

Policies and Review Topics for Exam #2

The following policies will be in effect for the exam. They will be included in a list of instructions and policies on the first page of the exam:

1. You will be allowed to use a non-wireless enabled calculator, such as a TI-99.
2. You will be allowed to use two 8.5 × 11-inch two-sided handwritten help sheets and a sheet of graphs and formulas that I will provide to you. No photocopied material or copied and pasted text or images are allowed on the self-prepared help sheets. If there is a table, formula, or image from the textbook or some other source that you feel would be helpful and that is not included on the sheet that I will provide to you, please notify me.
3. All help sheets will be collected at the end of the exam but will be returned to you either immediately or soon after the exam.
4. Use of a help sheet that is not completely handwritten will result in an automatic 5-point score reduction. Help sheets that are handwritten on a tablet and then printed are acceptable.
5. If you begin the exam after the start time, you must complete it in the remaining allotted time. However, you may not take the exam if you arrive after the first student has completed it and left the room. The latter case is equivalent to missing the exam.
6. **You may not leave the exam room without prior permission except for an emergency or for an urgent medical condition. Please use the restroom before the exam.** If you are allowed to leave the room, you must leave your cell phone behind. Only one student at a time may be absent from the room.

The exam will begin at 4:00 pm on Friday, March 27 in Breakiron 264. You will have until 5:50 pm to complete the exam.

The following is a list of topics that could appear in one form or another on the exam. Not all of these topics will be covered, and it is possible that an exam problem could cover a detail not specifically listed here. However, this list has been made as comprehensive as possible. **You should be familiar with the topics on the review sheet for the previous exam as well.**

Although significant effort has been made to ensure that there are no errors in this review sheet, some might nevertheless appear. The textbook is the final authority in all factual matters, unless errors have been specifically identified there. You are ultimately responsible for obtaining accurate information when preparing for exams.

Structure of inner ear

- ear canal (closed pipe resonance around 3 kHz) and eardrum
- ossicles (inner bones), commonly called the hammer, the anvil, and the stirrup

- cochlea
 - o oval window (pressure is 30 times that of eardrum)
 - o long tube wound into a spiral
 - o tube is split into two chambers or canals
 - o large “upper” canal is the scala vestibuli; it is connected to the oval window; large “lower” canal is the scala tympani; s. vestibuli and s. tympani are connected together at the far end of the cochlea; both scala are filled with fluid
 - o separating the canals is a complex structure that combines the basilar membrane, the cochlear duct, Reissner’s membrane, and the organ of Corti
 - o organ of Corti contains different types of hair cells that appear to be sensitive to different audio frequency ranges
- critical bands
 - o each critical band is a range of frequencies over which the same section of the basilar membrane (with the hairs of the organ of Corti) is mostly active
 - o about 24 critical bands span the audio spectrum (20–20,000 Hz)
 - o roughly 100 Hz wide below around 500–1000 Hz; proportional to frequency above 1 kHz
 - o play a significant role in the perception of pitch and other sound properties

Pitch fundamentals

- For single tones, pitch is essentially determined by frequency, although pitch can be affected slightly by loudness, duration, and “attack” (how the sound wave evolves over time).
- Complex tones (i.e., sounds consisting of tones at different frequencies) have pitches that are affected by a wide range of factors.
- Just-noticeable difference (jnd) in pitch is the minimum difference between pitches that a human can perceive; the jnd is roughly 1/30 the critical band at any given center frequency (see Fig. 7.2)
- Pitch varies slightly with sound level (see Fig. 7.3)
- Pitch takes longer to perceive at low frequencies than at high frequencies, although the time required is only about a dozen to a few dozen milliseconds (see Fig. 7.3)
- Virtual pitch: If a complex sound consists of a series of harmonically related frequencies, the pitch will correspond to the fundamental frequency, even if the tone at the fundamental frequency is missing (if the fundamental is a few hundred hertz).

Definitions of partial, harmonic, fundamental, periodic wave

Pitch standards

- seem to have been relatively stable during Renaissance (not much known about them before that) but rose considerably during 1700s and especially 1800s, probably because of widespread acceptance of brass instruments in orchestras
- standard frequency of A₄ (A above middle C):
 - o ~424 Hz in early 1600s
 - o ~422 Hz in time of Bach, Handel, Haydn, Mozart, and Beethoven
 - o Defined as 435 Hz by 1859 French commission
 - o “Scientific pitch” introduced in early 1900s; based C in consecutive octaves on powers of 2 (e.g., 128 Hz, 256 Hz, 512 Hz, etc.); A₄ is 427 Hz
 - o Defined as 440 Hz by 1939 international conference
 - o Time standard station WWV transmits a 440 Hz tone once per hour

Timbre

- Overall tone quality or tone “color” of a sound; it is the collective set of characteristics that help identify the type of sound and, often, its source
- Timbre depends mostly on frequency content (sound spectrum), but it can be affected by loudness and location within the spectrum
- Fourier analysis is the mathematical method of examining the spectrum of a sound.
- If the sound is periodic (i.e., the waveform repeats after a finite amount of time called the period T), then it can be represented as a Fourier series. If $p(t)$ is a periodic sound pressure wave as a function of time t , then the Fourier series representation is

$$p(t) = \sum_{n=1}^{\infty} [A_n \cos(2\pi n f_1 t) + B_n \sin(2\pi n f_1 t)],$$

where A_n and B_n are constants and f_1 is the fundamental frequency, which determines the pitch of the sound and is equal to $1/T$.

- For this course, it is enough to know that when a musical instrument plays a note, it produces a sound with a fundamental frequency and several harmonics. Thus, only the first dozen or two dozen harmonics in the Fourier series primarily determine the timbre of the sound.

Combination tones and harmony

- Beats:
 - o amplitude wavering effect when two tones that are close in frequency are generated
 - o a linear effect, meaning that no new tones are generated by the sound source or within the human ear
 - o mathematical representation (two sinusoids are added to produce a product)

$$p(t) = A \cos(2\pi n f_1 t) + A \cos(2\pi n f_2 t) = 2A \cos \left[2\pi \left(\frac{f_1 - f_2}{2} \right) t \right] \cos \left[2\pi \left(\frac{f_1 + f_2}{2} \right) t \right]$$

where f_1 and f_2 are two different frequencies (in Hz). Example: if the two tones are at 850 Hz and 858 Hz, an 8 Hz amplitude beat will be heard at the average frequency of 854 Hz.
 - o If the two frequencies are more than 10–15 Hz but less than a critical bandwidth apart, two separate tones (pitches) will usually be discernable, but the combination will have additional roughness
 - o If the two frequencies are more a critical bandwidth apart, two separate tones (pitches) will be easily discernable with no additional roughness
- Difference tones:
 - o a nonlinear effect, meaning that tones are generated at new frequencies beyond the original two tones at frequencies f_1 and f_2
 - o primarily an effect of the human auditory system; that is, they are mostly not produced by musical instruments (although they can be in some cases)
 - o quadratic (2nd-order) tones: $|f_1 - f_2|$
 - o cubic (3rd-order) tones: $|2f_1 - f_2|$ and $|f_1 - 2f_2|$
 - o higher-order (4th, 5th, 6th, etc.) tones can also be generated but loudness usually drops quickly with increasing order
 - o “Sum” tones (for example, at $f_1 + f_2$ or $2f_1 + f_2$) are not usually heard

- Amplitude modulation:
 - mathematical representation (two sinusoids are multiplied to produce a sum)

$$p(t) = A \cos(2\pi n f_1 t) \cos(2\pi n f_2 t) = \frac{A}{2} \cos\left[2\pi\left(\frac{f_1 - f_2}{2}\right)t\right] + \frac{A}{2} \cos\left[2\pi\left(\frac{f_1 + f_2}{2}\right)t\right]$$
 where f_1 and f_2 are two different frequencies (in Hz)
 - The two original frequencies do not have to be close together for the effect to be evident
 - The new frequencies generated ($|f_1 - f_2|$ and $f_1 + f_2$) are easily discernable and, of course, very different from f_1 and f_2
- Consonance and dissonance
 - Consonance is the subjective sense of “harmoniousness;” dissonance is the subjective sense of two tones “fighting” each other and possibly producing an almost buzz-like sound
 - Dissonance is not necessarily bad – the psychological tension it produces in music can evoke darker emotional responses that are vital in artistic expression
 - Importance of Figs. 5.10 and 8.15 in the textbook
 - Critical bandwidth of the ear plays a vital role in determining level of consonance
 - Some musical intervals are more consonant than others, primarily because of the differences in frequency of their partials (harmonics); however, very low frequency intervals can be very dissonant if the differences in their fundamental frequencies is a small fraction of the critical bandwidth
 - Triads (chords) can sound somewhat or very dissonant if the intervals that they contain are dissonant; moreover, slight mistunings (possibly due to use of equal temperament) can cause beating
- Beats of mistuned consonances
 - Beating between two tones that have a frequency ratio that is not a perfect integer ratio; fundamental relationship:

$$f_2 = \frac{n}{m} f_1 + \delta$$
 where n and m are integers that express the frequency ratio required for a perfect interval (e.g., $n/m = 3/2$ for a perfect fifth), and δ is the error frequency
 - If f_1 and f_2 do not form a perfect interval reducible to a ratio of integers, then a listener will hear beating at the frequency $m\delta$, where m is the same integer that appears in the formula above; mathematical proof:

$$f_2 = \frac{n}{m} f_1 + \delta \rightarrow \delta = f_2 - \frac{n}{m} f_1 \rightarrow m\delta = m f_2 - n f_1$$
 - If negative value of δ is obtained, it just means that the actual upper frequency f_2 is below what it should be for a perfect interval; the number of beats per second heard (equal to $m\delta$) is the same whether δ is positive or negative

Musical Scales and temperament

- Pythagorean scale
 - o Originated in 500s BCE with Pythagoras and his followers
 - o Based on circle of fifths (and fourths)
 - o Raising a tone by a perfect fifth is the same as lowering it by a perfect fourth after adjusting for the change in octaves
 - o Major disadvantages are mistuning of thirds and progressive mistuning that occurs after successively raising by fifths; e.g., raising a note by fifths 12 times should produce the same note seven octaves higher, but
$$\left(\frac{3}{2}\right)^{12} f_{\text{start}} \neq 2^7 f_{\text{start}} \text{ (It's close, though.)}$$
- Just intonation scale
 - o Corrects many flaws in the Pythagorean system
 - o Most (but not all) major and minor thirds have the correct frequency ratios
 - o The I, IV, and V triads (major chords) have perfect 4:5:6 frequency ratios
 - o Classic 12-bar blues musical style uses the I, IV, and V chord progression
 - o Major disadvantages are that transposition (changing from one scale to a different scale for the same piece of music) causes noticeable mistunings of all of the intervals in the new scale; requires retuning of the instruments to change scales, which is very difficult or impossible for some instruments, such as pianos and organs
- The Western chromatic scales contain all 12 notes in an octave, including all sharps and flats; e.g., the C chromatic scale is:
C C[#] D D[#] E F F[#] G G[#] A A[#] B C
 - o semitone = interval between each note in the chromatic scale
 - o whole step = two semitones
 - o half step = one semitone

Relevant course material:

- HW: #3 and #4
Readings: Assignments from Feb. 11 through Mar. 16
Web Links: Overview of the Cochlea
"Inner Ear" (Wikipedia)
Wave Interference and Beat Frequency (Academo.org)
Amplitude Modulation (Academo.org)