Solutions for PY231 Test 1, Spring 2003

1a) 4 Define resonance. (Point totals for each part are in italics)

Resonance is the large enhancement in the vibration amplitude of an oscillator when it is driven at or close to its natural frequency.

1b) 6 Give two examples of resonance, at least one of which taken from a musical situation. Identify what provides the driving force and why the response is frequency dependent. An emphasis on the frequency dependence is essential. Musical: when you are in a practice room, and for a certain note the light fixture vibrates, but it does not for any other note. When you change notes, the frequency changes. When the frequency of your note matches the frequency the light fixture wants to vibrate with, the sound waves will provide a driving force of the correct frequency.

NonMusical: In a propeller airplane, when the engine revs up to full speed, or when the engine is shut down and it goes from full speed to off, the whole cabin of the plane will shake at a certain engine speed. I have noticed this pronounced resonance on several models of propeller planes on which I have flown.

2a) 8 The two frequencies 900 Hz and 1000 Hz are sounded together. Give the simplest heterodyne components which are present if they are loud enough to make the ear’s response nonlinear.

\[ f_1 + f_2 = 1900 \text{ Hz}, \quad f_2 - f_2 = 100 \text{ Hz}, \quad 2f_1 = 1800 \text{ Hz}, \quad 2f_2 = 2000 \text{ Hz} \]

2b.i) 2 List all the frequencies which will be in the sound, including the simplest heterodyne components and the original frequencies.

100, 900, 1000, 1800, 1900, 2000 Hz

2b.ii) 2 What is the fundamental of the harmonic series to which these frequencies belong?

100 Hz

2b.iii) 4 List which of the the first 20 harmonics which are present in the sound (only their numbers, not frequencies), and the numbers of the missing harmonics.

<table>
<thead>
<tr>
<th>Present</th>
<th>Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 9, 10, 18, 19, 20</td>
<td>2-8, 11-17</td>
</tr>
</tbody>
</table>
2c) 8 Please indicate the first 16 harmonics of the harmonic series based on C2 on the musical staff below. Indicate which are “badly out of tune” with our usual convention of pitches, i.e. to indicate the “out of tune harmonics” use quarter notes.

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\begin{center}
\begin{tikzpicture}
  \draw \foreach \i in {1,...,16} { (\i*360/16:1cm) -- (\i*360/16+360/16:1cm) };
  \foreach \i in {1,...,16} { (\i*360/16:1cm) node {\i} };
\end{tikzpicture}
\end{center}
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2d) 6 Suppose a $C_4$ and $G_4$ are sounded together. Use the harmonic series you have written down to give the notes associated with the sum and difference tones.

Since the frequencies of the notes in the harmonic series are proportional to the harmonic number, $f_n = nf_1$ where $n$ is the harmonic number, and $f_1$ the the frequency of the fundamental of the harmonic series, we can replace the sum (difference) of frequencies with a sum (difference) of harmonic numbers. Thus $C_4$ is the 4th harmonic, and $G_4$ is the 6th, so the sum is $4 + 6 = 10$ which means that the 10th harmonic, $E_5$ is the sum tone, and $|4 - 6| = 2$ and the 2nd harmonic, $C_3$ is the difference tone.

3a) 4 How is intensity related to the amplitude of a wave?

The intensity is proportional to the amplitude squared

3b) 8 Tell whether the following pairs of sound sources are coherent or incoherent. Use C or I to indicate your answer.

i) Two clarinet players I

ii) A trumpet player and a horn player I

iii) A trumpet player and her echo off a side wall. C

iv) The sound from a person’s mouth and the output from a speaker part way back in the room which is part of a sound system. C
3c) If two incoherent sounds with identical SILs of 30 dB are sounded together? $33 \text{ dB}$

3d) Answer 3c if the sounds are coherent and in phase. $36 \text{ dB}$

4.) The Fletcher-Munson Curves are shown below.

4b) A signal generator which produces a sine wave (single component sound) is connected to an amplifier which drives a speaker so that you can hear it. It is set to 1000 Hz, and the sound level is adjusted to 30 dB. Answer the following questions with either SA for same, L for louder or SO for softer for the frequency changes listed below.

i) If the frequency is changed to 100 Hz. SO

ii) If the frequency is changed to 3000 Hz. L

iii) If the frequency is changed to 500 Hz. Almost the SA, but slightly L

iv) If the frequency is changed to 10,000 Hz. SO

4c) Now answer 4b if the intensity level is 80 dB.

i) If the frequency is changed to 100 Hz. SO

ii) If the frequency is changed to 3000 Hz. L

iii) If the frequency is changed to 500 Hz. L

iv) If the frequency is changed to 10,000 Hz SO

5a) The piano keyboard covers a frequency range of 27.5 Hz to 4186 Hz for the fundamental frequency of the harmonic series associated with the notes. Tell why it makes no musical sense to continue the keyboard much beyond 4 kHz. The JND for pitch discrimination rapidly increases above this frequency. n.b. This does not mean that you can’t hear these higher frequencies, it means that you would have trouble distinguishing individual notes.

5di) Define Place theory. The theory of pitch perception which states that different places on the basilar membrane are excited by different frequencies, so that the brain can tell which pitch is present depending on where the nerve hairs are excited by movement in the basilar membrane.

di) Define Fundamental Tracking. This is the phenomenon that when presented with a complex tone, if the partials are close to a harmonic series we will perceive a pitch for
this sound which is the fundamental of the harmonic series. If the partials are not close

to members of a harmonic series, then there will be a much more ambiguous sense of
pitch for the sound.

6a) Consider a trumpet held in the hands of a player. Unfortunately he is surprised
by the tympani player sitting behind him, and lets go of the trumpet. In terms of
energy (potential and kinetic) describe what happens next. After the incident is over,
the energy of the trumpet has changed. Where did the energy go? In the player’s
hands, the trumpet has a potential energy relative to the floor. Once dropped, it
will accelerate towards the floor, with the potential energy being converted to kinetic
energy by gravity. The instant before it hits the floor its energy will be entirely kinetic.
When it hits the floor, some energy will go into deforming the trumpet, and the rest
will be lost in the forms of heat and sound.

6b. You wait too long to get tickets to hear the string quartet in residence at Lower
Mudsplash University. When you finally get to the box office you discover that only
one seat remains, one that is just behind a pillar which is 0.344 m in diameter. Please
answer the following questions about this unfortunate seat.

6b.i) What is the frequency of a sound which has a 1 m wavelength in dry air at 20° C?
\[ f = \frac{v}{\lambda}, \text{ so } f = 344 \text{ Hz}. \]

6b.ii) What frequency does a wavelength of 0.344 m correspond to. using the formula
above, \( f = 1000 \) Hz.

6b.iii) Given this information, describe what the sound will be like in this choice seat.
(Consider only sound which comes directly from the performers in answerieing this
part). The longest wavelengths will diffract around the post, while the short wave-
lengths will only diffract at the edge, and there will be an acoustic shadow for the
shortest wavelengths. Since size of the obstruction determines the wavelength at
which things begin to change from diffraction to a shadow, at 1000 Hz the shadow
effect will start to become dominant. This means that the low and midrange sounds
will be heard (with reduced intensity compared with a seat where there is no ob-
strution) and the very highs (which we need to have reasonable fidelity) will be
largely absent. You probably would be better off staying at home and listening to a recording.

6b.iv) What other effects will at least help mitigate the bad sound you might expect in this seat? Fortunately diffraction from other obstructions, and the heads of the audience, along with reflections from walls, etc. will help to fill in the sound. Any musically sophisticated listener will not be pleased with the sound in this seat.