PRINCETON SCIENCE OLYMPIAD

2021 Division C
Sounds of Music Key

Instructions:

- You have 50 minutes for this test.
- You are to take this test WITHOUT using the internet (ex: Wikipedia, Google…)
- This test *does* require sound to be on, since there is an audio file, so make sure that you have either working speakers or headphones.
- There is no instrument testing section to this year's competition since it is online :(
- Order of tiebreaker questions are listed on the next page.

Point Total: ____/225

Introduction:
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This test is worth 225 points and consists of 3 sections:
Music Theory: 37 questions (#1-37), 60/225 points
Physics: 32 questions (#38 - 69), 110/225 points
Instruments: 4 multi-part exercises (2 shorter ones and 2 longer ones) (#70-95) , 55/255 points

Divide it up! The point values give a suggestion on one way to divide the test.

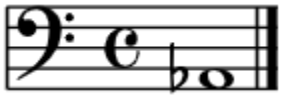
The tiebreaker order is 32,69,88,60,91,63,28,57,18,65,82,67,81,14,61,30,48,46,76,38. You shouldn't worry about this!

If at any time your answers are not saving, don't panic. Do not refresh your browser, continue your exam as normal, and hit submit once you are done. Record your answers somewhere else just in case. Send a message to your proctor to let them know.

Good luck, we hope you enjoy the exam :D

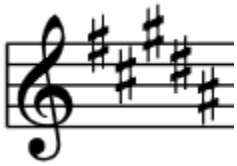
Section 1: Music Theory (55 pt)

1. Name the following notes (0.75 pt each)



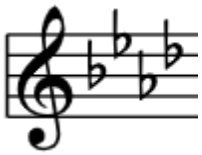
Ab

2. Name the major keys (0.75 pt each)



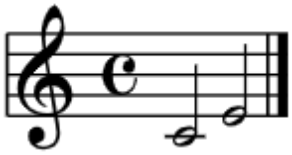
B

3. Name the minor key (0.75 pt each)

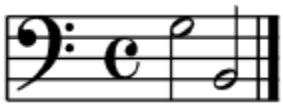


F

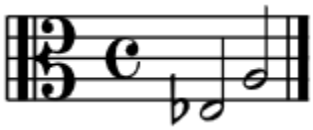
4. Name the following intervals! (1.25 pt each)



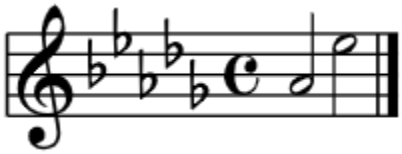
a) Major 2nd
b) Augmented 2nd
c) Minor 3rd
d) Major 3rd
e) Augmented 3rd
f) Perfect 4th



a) Major 3rd
b)Perfect 5th
c) Augmented 5th
d)Minor 6th
e) Major 6th
f) Major 7th



a)Diminished 4th
b)Perfect 4th
c)Augmented 4th
d)Diminished 65h
e)Perfect 5th
f)Augmented 5th



a)Diminished 5th

b)Perfect 5th

c)Augmented 5th

d)Major 6th

e)Minor 7th

f)Major 7th

5. Which two clefs below are “enharmonic”?

Here "enharmonic" will be defined as every note on the two staffs is the same pitch and octave. (2.5 pt)

a) 

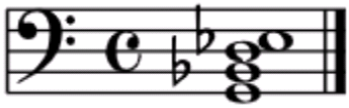
b)

c)

d)

e)

6. Answer the following about seven chords



6.1. What is this seven chord? (1.5 pt)

a) Major Seventh

b) Minor Seventh

c) Dominant Seventh

d) Augmented Seventh

e) Half-diminished seventh

f) Full diminished seventh

6.2. What is the inversion? (1 pt)

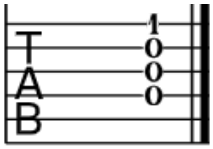
a) Root

b) 1st inversion

c)2nd inversion

d)3rd inversion

e)4th inversion



6.3. What is this seventh chord?(1.5 pt)

a) Major Seventh

b) Minor Seventh

c) Dominant Seventh

d) Augmented Seventh

e) Half-diminished seventh

f) Full diminished seventh

6.4. What note is the root?(1 pt)

G

7. Using movable do solfege, write the solfege for the following starting and engine at Do. (2 pt each)

Ascending Melodic Minor Scale

Do, Re, Me/Ma, Fa, Sol, La, Ti, Do

Descending Locrian Scale

Do, Te/Ta, Le/Lo,Se, Fa,Me/Ma, Ra,

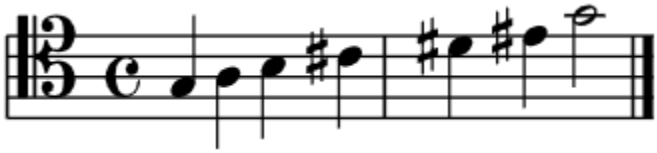
General Guidelines:

-1 point for one mistake

-1 point for fixed do

-.5 point for reverse direction

8.

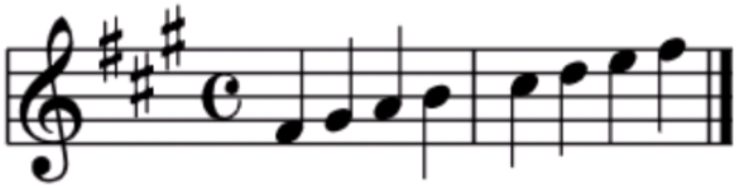


8.1. What is the name of a scale with this many notes? (0.75 pt)

8.2. List the number of semitones between each step. (1.5 pt)

8.3. What is the specific name of this scale (take a guess!)? (1.25 pt)

9. What type of scale is this? (1.5 pt)



a). Major

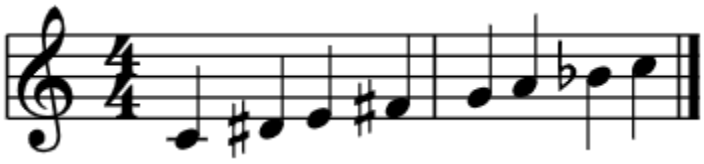
b). Natural Minor

c). Harmonic Minor

d). Melodic Minor

e). None of the above

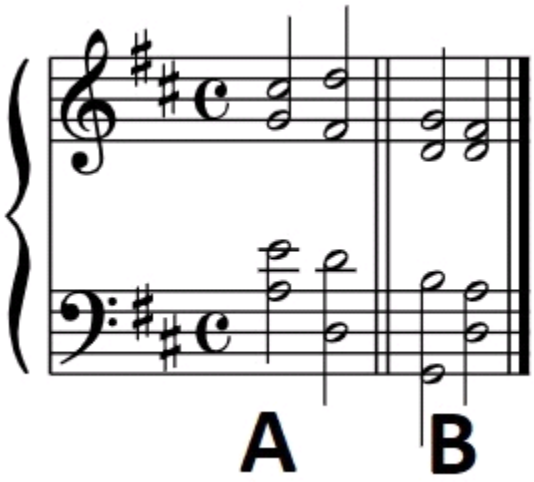
10. What is the name of this weird scale? (1.5pt)



Hungarian Major (a surprising number of teams got this!)

11.

Cadences are an important part to classical music (and music in general) as they end phrases. Generally 4th scale degrees like to resolve to the 3rd scale degree. 7th scale degrees like to resolve to the tonic.



11.1. What type of cadence is cadence A? (1.5 pt)

a) Perfect authentic cadence

b) Imperfect authentic cadence

c)Plagal cadence

d)Deceptive cadence

e) Half cadence

f)Evaded cadence

11.2. What type of cadence is cadence B?(1.5 pt)

a) Perfect authentic cadence

b) Imperfect authentic cadence

c)Plagal cadence

d)Deceptive cadence

e) Half cadence

f)Evaded cadence

11.3. Which cadence is generally considered the stronger, A or B? Justify your choice by referring to 4-3 resolutions and 7-1 resolutions in each cadence. (2.75 pt)

General Guidelines:

Correct choice (0.75 pt)

+0.75 pt for cadence A

~ 0.25 pt for "perfect authentic cadence"- that's an easy guess.

Resolutions (1.5pt):

+ 1.5 pt for mentioning cadence A both resolutions (4-3 and 7-1) while the other cadence only has a 7-1 resolution. Any form of this is fine.

~ 0.75 pt for only mentioning around half of the above answer.

~ 0.25 pt for trying to analyze resolutions.

Final justification (0.5 pt):

+0.50 pt connection between more resolutions and stronger cadence. (If most of above is correct/ makes sense)

Here is the sample of music:

https://flat.io/score/57793ccffb01d3ae741528f0-mii-channel-piano-arrangement

It's a nice arrangement!

12.

12.1. What is the time signature of the piece? (1 pt)

a) 6/8

b) 12/8

c) 2/4

d) 3/4

e) 4/4

f) 6/4

12.2. What is the highest note in the bass clef? (1.25 pt)

G#

0.25 pt for G (gotta watch the key!)

12.3. What is the dot (circled in red) above the note called? (0.75 pt)

Staccato (quite tricky to spell as I learned)

12.4. What is this line (green arrow pointing to it) between the notes called? (0.75 pt)

Tie

12.5. How many beats is the rest circled in blue? (0.75 pt)

2

12.6. Analyze closely which voice should be heard. Which line is the melody? (3.5pt)

a) Soprano

b) Alto

c)Tenor

d) Bass

12.7. Check the following that accurately describes the music. (2 pt)

a). Swung

b). Syncopated

c). Chromatic

d). Legato

e). Monophonic

f). Homophonic

1.5pt for B,C

0.75 for (B or C) and F

0.25 for B,C and E (you missed the 50/50) or B,C,F + another

0 otherwise

(I realize homophonic is very debatable depending on what definition you are using, so I only took off 0.5 pt if you didn't include it and put B,C)

12.8. For fun -

What piece do you think this is?

Here are a couple hints:

This is not the first section of the piece. This is actually the second (and last) section. Look at measure 1 (bridge) and the last measure.

The score is the 2nd half to the mii channel song!! This helps a lot with question 28 if you recognize it.

13.

13.1. Time signatures can be a little ambiguous when listening. We will state that a quarter note is given one beat in order to narrow down the options. You should know the bottom number now. What is the time signature of this sample? (2.0 pt)

a)2/4

b)3/4

c)4/4

d)5/4

e)6/4

f)7/4

13.2. Which word best describes the tempo of the piece (1.25 pt)

a). Lento

b). Adagio

c). Adagietto

d). Andante

e). Allegro

f). Presto

13.3. If you listen closely, some sort of electronic timpani comes in and strikes 6 times. We have added a bell that rings when it starts so you can better locate it. With the time signature in mind, how many beats does each strike get? (5 pt)

2/3

13.4. The rhythm is quite funky. Is there a swing? (1.5 pt)

a). 2:1 swing

b). 3:1 swing

e). 4:1 swing

f). No swing

13.5. What mode do you think this piece is in? (1.5 pt)

a). Major

b). Minor

c). Dorian

e). Lydian

d). None of the above

13.6. What are the scale degrees of the first 8 notes in the melody? (2.25 pt)

a). 2-2-1-2, 2-2-1-2

b). 3-3-1-3, 3-3-1-3

c). 5-5-3-5, 5-5-3-5

d). 1-1-7-1, 1-1-7-1

e). 4-4-3-4, 4-4-3-4

f). 6-6-4-6, 6-6-4-6

13.7. What about the next 5 notes? (2.25 pt)

a). 6-5-3-2-1

b). 6-5-4-3-2

c). 5-4-3-2-1

d).7-6-4-3-2

e). 7-6-5-2-1

13.8. If you listen very closely, there is an electric bass strumming in the background.
Can you write down the **scale degrees** of the first 2 distinct (different) notes of the bass? Use

numbers each separated by commas. (3 pt)

1.5 pt - 1,4 for each correct guess (i.e 1,3 or 6,4 each get 1.5 pt)

*Note, scilympiad has 1,6 which is the first and third base note (not the first and second). Sorry!!

Great job finishing the music theory portion!

Section 2: Physics (110 pt)

Multiple Choice:

The wave equation (1D) is a differential equation in the form of

$$\frac{\partial^2 s}{\partial t^2} = C^2 \frac{\partial^2 s}{\partial x^2}$$

A more familiar specific solution to this differential equation.

$$s(x,t) = A\cos(kx - \omega t + \phi)$$

Where $k = \omega C$

1. What are the following variables equivalent to? (We will make it multiple choice with all the possible answers)
   1.1. k **B**
   1.2. ω**C**
   1.3. ϕ**D**
   1.4. A **E**
   1.5. C^{-1} **A**

   Possible choices

   a) Velocity

   b)(Angular) Wavenumber

   c)Angular Frequency

   d) Phase shift

   e) Amplitude

2. What are the units for each?
   2.1. k

   a) m^2

   b) M

   c)m^(-1)

   d) m^(-2)

   e) Unitless

2.2. ω

a) s^2

b) s

c) s^(-1)

d) s^(-2)

e) Unitless

2.3. ϕ

a) m/s

b)m

c) s

d) m^(-1)

e) s^(-1)

f) Unitless

2.4. A

a) m/s

b)m

c) s

d) m^(-1)

e) s^(-1)

f) Unitless

2.5. C^{-1}

a) m/s

b)m

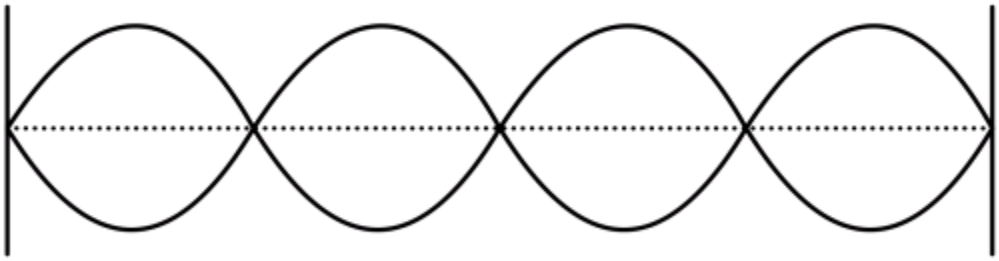
c) s

d) m^(-1)

e) s^(-1)

f) Unitless

3.



3.1. Which overtone is shown above? (2.25 pt)

a) First Overtone

b) Second Overtone

c) Third Overtone

d) Fourth Overtone

e) Fifth Overtone

3.2. How many nodes and antinodes are shown in the diagram? (2.25 pt)

a) 4 Nodes, 4 antinodes

b)4 Nodes, 5 antinodes

c) 5 Nodes, 4 antinodes

d)5 Nodes, 5 antinodes

4. Ben from the Instrument section gets on a plane to fly back home. When Ben looks to his left he hears two of his fellow passangers discussing the plane. He hears one man saying that this plane is traveling at a supersonic speed! Although this is skeptical, what Mach number could the plane be at if it was truly flying at a supersonic speed? (2.5 pt)

a) 0.5

b) 1.0

c)4.0

d)6.0

e)10.0

f)30.0

5. Which one of these is closest to a conventional dispersion relation? (g is the gravitational constant, c is the speed of light). (4 pt)

a). $\omega(k) = \frac{\omega^3}{gk} - ck$

b). $k(\omega) = \frac{\omega^2}{g} - 2\frac{\omega}{c}$

c). $\omega(k) = 4\sqrt{gk} + 3ck$

d). $k(\omega) = 3\frac{ck^2}{\omega} + 4k$

6. Noise cancelling headphones are a relatively new piece of technology that has become a staple buzzword for marketing. Although the details are complicated, the general idea makes sense. When the headphone receives the ambient noise, what additional signal does it send in order to cancel the noise? (3 pt)

a). In phase, half amplitude

b). In phase, same amplitude

c). In phase, double amplitude

d). 180 degrees out of phase, half amplitude

e). 180 degrees out of phase, same amplitude

f). 180 degrees out of phase, double amplitude

7. Anthony is in the chemistry lab. Assume the temperature is not extreme. He has three vials. Vial A contains mercury, vial B contains water vapor, and vial C contains nitrogen gas. In which vial is the speed of sound the fastest? (No references necessary.) (2.5 pt)

a) Vial A

b) Vial B

c) Vial C

8. (*Everyone received points for this question due to grossly wrong multiple choice answers*)

Bob and his friend are at an astronomy exhibit. They step into a dark room shaped as a hemisphere where they project the stars of the Milky Way on the ceiling. The radius of the hemisphere is 6 m. The floor has an absorption coefficient of 0.35 while the ceiling has a coefficient of 0.15. His friend says "Whoaaa" really loudly at 70 dB (from Bob's viewpoint)! How long does it take in seconds for the sound to decay to 10dB in the room? Round you answer to the nearest second. (5.5 pt)

a) 26 seconds

b)46 seconds

c) 66 seconds

d) 86 seconds

e) 106 seconds

f)126 seconds

How to actually do the problem:

We will find the average coefficient through weighted averages:

The surface area of the ceiling is twice that of the floor.

u = (0.15 * 2 + 0.35)/3 = 0.216666

Sabine's formula tells us:

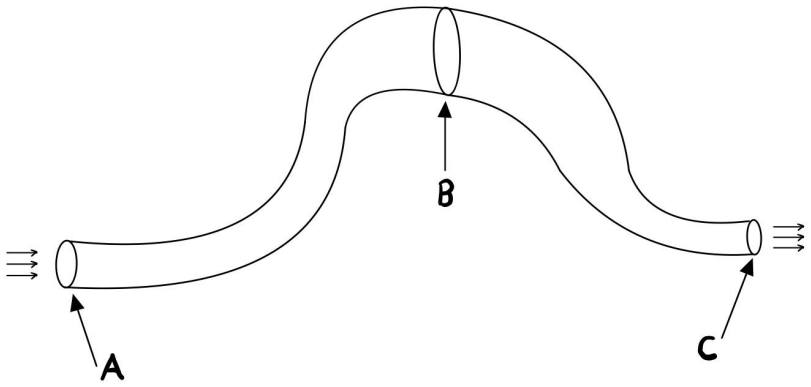
0.16 * Volume / (Surface Area * u) = 0.16 * (2/3 * pi * r^3) / ((3 * pi * r^2) u) = 0.16 * 2/9 * 6 / 0.21666 = 0.9846 s

Short answer:

1. Sarah and Olivia were playing hide and seek on a chilly -5 ℃ day in Princeton. Olivia went looking for Sarah in a cave, and ran in at a speed of 11 miles per hour (she's on the track team) yelling "Hellooooooooo?" As she continued running in at a constant speed she heard her voice reflected back at her, at a higher pitch than before. If she yelled her "Hellooooooooo?" at a constant pitch the same as that of Bb4, what would be the frequency of the sound she hears reflected off of the back of the cave? (8 pt)

f ≈ 480 Hz (You can apply doppler's twice, once for the wave coming from Olivia to the wall, then again for the wave coming from the wall back at Olivia, then combine the formulas)

2.



Water flows through a pipe in a house as shown above. The diameter of the pipe at certain points are as follows: A: 9 cm, B: 16 cm, C: 11 cm. The water flows at point A with a speed of 22 meters per second. How fast does the water flow out at point C? (4.5 pt)

14.7 m/s (Continuity Equation)

5. Pipes Pipes Pipes

8.1) Melinda is trying to create an organ. She is missing a pipe that is supposed to play the note D3. What should the length of this pipe be, assuming she plays the organ in a room at 20 ℃? (3.25 pt)

0.58 meters

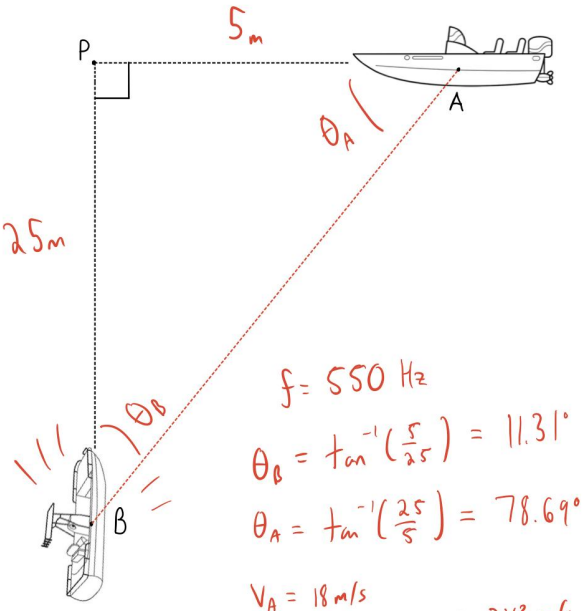
8.2) After making the pipe in part A, she compares the pitch made from that pipe with one from her organ at home. She hears a beat frequency of 2 Hz when they are played together, meaning that her organ at home is too flat. How much of the pipe should she add or remove to fix its frequency? (4 pt)

She should remove 0.01 meters of pipe

8.3) Now that both of her pipes are cut to the correct length, Melinda starts to practice using it. She is able to use her pipe to produce the fifth harmonic frequency. What is the wavelength of the sound waves produced? (2.75 pt)

(⅘)L =Lamba = 0.46 m

6. Two boats A and B are both traveling to point P. When boat B is 25 meters away from point P, the captain honks its horn, which has a frequency of 500 Hz. When boat A is 5 meters away from point P, the captain of boat A hears the horn from boat B. If boat A travels with a speed of 18 m/s and boat B travels with a speed of 22 m/s, what is the frequency of the horn heard by the captain on boat A? (You may assume that the speed of sound is 343 m/s) (10.5 pt)



$f = 550\ Hz$

$\theta_B = \tan^{-1}\left(\frac{5}{25}\right) = 11.31°$

$\theta_A = \tan^{-1}\left(\frac{25}{5}\right) = 78.69°$

$V_A = 18\ m/s$

$V_B = 22\ m/s$

$C = 343\ m/s$

$$f_{observed} = \left(\frac{C + V_A \cos\theta_A}{C - V_B \cos\theta_B}\right) f$$

$$f_{observed} = \left(\frac{343 + 18\cos(78.69)}{343 - 22\cos(11.31)}\right) 500$$

$$f_{observed} = \left(\frac{346.53}{321.43}\right) 500$$

$$f_{observed} \approx 539\ Hz$$

7. Alice has a speaker source emitting sound with 1W of acoustical power. Alice is 15 m away from the speaker. There is negligible attenuation of sound.

7.1) What is the sound intensity Alice hears in decibels? (2.75 pt)

85.5 dB

Then, Alice turns off the speaker because she doesn't like the song. She somehow runs at the speed of sound, 343m/s, and follows the wave to keep track of its intensity. After 3 seconds the intensity is 63 decibels. After 5 seconds the intensity is 50 decibels. There is attenuation of sound.

7.2) An older study measured a dog's threshold of hearing to be $10^{-13}\ W/m^2$. If we were to adjust the decibel scale to a dog's threshold of hearing, what would the intensity of sound be after 3 seconds in "dog decibels"? (2.25 pt)

73 dog decibels

7.3) The density of air is 1.2 kg/m^3. The ordinary frequency (f, not ω) of the sound is 500 hz. What is the amplitude of the sound wave after 5 seconds? (6 pt)

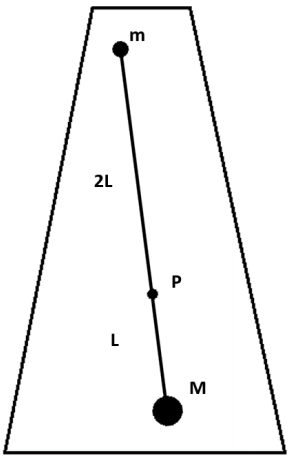
7.016 * 10^-9 m

7.4) What is the sound intensity after 10 seconds in regular decibels? (8 pt)

30 dB.

The goal is to realize that intensity vs. attenuation of sound is modeled by an exponential function.
In other words I(t) = A * bt
Using the points (0,85),(3,63),(5,50), we get a 85.42 * 0.8998^t.
Plugging in 10 we get I(10) = I 85.4 * .899810= 30 dB

8. Here is a simple mechanical metronome. It is composed of two point masses of mass M and m located on opposite sides of the rod. They are at distances of L and 2L from the pivot point P respectively. In this specific case, the period of oscillation of the metronome is $T = 2\pi\sqrt{\frac{I}{\tau}}$ where τ, the net torque is $MLg - 2Lmg$ and I, the moment of inertia about P, is $ML^2 + M(2L)^2$.



8.1) What condition does m and M need to satisfy in order for the oscillation to occur? (3.5 pt)

a) M < m

b)M < 2m

c)M < 3m

d) M > m

e) M > 2m

f) M > 4m

8.2) The **small angle** approximation is often made for harmonic motion when an angular component is involved. (2.5 pt)

8.3) If there is air resistance, there is a damping force of $-\ bv$where b is the drag coefficient and v is the velocity of the ball. The value of b is half of its critically damped value. By what factor does the frequency change compared to the original frequency? (5 pt)

a) $\frac{1}{2}$

b) $\frac{\sqrt{2}}{2}$

c) $\frac{\sqrt{3}}{2}$

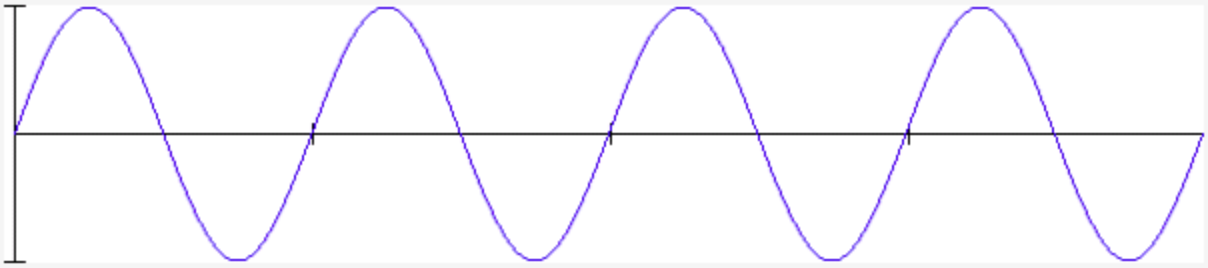
d) 2

e) $\sqrt{2}$

d) $\sqrt{3}$

9.

Below is the graph of the wave given by the function f(x).



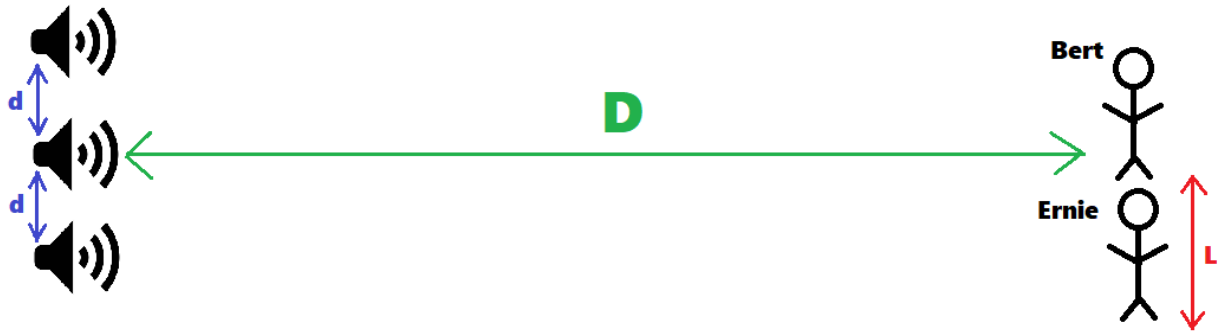
The wavelength of the wave is λ. Blake picks a random point on the wave given by $x = a$.

What are the two smallest values of b such that $f(a) + f(a + b\lambda) + f(a + 2b\lambda) = 0$?

(3 pt)

1/3 , 2/3

10.



As shown in the diagram above (not drawn to scale), two friends Bert and Ernie are a horizontal distance D away from a set of three speakers. Bert is positioned directly across from the middle speaker and will not move. The three speakers are separated in the vertical direction by a distance d between them. What are the THREE smallest vertical distances L that Ernie can move away from Bert so that Ernie can hear no sound, given that D = 100 m, d = 2 cm, and the speakers are playing a frequency of 2500 Hz. You may assume that the speed of sound is 343 m/s. (12 pt)

229m, 457m, 915m (Treat as triple slit diffraction pattern)

Section 3: Instruments (60 pt)

Warm up:

Match the following instruments to either a) Idiophones, b) Membranophones, c) Chordophones, d) Aerophones, & e) Electrophones. (1pt each)

1.1) Omele **B**

1.2) Benta **A**

1.3) Hosho **A**

1.4) Qanbus **C**

1.5) Theremin **E**

1.6) Saxophone **D**

1. Let's analyze violin strings

   Round all frequencies to the nearest whole number. Assume equal temperament tuning with A4 = 440hz.

   1.1. Why are the strings of violins different in thickness? (2.5 pt)

   a) The 4 strings are usually made out of different material

   b) The change in thickness changes the tensions in the string

   c) Because increasing thickness increases volumetric density

   d) Because increasing thickness increases area density

   e) Because increasing thickness increases linear density

   1.2. Bryan doesn't know the frequency of the D string. He wants to calculate it using equal temperament. Given A4 = 442 Hz, what expression should Bryan evaluate to calculate the frequency of the D string? (4 pt)

   442 * 2^(-7/12) or 442 / 2^(7/12)

   1.3. Bryan's violin is all in tune except for the D string. From nut to bridge, a violin is about 33cm. The mass of the D string is about 42 grams. What should the tension in the string be for the note to sound correct? (2.75pt)

   Tension ≈ 49 N

   1.4. Bryan is trying to learn a new technique. He is learning it on the G string. He presses his finger down on the string 3.5 cm from the nut on the G string.

   What frequency is this? (2 pt)

   Frequency ≈ 217 Hz

1.5. He lifts off my other finger. He lightly pressed his finger ⅓ up the string from the nut. This plays a harmonic.
What is the frequency of the resulting note (2.5 pt)?
Frequency ≈ 582 Hz

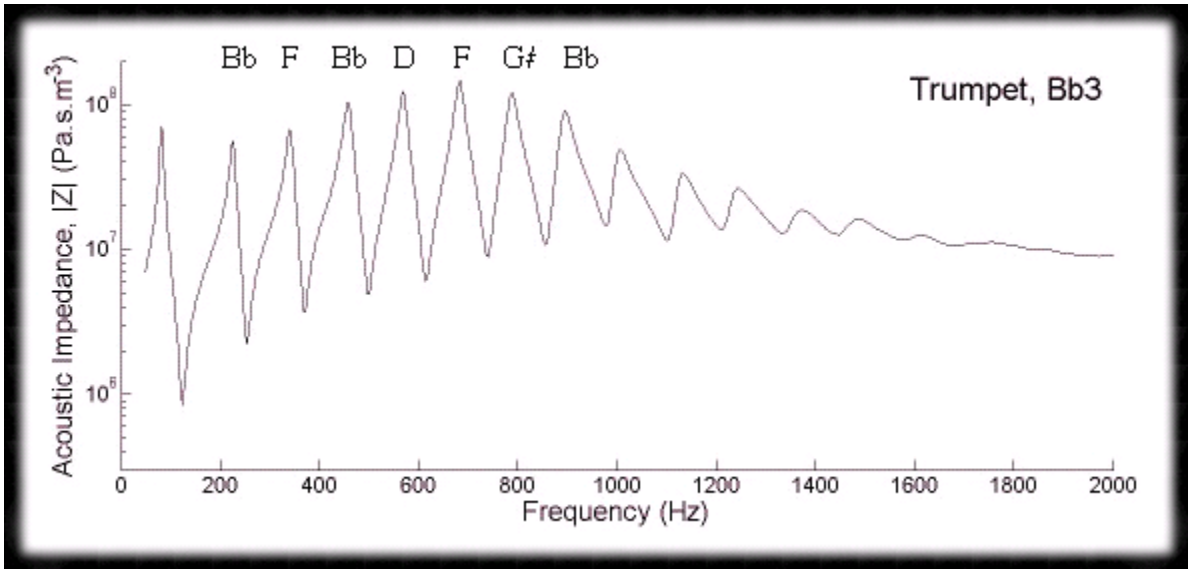
1.6. Finally, combine both questions 1.3 and 1.4. If He uses one finger to press the string down 3.5 cm from the nut, and lightly press his other finger approximately ⅓ up the string from the nut (the finger will need to be adjusted slightly) , what frequency will this be? (3.75 pt)
Frequency ≈ 868 Hz
Since no one got it, the key is to realize that by shortening the string lightly touching the string now creates the 4th harmonic, not the 3rd.

Although some likely string players knew the note was supposed to be 880 hz, the calculation is below that (868 hz).
The wavelength will be ((.33 - 0.35) * 0.5) = 0.1475 m
So f = 128 / 0. 1475 = 637.6 = 868 hz

1.7. What is this technique called? (2.25 pt)
Artificial Harmonic

1.8. What two fingers are most likely to be used for this example?(1.25 pt)
a). 1
b). 2
c). 3
d). 4

2. Jimmy plays a very loud instrument: the trumpet! He wants to learn more about it, so he records the notes and harmonics of the trumpet in the graph below.



2.1. Jimmy doesn't know the effect of the bell and the mouthpiece. So he takes the bell and mouthpiece off his trumpet and blows into just the tubing. Jimmy hears fewer harmonics. What is the series of harmonic numbers Jimmy hears (i.e. 1,4,7,10,13...) and why? (3pt)
Odd harmonics (1,3,5,7) because the tubing of a trumpet is open on the bell end and closed on the other end (due to the mouth).

2.2. Jimmy finds an old notebook explaining why the bell and mouthpiece allow the trumpet to hit more harmonics. However, some of the words are smudged. For questions x-y, help Jimmy fill the words in.
When you blow into the trumpet, transverse/longitudinal waves travel through the trumpet. For lower notes, the bell of the trumpet increases/decreases the frequency of the note because it causes the waves in the trumpet to be reflected earlier/later compared to higher notes. The point of reflection for the wave is proportional to where r is the radius of the bell and R is its Radius of Curvature.
For higher notes, the mouthpiece of the trumpet increases/decreases the frequency of the note. The resonance frequency of the part is proportional to F .

This is how the mouthpiece and the bell allow the trumpet to hit more notes of the equal-tempered scale.

Choose the correct word, and fill in the blank for D.
Point values are
A ,B,E (1.25 pt)
C (1.75 pt)
D (3.5 pt)
Choose from the following for F.
Let A be the cross-sectional area of the opening, let V be the volume of the cavity, and let L be the length of the opening.
a)$\sqrt{AL/V}$
b)$\sqrt{AV/L}$
c)$\sqrt{VL/A}$
d)$\sqrt{V/AL}$
e)$\sqrt{A/VL}$
f)$\sqrt{L/AV}$

2.3. Jimmy once read that there is a strange note in brass instruments referred to as the "pedal tone." Using the graph, which best approximates the pedal tone in hz? (2.5 pt)
a)60

b)120

c)180

d)240

e)300

f)360

2.4.

Wow! Jimmy understands the trumpet can produce most of the harmonics now! However, all these harmonics don't cover all the possible notes... the keys help accomplish this by lengthening the tube!

What keys do I need to press down to play a Bb3? (Check all that apply) (1.5 pt)

a) 1

b) 2

c) 3

2.5 Jimmy is so inspired he tries to build a trumpet for his sounds of music instrument. However, when playing the Bb, the trumpet is out of tune by 5 hz.

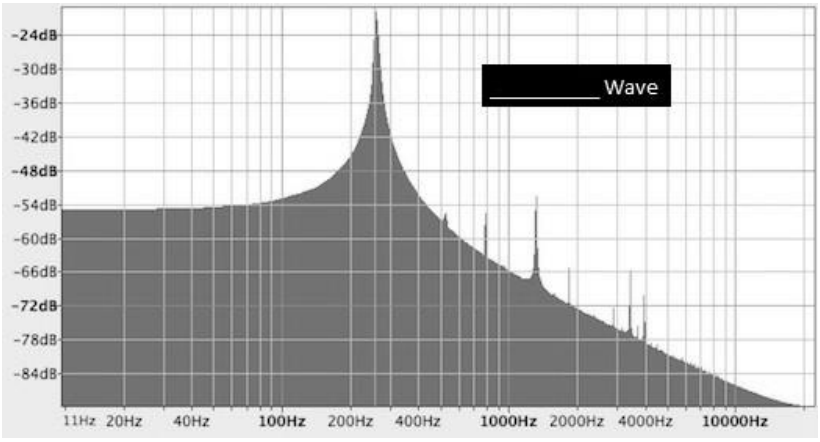
Which is closer to the original note in cents, 5 hz sharp or 5 hz flat? (2 pt)

a) 5 hz sharp

b) 5 hz flat

c) They are the same number of cents away from the original note.

3.1 Shown below is the Fourier Analysis of a particular wave. What wave does this Fourier Analysis represent? (3.75 pt)



a) Sine wave

b) Triangle wave

c) Square wave

d) Sawtooth wave

3.2 This Fourier Series can easily be described by just one note. What is that note? (2.75 pt)

C4

Congrats for finishing the exam!