UNIV 213 Science & Engineering of Music & Sound Spring 2026

Policies and Review Topics for Exam #3 (revised 4/16/26)

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 three 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, April 17 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 sheets for the previous exams 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.

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

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

  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 tonal (not percussion) musical instrument plays a note, it produces a sound with a fundamental frequency and several harmonics. The relative intensities of the various harmonics play an important role in determining timbre. Only the first dozen or so harmonics in the Fourier series are significant (the higher-order harmonics are either too weak or too high in pitch to hear).

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

- semitone = interval between each note in the chromatic scale
- whole step or whole tone = two semitones
- half step = one semitone

Scale of equal temperament

- a compromise scale; most of the important intervals are not perfect, but all of them are close enough not to be objectionable to most listeners
- based on maintaining a perfect 2:1 frequency ratio for the octave and on the semitone (smallest) interval having a frequency ratio of $2^{1/12}$
- mathematical basis: the frequency ratio corresponding to the semitone is the same for all 11 intervals (between the 12 notes) in the chromatic scale; if f_{start} is the frequency of the first note of a scale and r_s is the frequency ratio corresponding to one semitone:

  $$(r_s)^{12} f_{\text{start}} = 2 f_{\text{start}} \quad \rightarrow \quad (r_s)^{12} = 2 \quad \rightarrow \quad r_s = 2^{1/12}$$

- major advantage is that all keys played on an instrument sound equally (although not perfectly) in tune; allows straightforward transcription from one key to another
- another major advantage is that the frequency of any note can be found by counting octaves and semitones from the standard frequency of A_4 (440 Hz) and then multiplying multiple times by 2 or 1/2 for octave changes and by $2^{1/12}$ or $2^{-1/12}$ for semitone changes

The cent (¢) interval unit **[this section added 4/16/26]**

- 1 cent = $2^{1/1200}$, which equals $(2^{1/12})^{1/100}$ (the hundredth root of a semitone)
- The cent is a more convenient unit for expressing small musical intervals than frequency ratios.
- There are 100 cents per semitone and 1200 cents per octave.
- conversion formulas (*R* = frequency ratio; *I* = interval in cents):

  $$R = 2^{I/1200} \quad \rightarrow \quad \log(R) = \log\left(2^{I/1200}\right) = \frac{I}{1200}\log(2) \quad \rightarrow \quad I = \frac{1200\log(R)}{\log(2)}$$

- example perfect interval frequency ratios and their equivalent intervals in cents:
  - perfect fifth: *R* = 3/2, *I* = 702¢
  - perfect fourth: *R* = 4/3, *I* = 498¢
  - major third: *R* = 5/4, *I* = 386¢

String instruments (Chap. 10)

- tuning of strings in violin, viola, cello, and bass
- tuning of strings in guitar and bass guitar
- resonant frequency of a vibrating string (see Sec. 4.3 of textbook)
  - $f_n = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$,
  - where *n* = index of harmonic frequency (fundamental corresponds to *n* = 1), *L* = length of string between fixed ends (m, meters); *T* = tension on string (N, newtons), *m* = mass per unit length (kg/m, kilograms per meter)
  - *n* = 1, 2, 3, … (i.e., all harmonics can be present)
- vibration due to plucking strings
  - initial shape of string (before pluck is released) is triangular
  - when pluck concludes (at the instant of release), the peak of the triangle splits into two peaks that propagate in opposite directions along the string
  - propagating peaks are reflected at the fixed ends of the string; the reflected peaks point in opposite direction of incident peak (e.g., if incident peak was up, reflected peak will be down); sometimes called “inversion” or “180° phase shift”
  - sound spectrum (relative strengths of harmonics) depends on where string is plucked; plucking at specific locations suppresses specific harmonics
- vibration due to bowing strings
  - as with plucking, the shape of a bowed string is essentially triangular, but only one peak propagates up and down the string instead of two counterpropagating peaks
  - bowing is characterized by alternating periods of sticking and slipping between bow and string
  - during sticking, the part of the string touching the bow moves with the bow because of friction
  - during slipping, the string moves in the opposite direction of the bow; the restoring force of the string points in the opposite direction of the bow’s motion; the force is strong enough to overcome friction and slide the string along the bow
  - transitions between sticking and slipping occur as the peak of the propagating triangle passes through the bowing location
  - as with plucking, the fundamental vibration frequency of a bowed string is determined by the length, tension, and mass per unit length, not the location of the bow along the string
  - as with plucking, bowing generates harmonics in addition to the fundamental frequency, but the relative strengths of the harmonics are different; thus, bowing results in a different timbre than plucking
  - loudness of bowed string is determined primarily by the bow speed and the location of the bow relative to the bridge, not by bowing force
- most of the sound from an acoustic string instrument (e.g., violin, classical guitar) comes from the body, not from the strings, and from the hole in the body; the vibrations of the strings transfer to the body through the bridge; the body then radiates most of the sound

- body of a string instrument has many vibration modes; they can be revealed by observing Chladni patterns
- movement of air in and out of the hole(s) in the instrument's body enhances the low-frequency spectrum via the Helmholtz cavity resonances (resonant frequencies of an enclosed space)
- cross-bracing on an acoustic guitar's top plate affects its resonant frequencies
- sound from an electric guitar is mainly obtained via the pick-ups located under the strings; the body resonances are far less important; in fact, many electric guitars do not have hollow bodies; two or three pick-ups are used to sample all of the vibration modes of the strings because one pick-up location might be a vibration node or "dead spot"
- guitar pick-ups are usually made with a permanent magnet placed under the string and a coil around the magnet; when the string vibrates, it disturbs the magnetic field so that it varies with time instead of being static; the coil picks up the time variations in the magnetic field; the induced electrical current/voltage in the coil vary in step with the vibration of the string
- a humbucking pick-up uses two adjacent coils with counterwound turns (i.e., one wound clockwise and the other counterclockwise) to cancel the ambient magnetic fields (usually from 60 Hz power in the building) in the vicinity of the pick-ups
- electric bass guitar has only four strings tuned to E_1, A_1, D_2, and G_2; it has a longer fretboard than a standard electric guitar (usually 90 cm vs. 65 cm)
- guitar strings are often made a little long to compensate for the increased tension caused by the guitar frets when a string is pressed down to the fretboard

Brass instruments (Chap. 11) **[restructured 4/16/26]**

- resonant frequency of a closed cylindrical pipe (see Sec. 4.5 of textbook)

  $$f_n = n\frac{v}{4L}, \quad n = 1, 3, 5, \ldots$$

  where n = index of harmonic frequency (fundamental corresponds to n = 1) and the indices are *odd* integers, L = effective length of pipe (in meters); v = speed of sound at the ambient temperature (in meters per second)
- acoustic impedance:
  - a measure of the ability of a medium to allow sound to pass through it
  - defined as the ratio of the pressure at some location to the volume flow rate of the medium (usually air in the case of musical instruments) at the same location
  - for a given pressure level, a medium with a high acoustic impedance will not allow the air particles to flow very easily whereas the air particles in a medium with a low acoustic impedance flow much more easily
  - the acoustic impedance within a pipe driven by sound waves at one end varies along the length of the pipe because of the reflected waves from opposite end
  - the combination of the incident and reflected waves causes periodic variations in compressed and rarefied air along the pipe (a standing wave pattern)
- generating sound in brass instruments:
  - player "buzzes" their lips (forces them to vibrate) inside the mouthpiece, which causes puffs of air to be released into the instrument at a very high rate (hundreds of puffs per second)
  - the puffs of air create pressure waves, which are reflected at the opposite end (the bell)

    - the reflected waves interact with the player's vibrating lips, causing the frequency of the vibration to match the timing of the reflected waves
    - the result is that the vibration of the lips is supported by the instrument at a specific frequency and its harmonics
    - frequencies of vibration match frequencies of peaks in the acoustic impedance spectrum at the mouthpiece
    - most of the sound energy is contained within the instrument; only a small fraction of the sound energy is released through the bell per unit time because most of the sound energy that arrives from the mouthpiece is reflected back toward it
    - the sound pressure level within a brass instrument would be ear-splitting if a person could experience it
- flared bell of brass instruments
    - changes the frequency and height of the peaks in the acoustic impedance spectrum; the effective length of the instrument increases with frequency because of the bell
    - changes the directionality of the sound from the instrument; high frequencies are loudest in the direction that the bell is pointing
    - changes the spectrum of the radiated sound
    - allows more efficient radiation of the sound
- operation of trumpet/tuba/French horn valves and trombone slides and how they affect sound spectrum
- trumpet valves add lengths of tubing that lower the pitch by one, two, or three semitones (same for first three valves of tuba, French horn, euphonium, etc.)
- valves can be pressed in combinations to lower pitch by 1–6 semitones
- trombone slide can be moved to lower pitch by 1–6 semitones
- special case of French horn (hand in bell and two lengths of pipe)
- spectra and effects of the bell and loudness
- radiation efficiency and cut-off frequency of cylindrical pipe and of pipe with flared bell:
    - trumpet pipe cut-off frequency without bell is nearly 20 kHz
    - with bell it is several octaves lower (in the 2,000–2,500 Hz range or so; see Fig. 11.13b)
- mutes and their effects [not covered on Exam #3]

<u>Relevant course material:</u>

HW:	#5 and #6
Readings:	Assignments from Mar. 20 through Apr. 13
Web Links:	"Violin" (Wikipedia)
	What Are Pickups? (Yamaha)
	How Do Guitar Pickups Work? (YouTube)
	"Trumpet" (Wikipedia)
	Trumpet Fingering Chart (Amro Music)