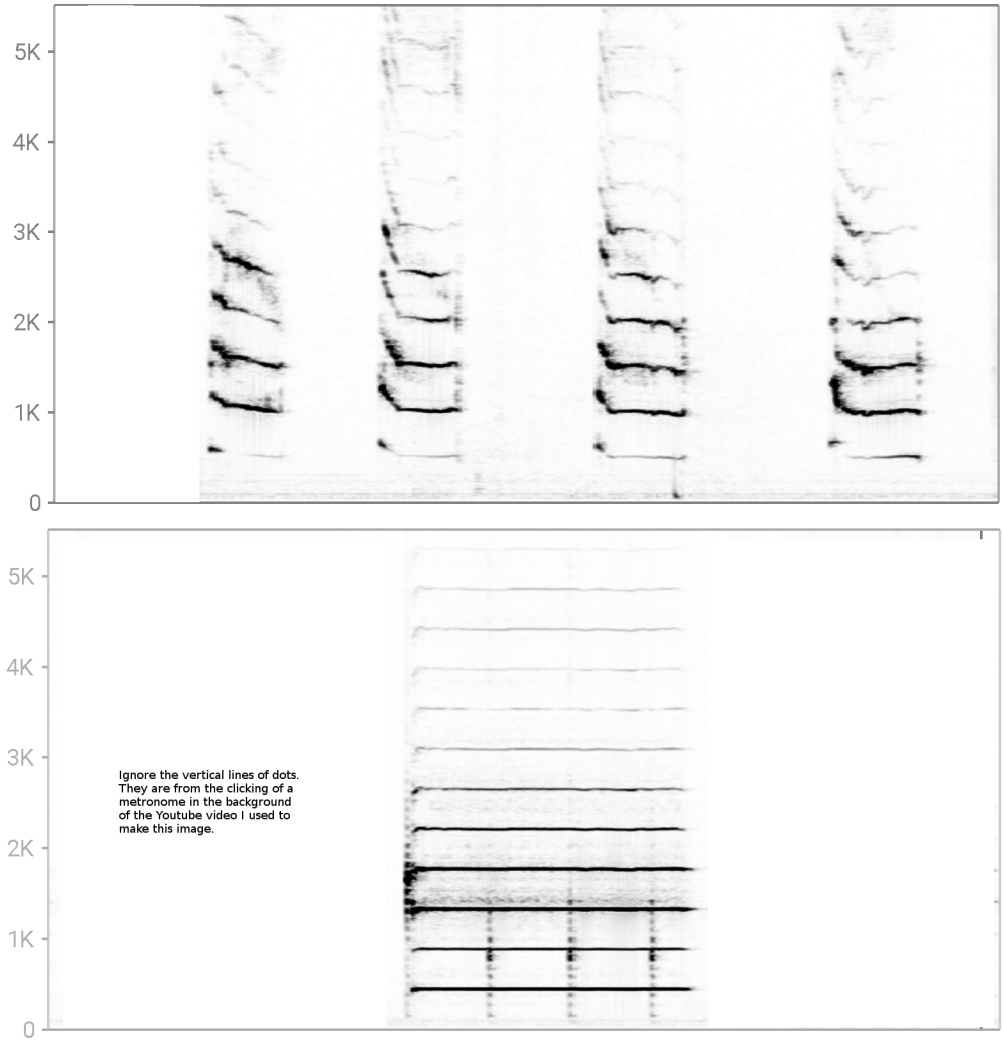
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Ignore the vertical lines of dots. They are from the clicking of a metronome in the background of the Youtube video I used to make this image.

10. The second-lowest string on a guitar is tuned to the note A_2, and has a tension of 80 newtons.

    (a) Suppose that you want to play this guitar along with a modern orchestra. To what frequency should you tune this string? (The reference in modern music is $A_4 = 440$ Hz.)

    (b) Now, suppose that you want to play this guitar with a Renaissance-music ensemble, where the reference pitch is $A_4 = 415$ Hz. Thus, you need to retune this string. Calculate the new tension that you should apply to it.

11. A clarinet plays the note E_4. Note that a clarinet is, essentially, a cylindrical pipe that is closed on one end.

    A guitarist also plays this note in a strange way, by plucking the top string on the guitar exactly in its center. (Normally guitar strings are plucked near the end.)

    You hear a strange similarity in the timbre of these two notes; in particular, the guitar sounds strangely "hollow", in the same way that the clarinet does.

    When you look at these sounds on a spectrogram, you observe the following frequencies: 330 Hz, 990 Hz, 1650 Hz, 2310 Hz, 2970 Hz. In other words, they produce only odd-numbered harmonics.

    (a) Draw diagrams of the lowest five vibration patterns for the guitar string. Then explain why the even-numbered ones are missing when the string is plucked precisely in its center.

    (b) Now draw diagrams of the lowest three vibration patterns for the clarinet (a closed/open pipe). Using these diagrams, explain why the even-numbered harmonics (for instance, 660 Hz and 1320 Hz) are missing for the clarinet.

(Use the entire next page for your diagrams.)

(Answer problem 11 on this page.)

12. Two musicians are arguing over the tuning of a harpsichord (an ancestor to the piano). They've decided to tune a reference note (suppose it is C_4) to 400 Hz.

    The first one, Antonio[1], argues that the note E_4 should be tuned precisely to $400 \times \frac{5}{4} = 500$ Hz. He claims that this is the superior choice because it matches the pattern of the harmonic sequence.

    The second one, Johannes[2], argues that the note E_4 should be tuned to $400 \times 2^{4/12} = 504$ Hz. He claims that this is the superior choice because it makes all intervals on the keyboard the same length.

    In short, Antonio wants all of the major thirds to have a ratio of 5/4; Johannes wants them to have a ratio of $2^{4/12}$.

    This gives the following values for the first few harmonics of each note. (This is useful in answering part (b), found on the next page.)

Harmonic number	C4	E4 (Antonio)	E4 (Johannes)
1	400	500	504
2	800	1000	1008
3	1200	1500	1512
4	1600	2000	2016
5	2000	2500	2520

    (a) Calculate the frequencies of $G_4^\sharp$ and C_5 using the definition of the major third adopted by each person. What does Antonio want C_5 to be tuned to? What does Johannes want it to be tuned to?

[1] Antonio Vivaldi, 18th-century Italian composer
[2] Johannes Sebastian Bach, 18th-century German composer

(b) Discuss (in a paragraph) the relative merits of their methods. (You will recognize Johannes' method as equitempered tuning, and Antonio's method as harmonic-sequence-based tuning.)