



Duke University Science Olympiad Invitational

Sounds of Music 2019-20

Do not begin until you are told to do so.

This test is way too long. You probably won't finish all of it in time, and that's okay. Use your time efficiently by skipping questions you don't know, and eliminating choices on the multiple-choice section. The order of questions is multiple choice, short answer, and free response. Each multiple choice question has only one answer and we won't deduct points for incorrect answers. For some short answer questions, you will get full credit even if you have a one-word answer.

I will call you by team number to test your instrument. One of you may continue to work, but both of you can come if you like. Good luck!

This test uses these conventions unless implied or stated otherwise:

- All frequencies are greater than 20 Hz.
- Sound sources are points emitting continuously in windless 20°C air at sea level.
- All strings and pipes are of very small, nonzero radius.
- An octave consists of twelve equally distant half steps referenced to $A_4 = 440$ Hz.

School: _____ Team number: _____

Student names: _____

Test score: _____/75 Final score: _____ Rank: _____

Questions? Feel free to contact me!
qedgary@ad.unc.edu

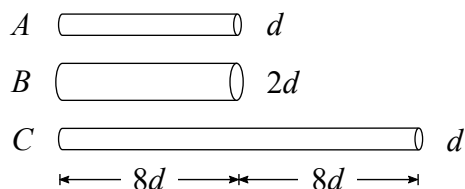
DUKE SCIENCE OLYMPIAD

1. A drum contains a circular membrane with lowest frequency f . What is the lowest frequency of a drumhead with twice the radius and twice the density under the same tension?

(A) $\sqrt{2}f$
 (B) f
 (C) $\frac{f}{2}$
 (D) $\frac{f}{4}$
 (E) $\frac{f}{\sqrt{8}}$

2. The speed of sound in an ideal gas is v . After work is done on the gas, the average kinetic energy of molecules in the gas increases by 10.0 percent. What is the new speed of sound in the gas?

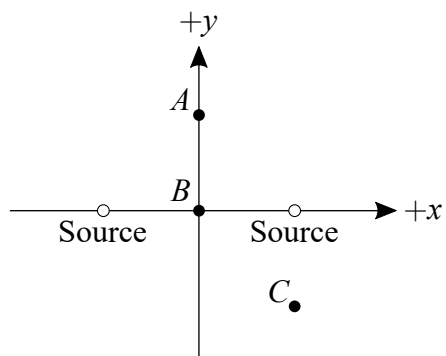
(A) $0.90v$
 (B) $1.00v$
 (C) $1.05v$
 (D) $1.10v$
 (E) $1.21v$



3. Open pipes A , B , and C have lengths and diameters as indicated in the figure above. Assuming pipes are NOT ideal (nonzero end correction), which of the following correctly ranks their fundamental frequencies from least to greatest?

Least Greatest

(A) $f_C < f_B < f_A$
 (B) $f_C < f_B = f_A$
 (C) $f_C = f_B < f_A$
 (D) $f_A < f_B < f_C$
 (E) $f_A < f_B = f_C$



4. Two sound sources at $(-1, 0)$ and $(1, 0)$ play a constant frequency f in phase, as indicated above. Complete destructive interference is possible at which of the labeled points?

(A) A only
 (B) B only
 (C) C only
 (D) A and B
 (E) A , B , and C

5. Ideal fluid flows through a pipe of constant radius. If the elevation of the pipe rises, then how does the fluid's speed and internal pressure change?

| Pressure | Speed |
|---------------|------------------|
| (A) Decreases | Increases |
| (B) Decreases | Remains the same |
| (C) Increases | Increases |
| (D) Increases | Decreases |
| (E) Increases | Remains the same |

6. A sound wave has angular wavenumber k . If its frequency increases by a factor of 3 and its pressure amplitude increases by a factor of 2, what is its new angular wavenumber?

(A) $\frac{2k}{\sqrt{3}}$
 (B) $\frac{k}{3}$
 (C) k
 (D) $\frac{k\sqrt{3}}{2}$
 (E) $3k$

Questions 7-8 refer to the table below, which lists properties of five strings. Assume all data have three significant figures.

| String | Length (m) | Wave speed (m/s) |
|----------|------------|------------------|
| <i>A</i> | 0.8 | 320 |
| <i>B</i> | 0.5 | 460 |
| <i>C</i> | 1.0 | 460 |
| <i>D</i> | 2.0 | 460 |
| <i>E</i> | 1.0 | 1840 |

7. Which of the strings has the lowest fundamental frequency?

- (A) *A*
- (B) *B*
- (C) *C*
- (D) *D*
- (E) *E*

8. A tuning fork of frequency 460 Hz is struck in close proximity to the strings. Which of the strings will resonate as a result?

- (A) *B*
- (B) *B* and *E*
- (C) *B*, *C*, and *D*
- (D) *B*, *C*, *D*, and *E*
- (E) All strings will resonate

9. If an observer at rest is sufficiently distant from a moving sound source, then as a result,

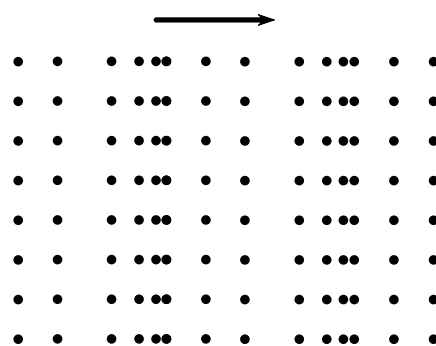
- (A) the Doppler Effect is negligible
- (B) the Doppler Effect is negligible only if the source moves away from the observer
- (C) the Doppler Effect is negligible only if the source approaches the observer
- (D) the distance does not affect the Doppler Effect

10. A sound source will have the greatest reverberation in a typical one of which of the following?

- (A) Empty car (sedan)
- (B) Empty classroom
- (C) Empty school bus
- (D) Empty cafeteria
- (E) All will have the same reverberation

11. A string on the International Space Station is stretched between two walls inside the station. Another string is on Earth with the same length, density, thickness, and tension. When observers directly beside each string compare measurements, the string in space

- (A) has a significantly lower fundamental frequency according to local observers
- (B) has a fundamental significantly higher frequency
- (C) has a negligibly different fundamental frequency
- (D) cannot be determined without knowing the mixture of gas inside the space station
- (E) cannot be determined without knowing the temperature inside the space station



12. The figure above illustrates a sound wave propagating from left to right after neglecting random thermal motion of each molecule. What is the waveform of the sound?

- (A) Sine
- (B) Triangle
- (C) Square
- (D) None of these
- (E) It is either sine, triangle, or square, but it cannot be determined which one it is

13. A string of length 0.75 m produces a frequency of 720 Hz. The wave speed on the string is 360 m/s. What is the wavelength of the standing wave on the string?

- (A) 0.25 m
- (B) 0.50 m
- (C) 0.75 m
- (D) 1.5 m
- (E) 4.5 m

____ 14. An observer and sound source move at +300 m/s and -155 m/s respectively on the x -axis, starting from the origin. If the source emits frequency f , what frequency is heard by the observer?

- (A) $\frac{343 + 155}{343 + 300}f$
- (B) $\frac{343 - 300}{343 - 155}f$
- (C) $\frac{343 - 300}{343 + 155}f$
- (D) $\frac{343 + 300}{343 - 155}f$
- (E) The observer moves away from the source too rapidly to hear a sound

____ 15. A sound source at rest plays a major scale from A_2 to A_3 . The source then plays the scale again while moving at 64.9 m/s away from a stationary observer. According to the observer,

- (A) the new scale is a major scale
- (B) the new scale is a minor scale
- (C) the interval of pitch between consecutive notes is larger than it would be for a source at rest
- (D) the interval of pitch between consecutive notes is smaller than it would be for a source at rest
- (E) It cannot be determined without knowing the overtones of each note

____ 16. Which of the following statements are accurate comparisons of music and noise?

- I. Noise consists of stochastic (unpredictable) frequencies, while music contains ordered frequencies.
 - II. Both noise and music carry energy and momentum.
 - III. Music has definite duration, while noise may not necessarily.
- (A) I only
 - (B) II only
 - (C) III only
 - (D) I and II
 - (E) I, II, and III

____ 17. Which of the following are properties of dispersive media?

- I. The group velocity of a wave must equal its phase velocity.
- II. Different wave frequencies travel at different speeds.
- III. If a non-sinusoidal wave enters from another medium, it will break into multiple sine waves.

- (A) I only
- (B) II only
- (C) III only
- (D) I and II
- (E) II and III

____ 18. Which of the following instruments has a timbre most similar to a pure tone?

- (A) Bugle
- (B) Voice of a human soprano
- (C) Xylophone
- (D) Piano
- (E) Tuning fork

____ 19. An accordion

- (A) is only a type of idiophone
- (B) is only a type of aerophone
- (C) consists of both an idiophone component and aerophone component
- (D) consists of both an aerophone component and membranophone component
- (E) is manufactured as either an idiophone or an aerophone, but not both

____ 20. The function of pedals on a concert harp is to

- (A) raise or lower certain strings by a half step
- (B) increase the maximum displacement of certain strings
- (C) change the elastic stiffness of certain strings
- (D) force the strings to play only odd harmonics

____ 21. What is the interval between the highest and lowest notes on a piano?

- (A) A major second and seven octaves
- (B) A minor third and seven octaves
- (C) A major third and seven octaves
- (D) A perfect fourth and seven octaves
- (E) Seven octaves

____ 22. On a French horn, multiple notes can be played by modifying vibration of the lips without changing the fingering. This process best exemplifies

- (A) Overblowing
- (B) Split tones
- (C) Multiphonics
- (D) Compensation
- (E) Debuccalization

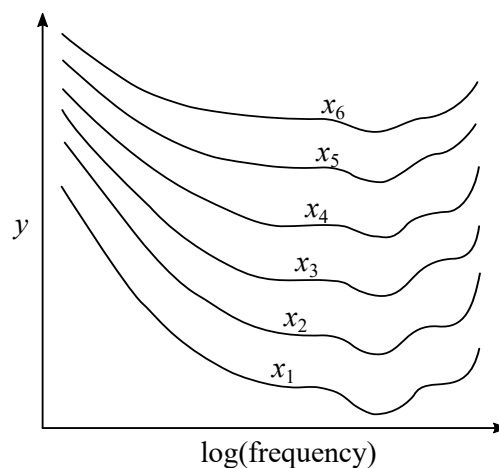
____ 23. A trumpeter plays E by pressing valves 1 and 2. Which valves should be pressed to play the F immediately above it?

- (A) 1 only
- (B) 2 only
- (C) 3 only
- (D) 1 and 3
- (E) 2 and 3

____ 24. An instrument consists of sonorous cables not held rigidly under tension. Two students disagree on whether the instrument should be considered a chordophone. A researcher in which of the following fields would provide the most relevant information to the debate?

- (A) Psychophysics
- (B) Acoustic physics
- (C) Organology
- (D) Phonetics
- (E) Ethnomusicology

Questions 25-27 refer to the graph of selected equal loudness contours.



____ 25. What units could be used for quantities x_1, x_2, \dots, x_6 ?

- I. Mels
- II. Phons
- III. Sones

- (A) I only
- (B) II only
- (C) III only
- (D) I and III
- (E) II and III

____ 26. What units could be plotted on the vertical axis, labeled with y ?

- I. dB SPL
- II. W/m^2
- III. N/m^2

- (A) I only
- (B) III only
- (C) I and III
- (D) II and III
- (E) I, II, and III

____ 27. The equal loudness contours depicted best exemplify

- (A) Fletcher–Munson effect
- (B) Nyquist–Fourier effect
- (C) Michelson–Morley experiment
- (D) Sapir–Whorf hypothesis
- (E) Pythagorean enharmonic dissonance

____ 28. When two pure tones of 1000 Hz and 800 Hz are played loudly together, the human ear hears another tone of 200 Hz. This phenomenon is known as

- (A) Beats
- (B) Interference
- (C) Tone color
- (D) Weber–Fechner Law
- (E) Combination tones

____ 29. What is the frequency ratio of the notes in a tritone, from highest to lowest frequency?

- (A) $\sqrt{2}$: 1
- (B) $\sqrt[4]{2}$: 1
- (C) $\sqrt[12]{2^5}$: 1
- (D) $\sqrt[3]{2^2}$: $\sqrt[3]{2}$: 1
- (E) 3 : 2 : 1

____ 30. All of the following accurately describe a Pythagorean tuning EXCEPT:

- (A) All half steps are equal in interval size
- (B) Only instruments with integer-multiple harmonics play in this temperament
- (C) Major seconds are pure relative to the tonic
- (D) Perfect fifths are pure relative to the tonic
- (E) The octave is pure relative to the tonic

____ 31. The dominant scale degree corresponds to which syllable of movable-*do* solfège?

- (A) *fa*
- (B) *sol*
- (C) *ti*
- (D) *re*
- (E) *la*

____ 32. When the notes of a major scale are played starting on the supertonic, what Greek mode is produced?

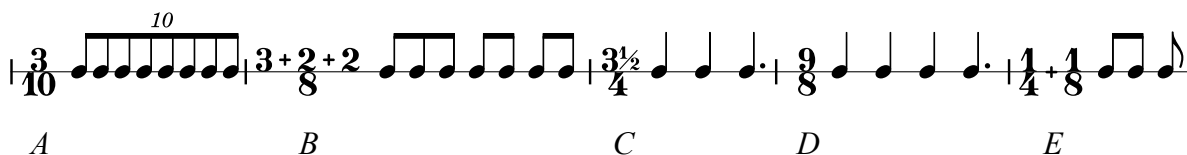
- (A) Aeolian
- (B) Ionian
- (C) Phrygian
- (D) Mixolydian
- (E) Dorian



____ 33. The scale above is

- (A) major
- (B) Dorian minor
- (C) melodic minor
- (D) natural minor
- (E) harmonic minor

Questions 34-35 refer to the labeled staff below.



____ 34. Which of the measures has an example of a compound time signature?

- (A) A
- (B) B
- (C) C
- (D) D
- (E) E

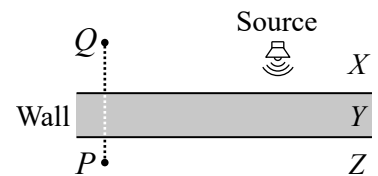
____ 35. The type of staff illustrated is most useful for which of the following instruments?

- (A) Tambourine
- (B) Violincello
- (C) Didgeridoo
- (D) Marimba
- (E) Kalimba

Short answer

A response with just one word or phrase is acceptable for most of these questions; no questions need more than a sentence for you to answer for full credit.

36. In musical notation, what Italian expression lets a player deviate from a consistent tempo by hastening then slowing the speed of playing?
37. Define flexure.
38. Define a compression of a wave.
39. A common misconception is that sound travels faster in denser media than less dense media. **Briefly** describe a specific, empirical counterexample. (2 points)
40. What is the root-mean-square value of a sine wave with amplitude of 3?
41. Describe the difference between *tremolo* and *vibrato*. (2 points)
42. Write the notes of the parallel major of B natural minor.
43. Write the notes of the relative major of B natural minor.
44. A microphone recorder can take samples of air pressure variation 44100 times each second. What is the upper bound of the frequencies that the microphone can record without aliasing? Is the upper bound inclusive or exclusive? (2 points)
45. A sound source lies on side X of a long, tall aluminium wall Y with thickness of 0.1 m, as shown. The source plays a constant sinusoidal tone which travels through the wall to side Z. Rank the frequencies in each region relative to each other, where 1 is the lowest frequency. Use the same number when frequencies are equal. If the ranking cannot be determined, write a question mark (?) in the blank. You don't have to explain your answers. (2 points)
- _____ X _____ Y _____ Z
46. A person at point P may perceive the sound source to be directly behind the wall at some point Q, when the source is actually to their right. Explain how refraction contributes to this effect. You may draw on the diagram as needed. (2 points)
47. Fun question: Is mayonnaise an instrument? Give three examples.^{Note 1}



¹please don't spend too much time on this lol it's not worth any points unless for some highly unlikely reason we *reallyyyyyy* need to break ties and the other tiebreakers listed in the rules manual don't work yay (but in the unlikely chance we actually grade this question to break a tie, a scientific answer is preferred)

Free response questions



48. A student blows into one of the ends of a PVC pipe of length L from a small distance from his mouth, producing a tone of loudness ϕ , as shown in the figure above. The airstream exits the student's mouth at a speed of v_s , and the speed of sound in air is v_{air} .

(a) Determine an expression for the fundamental frequency f of the pipe. (2 points)

- (b) The student now places the PVC pipe touching his mouth. The student blows such that no air escapes from his mouth except for the air that travels through the PVC pipe. The airstream speed remains at v_s . How does the loudness of the new sound compare to ϕ ? (2 points)

_____ Louder _____ No change _____ Softer _____ It cannot be determined

Justify your answer.

- (c) The student keeps the PVC pipe touching his mouth, but blows with an airstream of $2v_s$. How does the loudness of the new sound compare to the loudness of the pipe in part (b)? (2 points)

_____ Louder _____ No change _____ Softer _____ It cannot be determined

Justify your answer.

- (d) The student glues a saxophone mouthpiece with the same radius as the PVC pipe to one end of the pipe. The student blows on the mouthpiece. How does the loudness of the new sound compare to ϕ ? (2 points)

_____ Louder _____ No change _____ Softer _____ It cannot be determined

Justify your answer.

49. The excerpt is an arrangement of a piano minuet by Mozart, although the test writer has changed it from the original.
- In this time signature, what note gets the beat? (1 point)
 - The key signature of the original piece had two sharps. The current key signature is how many steps lower on the circle of fifths compared to the original? (1 point)
 - In the excerpt, there exist two vertically stacked notes where the higher note is an overtone of the lower when played on a stringed instrument, but not on a hinged bar instrument.
 - Draw a box around these two notes. (1 point)
 - A hinged bar, also known as a simply supported bar, is a bar with a hinged end. With respect to the physics of musical instruments, what is the definition of a hinged end? (1 point)
 - What is the interval and interval quality between the two notes in the treble staff marked below with ★? (1 point)
 - What is the letter name of the eighth note in the treble staff marked below with ★★? (1 point)
 - The quarter rest in measure 1 in the bass staff could be replaced by a chord. Of the the three chords below in Roman numeral analysis, check the option most consistent with the rest of the piece for replacing the quarter rest. (2 points)
 _____ I _____ ii^o _____ IV⁺
 Explain your reasoning. Feel free to label the notes in the excerpt with numbers for convenience if you need to refer to them in your explanation.