Massachusetts Institute of Technology:
Science Olympiad Invitational 2k19

Sound of Music Solutions

Total Points: 120

Total Questions: 34

Answer the questions in the spaces provided on the question sheets. Write your team number on every page. We are not responsible for pages that are lost or misplaced with no team number on them. You will be called up for instrument testing during this exam.

Names ____________________

School name: ____________________

Team Number: ____________________

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1. (1 point) Which of the following analogies to electrical power is most representative of the sources of sound for reed instruments and the flute?

   A. Reed: DC power, Flute: AC power

   B. Reed: AC power, Flute: DC power

   C. Both DC power

   D. Both AC power

Most woodwind instruments can be roughly generalized into tubes in which standing waves will travel through. The differences in this fundamental construction for instruments causes most of the differences in sound and timbre for woodwinds.

2. (3 points) Consider a perfectly cylindrical clarinet and a perfectly cylindrical flute, whose lengths are .5 meters long (that's a long flute, but we are using this for simplicity's sake). What is the maximum possible wavelength of a standing wave in each of these instruments?

Solution:

(a) (1 point) Identifying that a clarinet is a closed pipe on one end, identifying that a flute is a open pipe

(b) (1 point) An open pipe/ flute has the lowest fundamental frequency at $2L = 1m$

(c) (1 point) A closed pipe/ clarinet has a lowest fundamental frequency at $4L = 2m$

3. (4 points) Explain how a wind player creates a standing wave of sound within a flute and a clarinet (using this crude analogy). What is the main cause of the discrepancy in the above part?

Solution:

(a) (2 points) Something to the following explanation: When a wind player articulates on a wood wind, it sends a pulse of high pressure down the tube. When it reaches the bottom and is exposed to air, it subsequently dissipates. Due to the intensity of atmospheric pressures, the sum of this high pressure coming out and atmospheric pressure coming in causes a new wave of low pressure to travel up the tube. At this point, usually this wave will have been eliminated, but because the player is constantly pushing out waves of high pressures, a standing wave of pressure is created in the tube and causes sound to resonate.

(b) (2 points) to correctly identify that a pressure wave from a closed clarinet would have to travel twice the distance to be released from the tube. An open pipe tube can have the air pressure switch magnitudes on either end of the tube, but in a closed pipe, it can only switch at one end of the tube

4. (2 points) How do sound waves in a conical instrument such as a saxophone differ from those in a pipe-like instrument?

Solution:

(a) (1 point) Explain that in a conical instrument, the amplitude of the sound waves fall of by about 1/r with r as the distance from the mouthpiece. The waves reach a node at the end of the cone and are at an approximate anode at the mouthpiece.

(b) (1 point) Explain that the fundamental frequencies of a conical shape are 2L/n where n is a positive integer.

5. (4 points) How does the timbre and sound quality of a saxophone vary if the player blows faster air (high pressure) as opposed to slower air (low pressure)?

Solution:

(a) (2 points) At slower air/ low pressure, the sound waves are closer to pure sinusoidal with weak harmonics and a strong fundamental. Sound is like a pure fundamental, but weaker, with less resonance. (Reed also has less resonance, just as an aside)

(b) (2 points) At higher pressure, sound waves contain stronger harmonics. Sound is more full, timbre improves, and sound amplifies.

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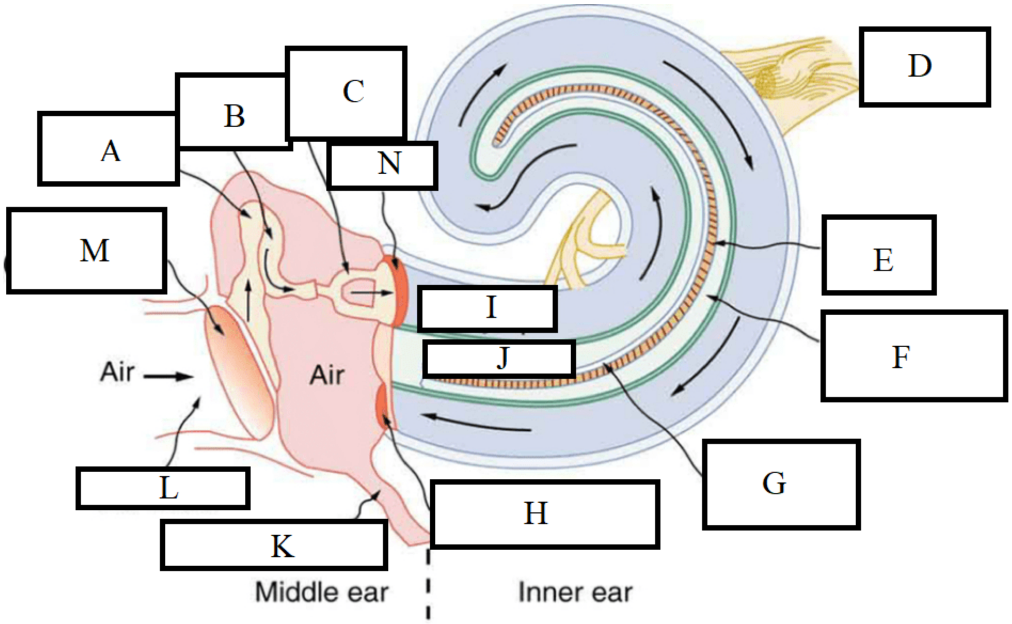
Pythagorean Tuning was a popular type of tuning used in the middle ages. However, this type of tuning has some drawbacks for modern music which led to alternatives being developed.

6. (6 points) Pythagorean Tuning is developed around the idea of the perfect fifth. What ratio(s) do you need to use to be able to generate all the relative frequencies of the notes in the standard harmonic series? How does using this form of tuning favor making certain tones more in tune with each other, and how does this give rise to wolf intervals? (Tie Breaker 6)

> **Solution:**
> (a) (2 points) 2:1 and 3:2
>
> (b) (1 point) Travel up and down the scale jumping by octaves and fifths.
>
> (c) (2 points) Favors unison, octave, fifth, and fourth because these intervals are within 1 step of the first fundamental
>
> (d) (1 point) steps farther away from the fundamental become more and more out of tune with the fundamental, giving rise to wolf intervals.

7. Calculate the following frequency ratios of the ratios in Pythagorean tuning: (1pt each)
   (a) (1 point) Major Second: **9/8**
   (b) (1 point) Perfect Fourth: **4/3**
   (c) (1 point) Major Seventh: **243/128**
   (d) (1 point) Tritone: **1024/729 or 729/512**

8. The Cochlea is a spiral organ that transforms mechanical vibrations into electro-chemical signals to nerves to the brain that it perceives as sound. Label the following diagram with the parts of the cochlea: (1pt each)



(a) (1 point) **Malleus**

(b) (1 point) **Incus**

(c) (1 point) **Stapes**

(d) (1 point) **Auditory nerves/ Ciliary/ Cochlear neres**

(e) (1 point) **Cilia**

(f) (1 point) **Organ of Corti**

(g) (1 point) **Tectorial membrane**

(h) (1 point) **Round window**

(i) (1 point) **Perilymph**

(j) (1 point) **Endolymph**

(k) (1 point) **Eustachian Tube**

(l) (1 point) **Ear canal**

(m) (1 point) **Ear drum/ Tympanum/ Tympanic membrane**

9. (1 point) The ear can hear a much larger range of sounds than the dynamic range of the inner hair cells inside the inner ear. What allows the ear to do this?

> **Solution:** Inner hair cells respond to higher frequency dynamics as well; Harmonics of hair cells don't weight every frequency the same, the brain filters it out

10. (1 point) What physical characteristic of the ear allows the phenomena described in the above problem?

> **Solution:** Outer hair cells amplify small amplitude responses

Who says music can only be made with pieces of wood and metal vibrating? What if we wanted living flesh to also make music? Before you get morbid, I'm talking about our vocal cords!

11. Please match the following sections of the body with its function in producing sound. (1pt each)

Lungs and diaphragm Vocal folds Vocal tract

(a) (1 point) **Vocal folds** Modulate airflow and produce vibration source

(b) (1 point) **Lungs and Diaphragm** Provide air and pressure

(c) (1 point) **Vocal Tract** Modify source to create specific sounds

12. (3 points) What are the three major mechanisms involved in producing sound (Edit: in the voice. I apologize that I was not clear enough on the original test)? (Tie Breaker 2)

> **Solution:**
> (a) (1 point) Sound source due to air displaced by vocal fold vibration
> (b) (1 point) Sound source due to force of the vocal cords on the airflow
> (c) (1 point) Sound source due to turbulence at the glottal exit

13. (3 points) What are the false vocal cords, and what is their function in speech? (Tie Breaker 3)

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Solution:

(a) (1 point) Vestibular folds: thick folds of membrane that bound the larynx

(b) (2 points) Suppress dysphonia (hoarse voices, like the screams in death metal, and creates that villain laugh and voice, think of the words diarrhea, go ahead, scorpions, and to swallow)

14. (2 points) What voice quality is associated with the glottis having a very short open phase? **Hoarse voice or pressed voice quality**

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15. (2 points) Continuing from the previous question, which harmonics in the voice become weak and strong, respectively?

> **Solution:**
> (a) (1 point) Weak first fundamental harmonic
>
> (b) (1 point) String second or fourth fundamental harmonic

16. (1 point) How does the soft palate change the sound quality of your singing?

> **Solution:**
> (a) (1 point) Lowered SP: Nasally voice Raised SP: More resonant, air flow directed into mouth

Straightforward Piano Questions, because the piano just might be important. Like, just a little bit:

17. (1 point) What material covers the hammers on a grand piano? ____**Felt**____

18. (2 points) How do pianos create relatively low pitches without being impractically long?

> **Solution:**
> (a) (1 point) Increase mass per length
>
> (b) (1 point) Use wound strings/ springs

19. (2 points) Why do we generally use longer strings on the bass notes, while we compensate on the upper register by having multiple strings? (Tie Breaker 1)

> **Solution:**
> (a) (1 point) Longer strings on the bass notes reduces stiffness and allows fundamentals on the bass note to be more in tune, allows each chord to be grounded more and easier to hear
>
> (b) (1 point) Thin strings are weaker, so they need to have more strings to reduce pressure
>
> (c) The smaller strings are de-tuned in order to increase nonlinearity and cause more color on the top notes.

20. Name these intervals: (Note: Functionally, these are the only correct answers, even if other intervals sound the same. A C to a C# sounds the same as C to a Db, but they function differently in theory.)
    (a) (1 point) C4 to Bb4 **Minor Seventh**
    (b) (1 point) F1 to G#1 **Major Second**
    (c) (1 point) G#4 to B4 **Minor Third**
    (d) (1 point) Cb6 to A6 **Augmented Sixth**
    (e) (1 point) D4 to Ab4 **Diminished Fifth**
    (f) (1 point) Bb4 to E4 **Augmented Fourth/ Tritone**
    (g) (1 point) C7 to D#8 **Augmented Ninth**
    (h) (1 point) Gb4 to Fb5 **Major Seventh**
    (i) (1 point) Fb3 to C4 **Diminished Fifth**
    (j) (1 point) Ab5 to B5 **Augmented Second**

21. (6 points) Name the circle of fifths in order starting from C, going from least sharps to least flats:

> **Solution:** C G D A E B Gb/F# Db Ab Eb Bb F
>
> (1/2 pt per correct scale, but C can be in the front or in the back, do not take off points if C is written twice on both ends)

22. (1 point) How many semitones are in a diminished fifth interval? **6 semitones**

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23. Match the term with the equivalent physical meaning:

Period	Wavenumber	Amplitude
Frequency	Wavelength	Phase
Angular Frequency	Velocity	

(a) (1 point) **Angular Frequency** Rate of change of the phase of the waveform

(b) (1 point) **Period** Inverse of frequency

(c) (1 point) **Frequency** Number of times an event occurs per measurement

(d) (1 point) **Velocity** Angular frequency divided by wave number

(e) (1 point) **Amplitude** Maximum height of the waveform

(f) (1 point) **Phase** The location of a waveform at a certain point in time

(g) (1 point) **Wavenumber** In units of cycles per unit distance

(h) (1 point) **Wavelength** Spatial period of a wave

24. (2 points) What kinds of materials are best at absorbing sound and why? (Tie Breaker 4)

Solution: Fiberous or porous materials can absorb sound by having the fibers or surfaces oscillate and absorb energy from the sound transferring the sound into mechanical energy

25. (1 point) If you wanted to someone to hear you on the other side of a brick wall, would you use a high or low frequency voice to shout at them? (Tie Breaker 5)

Solution: Low frequency, because low frequency sounds are difficult to absorb due to their longer wavelengths

26. (1 point) What is the purpose of the foam used in sound proof rooms?

Solution: To absorb echoes created within the room. The sound emitted will not interfere, causing a more pure sound from the source

27. (1 point) If an everyday material absorbs the energy from sound, what does most of the energy transfer as?

Solution: Heat Energy

28. (2 points) Since the lungs expel enough air to open the vocal folds, how do the vocal cords ever counteract this force to close?

Solution: The Bernoulli effect: The fast air caused by the lungs causes a region of low pressure near the folds that causes them to close, which allows the lungs to blow them open, and this creates an oscillatory motion

29. (1 point) To sing a higher pitch, how do the vocal cords change?

Solution: The tension on the cords rise, increasing the fundamental frequency

30. (1 point) How do the vocal folds cause an intensity change (ie., louder or softer) (Edit: There was a typo on the exam, I'm so sorry)?

Solution: The folds stay open and closed longer, creating a larger difference in low and high-pressure waves, causing a wave of higher pressure difference

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31. (7 points) Due to the theory of superposition, anytime we pluck the string of guitar, we can expect it to form a wave form that is the sum of a bunch of sinusoidal waves. However, there is a set of sinusoidal waves whose contribution to the sum will always be zero. Consider a string that is plucked at a position x along a string of length L, where $0 < x < L$ and the string behaves in a linear fashion. Let the resulting waveform on the string be given by $y(x) = \sum_{n=0}^{\infty} a_n sin(2\pi nx/L), a_n \in \mathbb{R}, n \in \mathbb{Z}$. Derive all n such that $a_n = 0$.

Solution:

(a) (2 points) All sin waves where there is a node at x cannot be excited by this motion

(b) (2 points) Somehow get to $sin(2\pi nx/L) = 0$

(c) (3 points) Right answer: $n = kL/2x, k \in \mathbb{Z}$

(d) Partial credit given based on the situation

32. (10 points) A source of sound travels perpendicularly towards a flat wall at velocity v emitting sound at frequency f. We have two stationary receivers away from the source, one between the wall and the source and one behind the source so that there is a straight line with receiver 1, the source, receiver 2, and the wall in that order. Let the velocity of sound be v_s and $v << v_s$ and assume that the wall perfectly reflects the sound waves. Which receiver will perceive a beats phenomena and what frequency will it be? Assume that the source never passes the second receiver.

Solution:

(a) (2 points) Receiver 1 will perceive the beats, receiver 2 will receive two signals at the same frequency.

(b) (3 points) The sound from the source will be at frequency $f_1 = \frac{v_s}{v_s+v} f$

(c) (3 points) The sound reflected from the wall will be at frequency $f_2 = \frac{v_s}{v_s-v} f$

(d) (2 points) The beats will be at frequency $\Delta f = f_1 - f_2 = \frac{2vv_s f}{{v_s}^2-v^2}$

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33. (5 points) Consider a diatomic ideal gas at 300^oC that has a molar mass of 16 g/mol. What is the speed of sound through it?

Solution:

(a) (3 points) The speed of sound through a fluid is given by the Newton-Laplace equation

$$v_{sound} = \sqrt{\frac{K}{\rho}} \tag{1}$$

where K is a stiffness coefficient (can also be B for Bulk modulus) and ρ is the density

For ideal gases, the equation turns into

$$v_{sound} = \sqrt{\frac{\gamma RT}{m}} \tag{2}$$

where γ is the adiabatic index, R is the molar gas constant, T is the temperature in kelvin, and m is the molar mass of the gas

(b) (1 point) The adiabatic index of a diatomic gas is $\frac{7}{5}$

(c) (1 point) The velocity is 646 m/s

34. There exists a source of sound with frequency f. The sonic power of the source is P. The velocity of sound in medium is v_s. The density of the medium is ρ. Consider a point d meters away from the source.

(a) (3 points) Find the pressure oscillation amplitude p.

Solution:
The intensity of a sound wave is governed by the following equivalences, derivable with dimensional analysis and/or with calculus, but readily available:

$$I = \frac{P}{4\pi d^2} = \frac{p^2}{2\rho v_s} \tag{3}$$

where P is power of the source, d is the distance from source, p is the pressure amplitude of the sound wave, ρ is the density of the medium, and v_s is the velocity of sound in the medium. Thus

$$p = \sqrt{\frac{P\rho v_s}{2\pi d^2}} \tag{4}$$

(b) (3 points) Find the oscillation amplitude of the particles in the medium, knowing the pressure amplitude p.

Solution: The pressure amplitude is related to the wave motion of the particles by the equation

$$p = BAk \tag{5}$$

where p is the pressure amplitude, B is the bulk modulus of the medium, A is the amplitude of the physical displacement wave of the particles, averaged over mean distance traveled, and k is the wavenumber of the wave.

We also know from the Newton-Laplace equation that the velocity of sound through a medium is

$$v_s = \sqrt{\frac{B}{\rho}} \tag{6}$$

where v_s is the velocity, B is the bulk modulus, (can also be K for stiffness coefficient) , and ρ is the density.

Thus

$$A = \frac{p}{Bk} = \frac{p}{{v_s}^2 \rho k} = \frac{p}{{v_s}^2 \rho \frac{2\pi}{\lambda}} = \frac{p}{2\pi v_s \rho f} \tag{7}$$

End of Examination (I'm so sorry)

Team Number: ____________

Question	Points	Score
1	1	
2	3	
3	4	
4	2	
5	4	
Total:	14	

Question	Points	Score
6	6	
7	4	
8	13	
9	1	
10	1	
Total:	25	

Question	Points	Score
11	3	
12	3	
13	3	
14	2	
15	2	
16	1	
Total:	14	

Question	Points	Score
17	1	
18	2	
19	2	
20	10	
21	6	
22	1	
23	8	
24	2	
25	1	
26	1	
27	1	
28	2	
29	1	
30	1	
Total:	39	

Question	Points	Score
31	7	
32	10	
33	5	
34	6	
Total:	28	