Exploring the World of Science

University of Michigan Science Olympiad
2021 Invitational Tournament

Sounds of Music C

Test length: 50 Minutes

Team name: KEY

Student names: KEY

Perceived Frequency:

1. Two people are standing near each other and humming with frequencies 281 Hz and 295 Hz, respectively. What frequency do people next to them hear?
   a. 576 Hz
   b. 103 Hz
   c. 288 Hz
   d. 14 Hz
   e. None of the above

2. What beat frequency do people standing near them hear?
   a. 576 Hz
   b. 103 Hz
   c. 288 Hz
   d. 14 Hz
   e. None of the above

3. Explain how beat frequency can be used to tune an instrument.

Since the beat frequency is the difference between the two frequencies, two closer notes have smaller beat frequencies. Playing with a tuning pitch and monitoring the beat frequency can help tune.

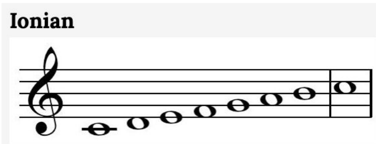
Sound Intensity:

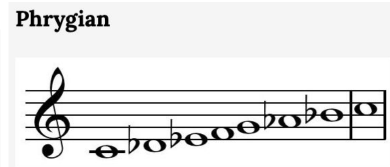
4. What effect on the decibel level will doubling sound intensity have?
   a. Increase by 5 dB
   b. Increase by 3 dB
   c. Stay the same
   d. Decrease by 3 dB
   e. Decrease by 5 dB

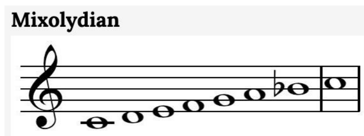
5. By what factor must the sound intensity change so that the resulting decibel level increases by 7 dB?
   f. 1/3
   g. 1/5
   h. 3
   i. 5
   j. None of the above

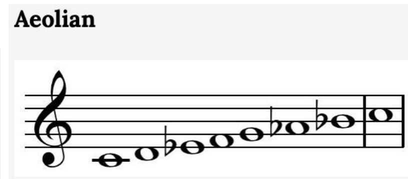
Musical Modes:

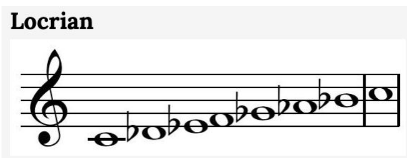
6. Name the seven main musical modes, and write a scale in each mode starting on middle C in the staffs provided.











Pythagorean Scale:

In this problem, you will construct the Pythagorean scale.

You are given two strings: a short string of length 1 and a long string of length 2. You will need to fill in the notes in the middle.

7. Pythagoras started with the two simplest ratios for the best consonance: the first was 2:1; what was the second?

3:2

8. Using the ratio from part a., construct two more notes for the scale. Together with the 1:1 and 2:1 notes, these four ratios were used to tune ancient Greek lyres. What are the four ratios? What are the two new intervals called?

1:1, 4:3, 3:2, 2:1. Fourth and fifth.

9. Your scale now has four notes. Add the next two notes to this scale using the ratio from part a. What is this scale called?

1:1, 9:8, 4:3, 3:2, 16:9, 2:1. The pentatonic scale.

10. Western music generally uses an eight note scale (seven notes + octave). Again, using the ratio from part a., add the final two notes to the scale. You have created the Pythagorean scale! What are the ratios of all of the adjacent notes in the scale?

1:1, 9:8, 32:27, 4:3, 3:2, 27:16, 16:9, 2:1. The adjacent ratios are 9/8 for all but two pairs, which have ratio 256/243.

11. If the frequency of the short string is 100Hz, list the frequencies of all of the notes in the scale.

100, 112.5, 118.5, 133.3, 150, 168.8, 177.8, 200.

Intervals:

Fill in the musical interval with which these pieces of music start (the first change in pitch).

12. Harold Arlen, “Over the Rainbow”: octave

13. Ludwig van Beethoven, Symphony No. 5, first movement: major third

14. Richard Strauss, *Also Sprach Zarathustra*: fifth
15. Richard Wagner, Lohengrin, Wedding March: fourth
16. Ludwig van Beethoven, Fur Elise: minor second
17. Wolfgang Mozart, Symphony No. 25, first movement: fourth
18. Aaron Copland, Fanfare for the Common Man: fourth

String - First Mode:

Given a string of length L that has a standing wave in the first mode, determine the following:

19. Express the wavelength λ in terms of the length L.

$\lambda = 2L$

20. Express the frequency of the first mode in terms of L and the string's wave velocity.

$f_1 = \frac{v}{2L}$

21. Express the string's wave velocity in terms of the string's linear mass density μ and its tension T.

$v = \sqrt{\frac{T}{\ }}$

22. Combine the above equations to express the frequency of the first mode in terms of L, T, and μ.

$f_1 = \frac{\sqrt{\frac{T}{\ }}}{2L}$

23. Describe qualitatively what changing each of L, T, and μ will do to the frequency of the first mode.

As the string length increases, the frequency decreases. As the tension increases, the frequency increases. As the linear mass density increases, the frequency decreases.

24. Express the frequency of the second mode in terms of L, T, and μ.

$f_2 = \frac{\sqrt{\frac{T}{\ }}}{L}$

25. Explain how the above applies to pan pipes; why do the different pipes produce different sounds?

In a pan pipe, the simplest way for the air to vibrate is in the first mode. As the length of the pipe changes, so does the frequency of vibration.

Pan Pipes:

26. Explain the end effect in pan pipes and how to combat it.

When a standing wave reaches the closed end of the pipe, there is a hard reflection. However, when it reaches the open end, the reflection is not as hard. This makes the pipes acoustically longer than their actual length, and thus sound flat. Therefore, the pipes have to be modified — compared to the correct theoretical length — to account for the end effect.

Breaking stride (Tiebreaker #3):

27. Explain the physics behind why soldiers are ordered to break stride (not march in step) on bridges.

If the soldiers' marching hits the correct resonant frequency, the bridge could collapse.

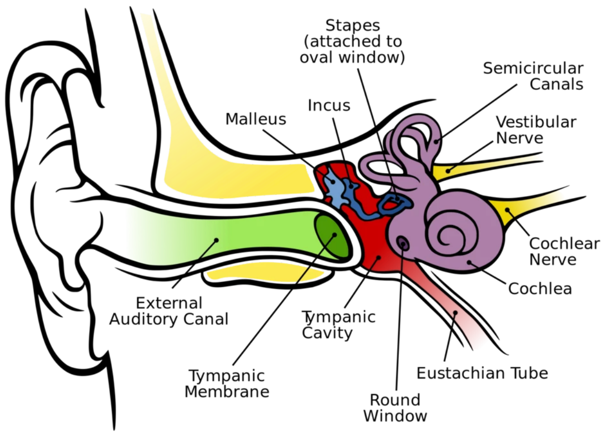
Harmonics:

28. On a classical guitar, harmonics are played by lightly touching a string at a certain fret, rather than pressing down, as would be done for a regular note. Explain why on a classical guitar, the harmonic E can be played both on the fifth string, seventh fret (originally an E) and on the sixth string, fifth fret (originally an A).

Harmonics are integer multiples of the fundamental frequency of the note. The harmonic E can be played above the original E, because the harmonic's frequency is double the original note's frequency. The same harmonic E can be played above the original A, because the A is a fifth below E, so has frequency a multiple of 1.5 less than the original E. So, an integer multiple of 3 of the original A produces the harmonic E.

The Human Ear:

29-40. Label the following diagram of a human ear:



Musical Elements:

41. What is the texture of the following piece? Monophonic
https://www.youtube.com/watch?v=jHJZlPnp2i8

42. What is the meter of the following song? https://www.youtube.com/watch?v=4OzU1jdjSZA
    a. Duple simple
    b. Triple compound
    c. Duple compound
    d. Quadruple compound

The Human Voice:

43. Consider an adult human male, where the distance from his vocal chords to lips is 17 centimeters (consider this a closed pipe). What are the frequencies of the first three harmonics his voice produces including the fundamental? Round your answer to the nearest one. 504 Hz, 1513 Hz, 2522 Hz

44. If the shape of your mouth produces formants at 2500 Hz and 300 Hz, what vowel sound are you producing?
    a. The vowel sound in "seat"
    b. The vowel sound in "sought"
    c. The vowel sound in "sat"
    d. The vowel sound in "soon"

Marimba:

A marimba has rectangular bars made of wood with density 525 kg/m^3 and Young's modulus of 1.3 x 10^10 N/m^2

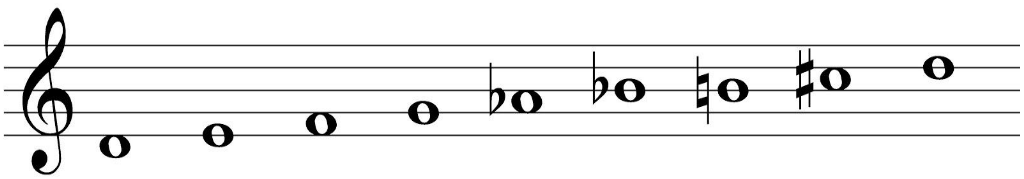
45. The shortest bar, which plays the note C3 is 42.5 cm long. Calculate its thickness. 0.5 cm

46. What are the frequencies of the first three overtones after this bar's fundamental frequency? 360.5 Hz, 706.7 Hz, 1168.2 Hz

47. Are these overtones harmonic? Explain your answer with reference to the periodicity of the waveforms produced. No, waveforms of the overtones are aperiodic. The overtones are inharmonic.

Scale Identification:

48. Name the following scale:



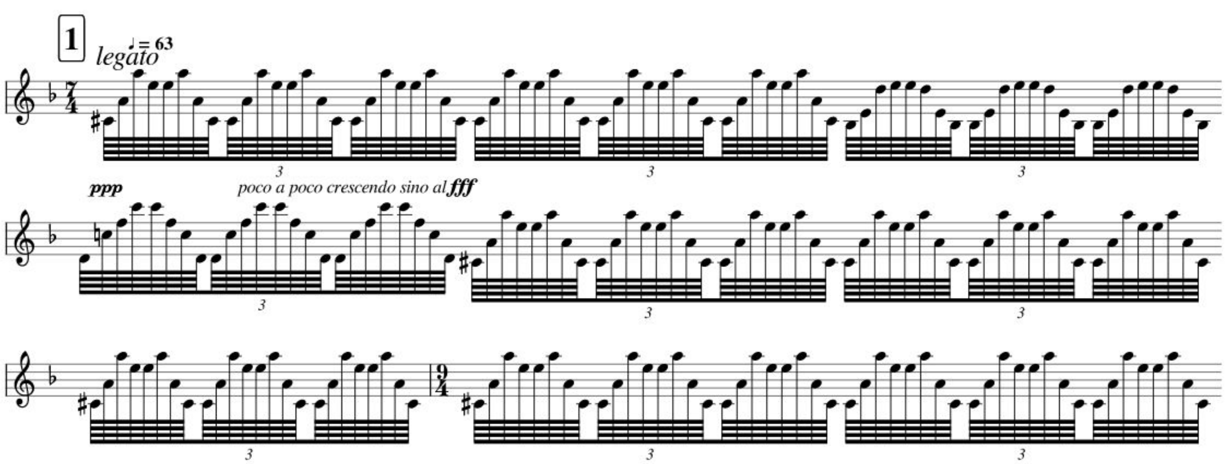
Octatonic

The Electric Guitar (Tiebreaker #1):

49. In a solid-body electric guitar, there is no soundboard such as there would be in an acoustic guitar, and the electric guitar itself produces very little sound. What is used to generate sounds from an electric guitar and how does it work? A pickup. Pickups use many loops of wire because each loop creates the same amount of current and the currents add up. More loops equals more current and a stronger signal. In other words, we make a coil. Second, we put a magnet inside the coil. The steel guitar string is magnetized by the magnet, and moves to produce a current in the coil which is transmitted to a speaker.

Tempo:

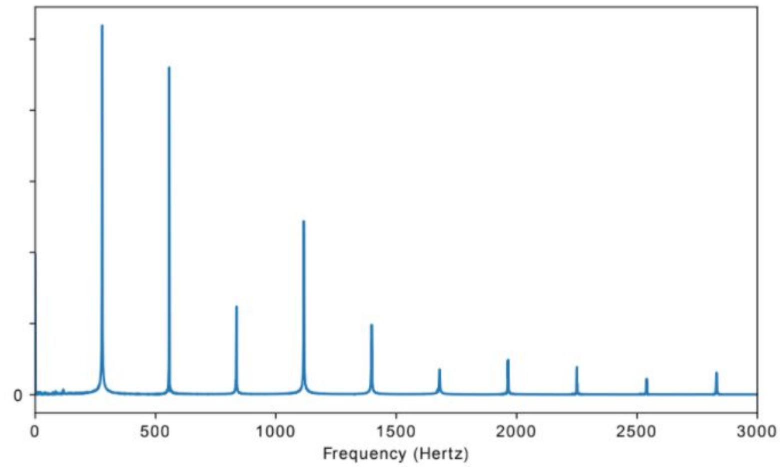
50. Note the tempo in the following excerpt. What length of time in seconds does each note take? Round to the nearest hundredth.



0.04 seconds

Fourier Spectra:

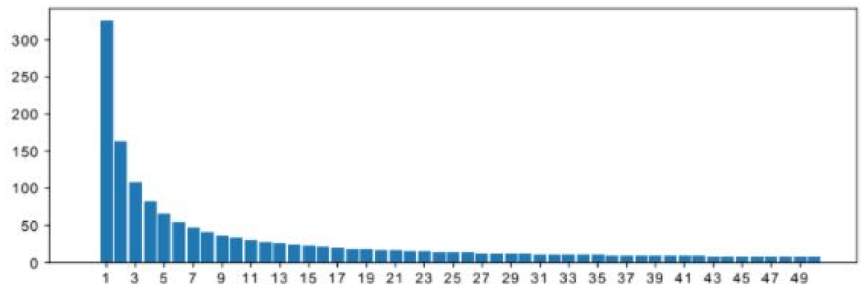
51. Consider the following Fourier spectra of a note being played on a piano. What note is being played? (We will accept an answer one half-step above or below)



C4

52-54. Label the following Fourier spectra as either a sine, square, or sawtooth wave:

(i)



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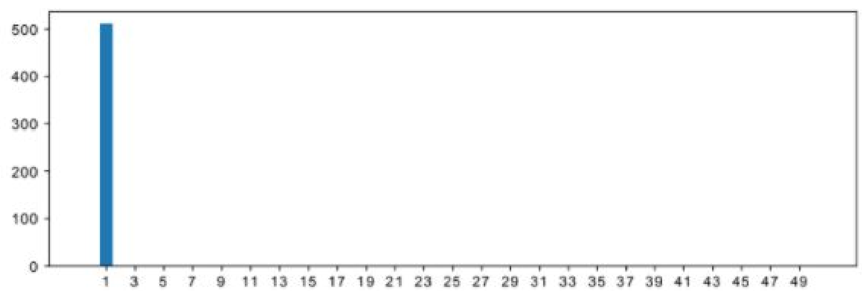

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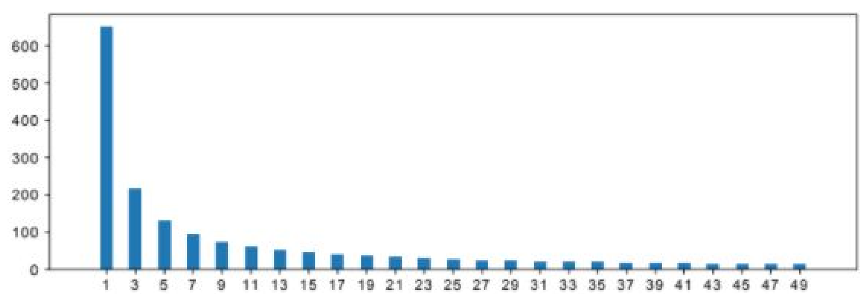


Sawtooth, sine, square

Unknown Planet:

Consider a planet with an atmosphere composed of an unknown gas. This gas has density 0.23 kg/m^3 and a bulk modulus of 1.11 x 10^5 N/m^2.

55. Calculate the speed of sound on the planet. 694.7 m/s

56. If an organ pipe plays the note D5 on earth, what note would it play on the planet with the unknown gas atmosphere? Slightly sharp D6

Recording Studio (Tiebreaker #2):

57. Professional recording studios usually record music digitally at 24-bit resolution. Calculate the number of levels that can be stored with this resolution and its corresponding dynamic range. n = 2^24 = 16,777,216 levels. Dynamic range = 20logn = 20log16777216 = 144.49 dB

Absorption and Reverberation:

58. A rectangular prism room is built with the following dimensions: width = 5 meters, height = 12 meters, length = 7 meters. The ceilings, walls, and floors are made out of brick. Calculate the total absorption and reverberation time of the room. SA = 358 m^2
S = 358 * 0.04 = 14.32 = total absorbance. 0.161*(420/14.32) = 4.72 seconds = reverberation time

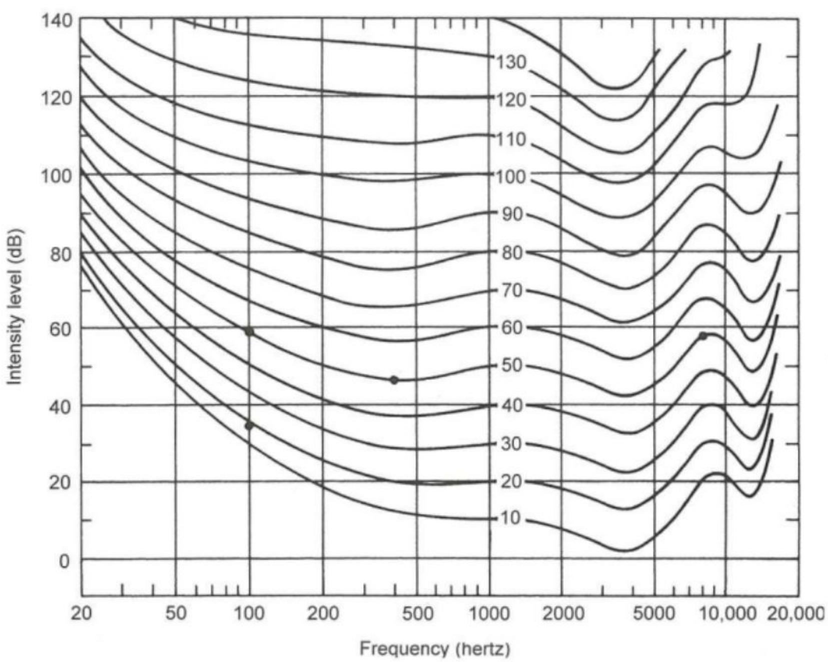
Cello:

59. Consider the lowest-tuned string on a standard concert cello. Assume its diameter is 1.18 mm, length is 69 cm, and mass per unit length is 1.56 x 10^-2 kg/m. Calculate the tension on the string. Density = 14264.96 kg/m^3. T = pi * 14264.96 * (65.4^2) * (0.69^2) * (0.00118^2) = 127 Newtons

Sine Waves:

60. One sine wave with frequency 1000 Hz is played at 40 dB. Another sine wave with frequency 100 Hz is also played at 40 dB. Which note is perceived to be louder and by how many decibels?

100 Hz by around 10 dB



Video Questions:

In any other circumstances, competitors would be allowed on the campus of the University of Michigan, to experience its world-class buildings and facilities. To somewhat emulate that experience, we have recorded two video questions regarding the University's renowned instruments and auditoriums. Though the questions are in the form of videos uploaded to YouTube, please type your answer in Scilympiad.

61. https://youtu.be/FypeyrIzDKA

    10.7 meters

62. https://youtu.be/DW3GAoAGhsc

Early reflections are the first echos that reach the listener from the walls, ceiling, etc. They are important in that you do not want to hear them (1 pt). Thus, they must occur faster than the flicker fusion rate. Acoustics experts typically recommend that they occur in 30 ms (1pt)