

Policies and Review Topics for Exam #1

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 one 8.5 × 11-inch two-sided handwritten help sheet 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 sheet. 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, February 20 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.

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.

What causes sounds?

Sound waves

- alternating compression & rarefaction of air molecules; transitions from compression to rarefaction are often periodic (i.e., pattern repeats over time)
- longitudinal waves (most sounds) vs. transverse waves

- In most cases, individual particles (usually molecules) oscillate back and forth over a tiny distance and eventually return to their original position after the wave passes (superimposed on random Brownian motion).
- Wave energy and waveforms move at the speed of sound.
- Individual molecules move very slowly relative to speed of sound.
- energy transmission vs. motion of individual particles

Traveling waves vs. standing waves

- traveling waves have the mathematical representations

$$p(x, t) = A \cos(kx - \omega t) = A \cos(\omega t - kx)$$
 for waves traveling in +x direction

$$p(x, t) = A \cos(kx + \omega t) = A \cos(\omega t + kx)$$
 for waves traveling in -x direction
 where A = amplitude, k = wave number (sometimes called phase constant), and ω = radian frequency
- standing waves have the mathematical representation

$$p(x, t) = 2A \cos(\omega t) \cos(kx)$$
 ...a stationary cosine wave with time-varying amplitude

Traveling sound waves

- almost always longitudinal (can be transverse on strings, solid surfaces, & a few other cases)
- Pressure is in phase with particle velocity but out of phase with particle displacement.
- speed of sound in air:

$$v = 20.1\sqrt{T}$$
,
 where T = temperature in kelvins ($T[\text{K}] = T[^\circ\text{C}] + 273$)
- mathematical representation:

$$p(x, t) = A \cos(kx \pm \omega t) = A \cos(\omega t \pm kx)$$
,
 where A = amplitude, k = wave number, and ω = radian frequency
- definitions of wave number, radian frequency, frequency, period, wavelength, speed, and their relationships

$$k = \frac{2\pi}{\lambda} = \frac{\omega}{v}, \quad \omega = 2\pi f, \quad f = \frac{v}{\lambda}, \quad T = \frac{1}{f}, \quad \lambda = \frac{v}{f}$$
- T can represent period or temperature; use context to determine which one applies

Vibration and resonance

- Vibrations are almost always standing sound waves.
- resonance of pipe that is open at both ends

$$f_n = n \frac{v}{2L}; n \text{ is any integer } (1, 2, 3, 4, \dots)$$

 where n = index of harmonic frequency (fundamental corresponds to $n = 1$), v = speed of sound, L = effective length; at f_1 , length of pipe is $\lambda/2$
- resonance of pipe that is open at one end and closed at the other end

$$f_n = n \frac{v}{4L}; n \text{ is any odd integer } (1, 3, 5, 7, \dots)$$
- effective length is the actual length plus the end correction:
 correction = $0.61r$ for closed pipes;
 correction = $1.22r$ for open pipes, where r = radius of pipe

- resonance of string with both ends tied to stationary objects

$$f_n = n \frac{v}{2L}; n \text{ is any integer (1, 2, 3, 4, ...),}$$

where n = index of harmonic frequency (fundamental corresponds to $n = 1$), v = speed of sound, L = length of string; at f_1 , length of string is $\lambda/2$

Sound power (usually represented by P , although the textbook uses the symbol W) and sound power level (L_W)

- power unit is the watt, W
- change in power (increase or decrease) as a multiplying factor expressed in decibels

$$\Delta L = 10 \log \left(\frac{P_2}{P_1} \right)$$

- sound power level (always expressed in decibels)

$$L_W = 10 \log \left(\frac{P}{P_0} \right),$$

where $P_0 = 10^{-12} \text{ W} = 1 \text{ pW}$ (reference power)

Sound intensity (I) and intensity level (L_I)

- intensity is the power per unit area (unit is watts per square meter, W/m^2)
- intensity level (always expressed in decibels)

$$L_I = 10 \log \left(\frac{I}{I_0} \right),$$

where $I_0 = 10^{-12} \text{ W/m}^2 = 1 \text{ pW/m}^2$ (reference intensity)

- intensity due to power source radiating in free space (no nearby obstacles, no ground)

$$I = \frac{P}{4\pi R^2},$$

where P = power of sound source (such as a loudspeaker or sonar transducer) and R = radius of spherical surface centered on sound source

- intensity due to power source radiating in hemispherical space with no nearby obstacles but over solid ground

$$I = \frac{P}{2\pi R^2};$$

intensity is twice as great for given applied power because the power is distributed over half the volume compared to completely open three-dimensional space

- both formulas for I ignore possible reflections and other interactions with nearby objects

Sound pressure (p , a lower-case P) and sound pressure level (L_p or SPL)

- pressure is force per unit area; unit is newtons per square meter, N/m^2 , or pascal, Pa; $1 \text{ N/m}^2 = 1 \text{ Pa}$
- sound pressure level (always expressed in decibels)

$$L_p = 20 \log \left(\frac{p}{p_0} \right),$$

where $p_0 = 2 \times 10^{-5} \text{ Pa} = 20 \text{ } \mu\text{Pa}$ (reference pressure; roughly equal to the threshold of hearing); note that 20, not 10, multiplies the logarithm for SPL

- relationship between sound intensity and sound pressure

$$I = \frac{p^2}{\rho v},$$

where p = pressure, ρ = mass density of air (close to 1.2 kg/m^3 at room temperature and sea level; symbol is lower-case Greek letter rho), and v is the speed of sound; $\rho v \approx 400$ at room temperature and sea level

Calculation of sound power required to produce a specific SPL at a given distance

- use $I = \frac{P}{4\pi R^2}$ or $I = \frac{P}{2\pi R^2}$ to approximate relationship between radiated power P from sound source to intensity at distance R ; there could be considerable error using simple formulas, but they often provide accuracy to within a few dB
- account for efficiency of loudspeaker or other sound transducer being used (speaker efficiency can be very low; 2% to 5% is typical)
- use $I = \frac{p^2}{\rho v}$ (approximated using $I \approx \frac{p^2}{400}$ at room temperature and sea level) to relate intensity to pressure
- use $L_p = 20 \log\left(\frac{p}{p_0}\right)$ to convert from pressure (in Pa) to sound pressure level (in dB)

Fletcher-Munson curves

- original research by Fletcher and Munson completed in the early 1930s
- modern curves are actually the ISO 226:2003 standard, but are often called Fletcher-Munson curves anyway
- curves express the perceived loudness of sounds at different frequencies relative to the loudness at 1000 Hz
- perceived loudness expressed in the phon unit; corresponds to loudness at 1000 Hz; for example, a 100-Hz tone with a perceived loudness level of 40 phons has an SPL of ~ 51 dB, but a 1000-Hz tone at the same perceived loudness level has an SPL of 40 dB
- loudness of composite sounds (made up of sounds over a range of frequencies) measured using sound level meter
 - o A-weighting corresponds to sensitivity of human ear to audio range; low-frequencies and extremely high frequencies are weighted less than middle frequencies
 - o Z-weighting applies even weighting (i.e., no filtering) to all frequencies across the audio spectrum

Relevant course material:

HW: #1 and #2
Readings: Assignments from Jan. 23 through Feb. 16, excluding Chap. 5
Web Links: Longitudinal and Transverse Wave Motion
Wave Motion in Time and Space
Standing Longitudinal Waves
"Equal Loudness Contour" (Wikipedia)
"A-Weighting" (Wikipedia)