RHSOi

## River Hill Science Olympiad Invitational 2021

# Sounds of Music


# Exam Key

**Total Points: ______/120**

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# Exam Instructions

- You will have **50 minutes** to complete this exam.
- You may use any resources that you have compiled prior to the start of this exam (print or online, but this test is **NOT** open-internet) and two calculators as allowed by national Science Olympiad rules.
- Please use at least **three significant figures** in your answers. More is fine, fewer is not.
- Assume the speed of sound is **343 m/s** unless stated otherwise.
- Assume A4 = **440. Hz** unless stated otherwise.
- Assume pitches are **equally tempered** unless stated otherwise.

## GOOD LUCK! Hope you enjoy the test!

The displacement of a particle on a string (in meters) over time (in seconds) is characterized by the function $x(t) = 0.571\sin(876t)$. Calculate:

1. (1.00 points) The frequency of the function, in Hz. (Don't write units as part of your answer.)

   This function is a simple harmonic motion equation taking the form $x(t) = A\sin(\omega t)$, where $\omega = 2\pi f$. Consequently, $f = \frac{\omega}{2\pi} = \frac{876}{2\pi}$, which gives ***139*** Hz after three sig figs.

2. (1.00 points) The period of the function, in milliseconds. (Don't write units as part of your answer.)

   It just so happens that the period is the reciprocal of the frequency, so $\frac{1}{139}$ gives ***0.00717*** seconds.

3. (1.00 points) The amplitude of the function, in centimeters. (Don't write units as part of your answer.)

   Amplitude is the *A* in $A\sin(\omega t)$, so it's 0.571 meters. Multiply by 100 to convert to centimeters and you get ***57.1*** as your answer.

4. (2.00 points) The wavelength of the function, in decimeters. (Don't write units as part of your answer.)

   Wavelength is the speed of sound divided by the frequency. The speed of sound is 343 m/s, so divide that by the frequency to get 2.46 meters, which is ***24.6*** decimeters.

5. (2.00 points) Which of the three most common states of matter (solid, liquid, gas) is sound slowest in? What property of matter causes sound to be slowest in this state of matter?

   Sound is slowest in ***gases*** because ***they have a lower density than solids and liquids***. Sound is propagated through collisions between particles, so a less dense medium means that collisions don't occur as often and sound can't move as fast.

6. (3.00 points) You are a certain cabbage vendor in the Earth Kingdom city of Omashu, and you're absent-mindedly tending to your goods one day when you hear a shout. You turn, startled, to see a bunch of kids hurtling toward you on the package delivery system at 20.0 m/s and shouting what you perceive as a perfectly in-tune, equally tempered G4. What frequency were they actually shouting at?

   An equally tempered G4 has a frequency of 392.00 Hz (I'm adding some extra sig figs for now, just so that we can be precise), so we can plug this into the Doppler effect formula:

   $$392.00 = \frac{343 \pm v_r}{343 \pm v_s} f_0$$

   In this case, we will set $v_s$ to 20.0 m/s and subtract it from 343, since an approaching source causes the initial frequency to be perceived as higher than it actually is. $v_r$ is 0, so we can just toss that part out. After that, it boils down to algebra:

   $$\frac{392.00}{\frac{343}{343-20.0}} = \frac{392.00(343-20.0)}{343} = f_0 = 369.14\ Hz$$

   Bringing it back to three sig figs gives ***369 Hz*** as the answer to this question.

7. (3.00 points) The kids pass by you, still heading at the same speed and shouting at the same frequency, and you breathe a sigh of relief, but then you see another group of kids coming down the ramp at 25.0 m/s shouting what you perceive as an in-tune, equally tempered A4. What beat frequency do you perceive between the first group of kids and the second?

   Now we need to calculate the *perceived* beat frequency between the groups. That means calculating what frequencies we *hear* the shouts as, not what frequencies they actually are. The good news is that one of those frequencies is already provided - it's 440. Hz. That means we just need to calculate the perceived frequency for the first cart as it moves away. Let's take our answer from the last question (using the extra sig figs for precision's sake) and plug it into the Doppler effect formula:

$$f = \frac{343 \pm v_r}{343 \pm v_s}(369.14)$$

   Once again, $v_r$ is 0 and $v_s$ is 20.0 m/s - but we need to change the sign on $v_s$ from - to + since they're moving away from us now, so the effective wavelength is longer and the effective frequency lower. (I will do a poor job explaining this, so instead I urge you to look up "Doppler effect diagram" if you're confused. It will make more sense visually.) Then you actually crunch the numbers to get 348.80 Hz.

   Now for the final step - beat frequency! Just subtract 348.80 from 440. to get 91.20 Hz, which is ***91.2 Hz*** after sig figs.

8. (3.00 points) What is the actual beat frequency between the two groups of kids?

   We already have the actual frequency of the first cart... Now to find the second cart's actual frequency the same way. Pull out the formula:

$$440.00 = \frac{343 \pm v_r}{343 \pm v_s} f_0$$

   We're still not moving, so $v_r$ = 0, and $v_s$ is 25.0 m/s. Remember to subtract in the denominator since the cart is approaching us, and we get:

$$\frac{440.00}{\frac{343}{343-25.0}} = \frac{440.00(343-25.0)}{343} = f_0 = 407.93\ Hz$$

   Now, take 369.14 Hz from question 6 and subtract from 407.93 Hz to get 38.79 Hz, which is ***38.8 Hz*** after sig figs.

9. (2.00 points) Meet Stringy. Stringy is 1.86 meters long with a linear density of 70.0 g/m. What tension does Stringy need to have in order to vibrate at a second harmonic of 440. Hz?

   Hi Stringy! The relevant formula for this problem (relating a string's frequency to tension) is as follows:

$$f = \frac{nv}{2L} = \frac{n\sqrt{\frac{T}{\rho}}}{2L}$$

   The Greek letter *rho* (the weird-looking p) represents linear density, while *n* is the harmonic number. This is fairly straightforward - just plug the values into the formula.

$$440. = \frac{2\sqrt{\frac{T}{0.0700}}}{2(1.86)}$$

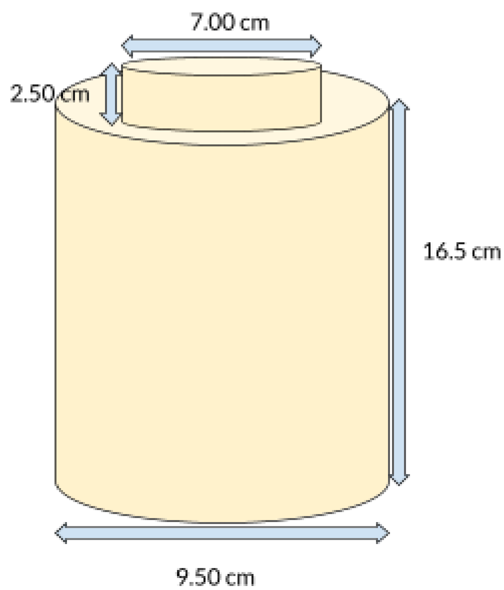
Note that the density is written as 0.0700 instead of 70.0; the formula only works correctly if provided density in kg/m, so we'll have to divide by a factor of 1000 to achieve that. Remember that $\sqrt{\frac{T}{0.0700}} = \frac{\sqrt{T}}{\sqrt{0.0700}}$ as we rearrange the equation:

$$\frac{440.}{\frac{2\sqrt{\frac{1}{0.0700}}}{2(1.86)}} = \frac{440.(2)(1.86)(\sqrt{0.0700})}{2} = \sqrt{T} = 216.53 \rightarrow T = 46884.50$$

With three sig figs, that becomes ***46900 N***. I guess you could say Stringy's a little high-strung...

Patrick Star finally gets fed up with everyone telling him mayonnaise isn't an instrument, and he sets out to prove Bikini Bottom wrong. He presents his neighbors with an empty mayonnaise jar whose dimensions are displayed in the artist's rendering below. (That's a neck on top, not a cap.)

(Additional author's note: I admit that the dimensions of this jar are not very conducive to actually producing sound, but it's Patrick, what did you expect?)




10. (3.00 points) Patrick blows across the opening of the jar's neck. Assuming that Patrick knows nothing about end correction, what frequency can he expect to hear?

There is, in fact, a formula for this! It's $f = \frac{c}{2\pi}\sqrt{\frac{A}{VL}}$, where *c* is the speed of sound, *A* is the area of the neck, *V* is the volume of the jar (sans neck), and *L* is the length of the neck. We have *c* and *L* already, and some geometry formulas will get us *V* and *A* (remember to convert centimeters into meters!):

$$A = \pi r^2 = \pi(\frac{0.07}{2})^2 = 0.00385$$
$$V = \pi r^2 h = \pi(\frac{0.095}{2})^2(0.165) = 0.00117$$

If you think those numbers are way too small, you're not alone (I initially did too!), but remember that a square/cubic meter is actually pretty big. Now that we have all our formulas, plug and chug:

$$f = \frac{343}{2\pi}\sqrt{\frac{0.00385}{0.00117 \cdot 0.025}} = 626.29$$

After sig figs, that comes out to ***627 Hz***.

11. (3.00 points) Squidward, Bikini Bottom's resident acoustics expert, informs Patrick that end correction does, in fact, apply to the mayonnaise jar, and that the equivalent length of the jar neck can be determined by $L_{eq} = L + 0.3D$, with *D* representing the diameter of the neck. Patrick looks at him blankly, says "Oh", and redoes his math. Now what frequency does Patrick expect to hear from the mayonnaise jar if he blows across the top?

    Same formula as last time, just substituting in $L_{eq}$ for *L*. *D* is 0.07 m.

    $$f = \frac{343}{2\pi}\sqrt{\frac{0.00385}{0.00117(0.025 + 0.3 \cdot 0.07)}} = 461.71$$

    The new frequency is ***462 Hz***.

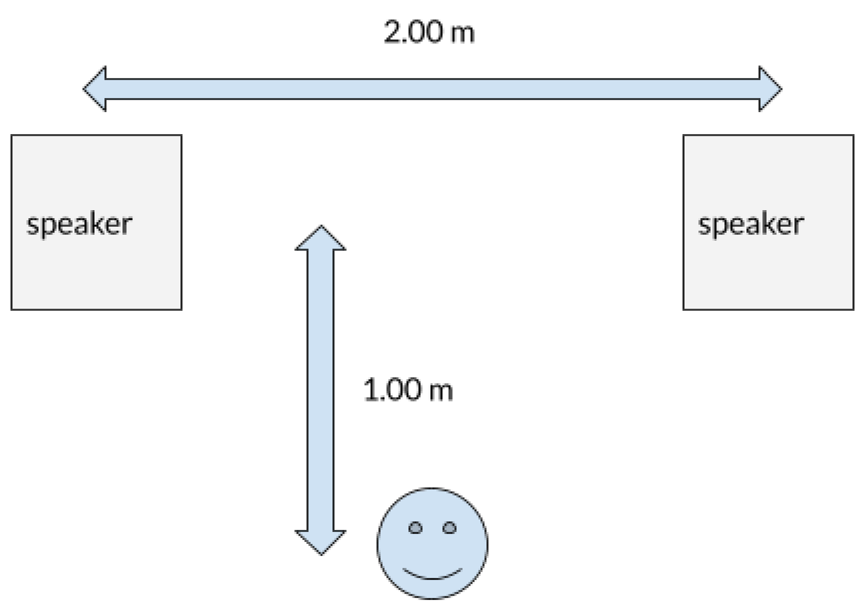
12. (1.00 points) After embarrassing himself in front of the populace of Bikini Bottom with his jar antics, Patrick eventually realizes that his "instrument" isn't actually very good at making sound. Had it worked though, the mayonnaise jar would exemplify what specific acoustical device?

    This type of device is known as a ***Helmholtz resonator***.

13. (2.00 points) A standing wave has a fundamental frequency of 622 Hz. What is the wavelength of the 3rd overtone of this wave?

    "3rd overtone" is just another way of saying "4th harmonic". That means we just multiply the fundamental frequency by four to get *f* = 1288 Hz. Divide 343 m/s by this frequency for a wavelength of ***0.266 meters***.

Two speakers are positioned 2.00 meters apart. You are standing equidistant from the speakers, 1.00 meters in front of both. The artfully rendered diagram below illustrates this configuration.



14. (3.00 points) The speaker on the left emits a tone whose wavelength is equal to the distance between you and the speaker. Some time *t* later, the speaker on the right emits the same tone at the same amplitude. What is the minimum value of *t* such that you hear nothing when the second speaker starts playing?

    The trick is to use the delay to set the speakers out of phase from each other; that is, when the left speaker is at its peak (at your location) the right speaker is at its trough and vice versa, causing the waves to cancel out. For this to work with a minimum value of *t*, the right speaker needs to start while the left one is halfway through its first wavelength. In other words, *t* needs to be half of the period of the wave.

    That's good to know. Now what? Well, period is the reciprocal of frequency, and frequency is the speed of sound divided by wavelength. We can use the Pythagorean theorem to calculate the wavelength - you're one meter to the left/right and one meter to the front of the two speakers. Use 343 m/s as the speed of sound to calculate the following:

$$c = 343,\ \lambda = \sqrt{1.00^2 + 1.00^2},\ f = \frac{c}{\lambda},\ T = \frac{1}{f} \Rightarrow \frac{T}{2} = \frac{\lambda}{2c} = \frac{\sqrt{1.00^2+1.00^2}}{2(343)} = 0.0020615$$

    Therefore, the minimum value of *t* is ***0.00206 seconds***.

15. (2.00 points) What is the name of the phenomenon at work here? What is a real-world use of this phenomenon?

    The phenomenon is ***destructive interference***. Answers may vary for real-world uses; an example would be active noise cancelling, which uses destructive interference to remove background noise.

16. (2.00 points) Remember Stringy? Well, Stringy has a son, named Stringson. (Wow, I'm so original with names!) Stringson is 3.00 meters long, with a speed of sound of 600. m/s. If Stringson vibrates with a frequency of 300. Hz, what is an equation *D(t)* that represents the displacement over time of a particle on Stringson located 1.00 meters from one of Stringson's ends?

    Let's start with the equation for frequency of a vibrating string:

$$300 = \frac{n(600)}{2(3.00)}$$

    Solve for *n* to get *n* = 3. We now know that Stringson is vibrating at its (his?) third harmonic, which means that there are three standing waves, separated by nodes (points with zero displacement) at the ends of the string and every $\frac{l}{n}$ meters in between. Wait a second…

$$\frac{l}{n} = \frac{3.00}{3} = 1.00$$

    That's right, the particle is at a node! The equation is just ***D(t) = 0***, because it never moves.

Saketh lights a firecracker to celebrate the very first RHSOI, but forgets to get away from it in time. He's 1.00 meters away from the firecracker when it detonates with a sound intensity of 160. dB, and poor Saketh has to be taken to the hospital for potential ear damage.

17. (4.00 points) (Tiebreaker 3) Where Jeff is standing, the firecracker has a sound intensity of 100. dB, and from Victoria's location it has an intensity of 60.0 dB. If Victoria, Jeff, Saketh, and the firecracker are all along a straight line, how far apart are Victoria and Jeff?

First off, don't be like Saketh. Be safe around firecrackers, and don't buy firecrackers that loud.

Anyway, let's calculate the sound intensity of the firecracker at Saketh's location in $W/m^2$. The formula for intensity in decibels is:

$$I\ (dB) = 10\log(\tfrac{I}{I_0}),$$

where $I_0$ is $10^{-12}$ $W/m^2$. If you're comfortable with logarithms, you may recognize that the equation can be simplified:

$$I\ (dB) = 10(\log I - \log I_0) = 10(\log I - \log 10^{-12}) = 10[\log I - (-12)] = 10(\log I + 12) = 10\log I + 120$$

From here, we substitute 160 for *I (dB)* and solve for *I* in $W/m^2$. We get that *I* = 10,000 $W/m^2$ at Saketh's location, which is a *lot*. Now, let's relate the intensity to Saketh's distance from the firecracker:

$$I = \tfrac{P}{4\pi r^2}$$

Just plug the numbers in (*I* = 10,000 $W/m^2$, *r* = 1.00 m) and solve to get *P* = 40,000π W. Now, we have to solve for the intensities from Jeff's and Victoria's locations using $I\ (dB) = 10\log I + 120$, which gives us *I* = 0.01 $W/m^2$ for Jeff and 0.000001 $W/m^2$ for Victoria. Using these values for *I* and *P* = 40,000π W from earlier, we can get our distances:

$$I = \tfrac{P}{4\pi}\cdot\tfrac{1}{r^2} \rightarrow r = \sqrt{\tfrac{P}{4\pi I}}$$

For Jeff: $r = \sqrt{\frac{40000\pi}{4\pi(0.01)}} = 1000$

For Victoria: $r = \sqrt{\frac{40000\pi}{4\pi(0.000001)}} = 100000$

Subtract the two numbers and you get ***9.90 x 10⁵ m***, or ***99.0 km***. (Consider that 60 dB is about the volume of a normal conversation… if Victoria could hear that from 100 km away, then the firecracker must have been *loud*.)

18. (3.00 points) Express the sound intensity of the firecracker at Saketh's location in terms of the threshold of hearing pain *I* = 1.00 $kg/s^3$.

Wait, isn't intensity in $W/m^2$? It is indeed, so how do you measure in $kg/s^3$? Well, let's do some dimensional analysis.

$$\frac{W}{m^2} = \frac{N\cdot m\cdot s^{-1}}{m^2} = \frac{kg\cdot m\cdot s^{-2}\cdot m\cdot s^{-1}}{m^2} = \frac{kg\cdot m^2}{s^3\cdot m^2} = \frac{kg}{s^3}$$

That's right, they're the same thing! Now to calculate the ratio. Let's get *I* at Saketh's location in $W/m^2$:

$$160 = 10\log I + 120 \rightarrow I = 10000$$

Now just take the ratio of the two *I* values. Conveniently enough, 10000 divided by 1 is 10000. Who'd've imagined? That makes the answer ***10000I***. (Make sure to add the *I* at the end for full credit - it's a ratio in terms of *I*, after all!)

19. (6.00 points) (Tiebreaker 1) The local hospital is busy treating JOVID-21 patients and has no space for Saketh, so he's taken by helicopter to another location. The helicopter happens to fly at 343 m/s. Given that the adiabatic heat index for the speed of sound $\gamma$ is 1.4, the ideal gas constant *R* is 8.31 J/mol, the molecular mass of air *M* is 0.0290 kg/mol, and the temperature in degrees Celsius varies linearly with altitude in meters by *T*(*a*) = 108 - 0.00200*a*, what is the highest altitude the helicopter can fly at in order to avoid exceeding the speed of sound?

    The formula to calculate speed of sound given all these numbers is $v = \sqrt{\frac{\gamma RT}{M}}$. Let's set *v* to 343 m/s and substitute:

$$343 = \sqrt{\frac{(1.4)(8.31)(308-0.00200a)}{0.0290}}$$

    We can change the large radical into two radicals - one for the numerator and one for the denominator - and multiply both sides by the square root of 0.0290.

$$343\sqrt{0.0290} = \sqrt{(1.4)(8.31)(308-0.00200a)}$$

    Square both sides and divide by the product of 1.4 and 8.31:

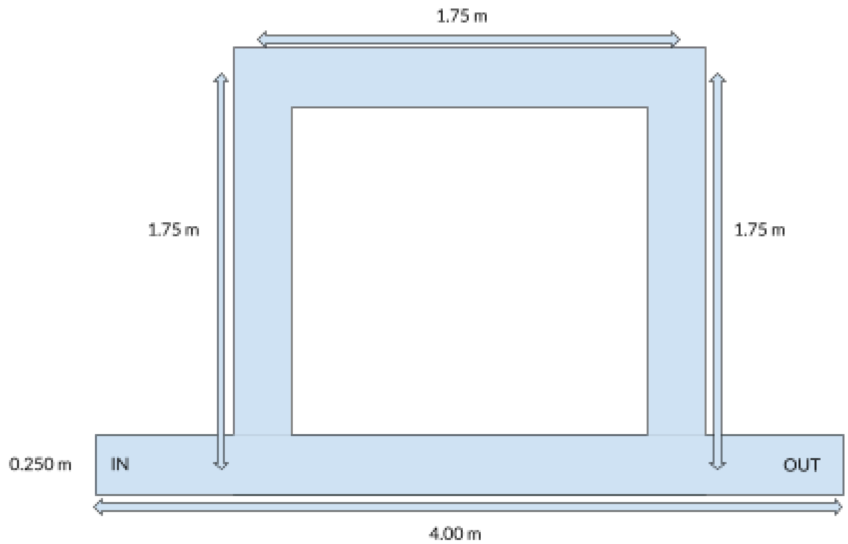
$$\frac{(343)^2(0.0290)}{(1.4)(8.31)} = 308 - 0.00200a$$

    It's just relatively straightforward algebra from here.

$$a = \frac{308-\frac{(343)^2(0.0290)}{(1.4)(8.31)}}{(0.00200)} = 500(308 - \frac{(343)^2(0.0290)}{(1.4)(8.31)}) = 7368.53$$

    Adjusting for sig figs, that means the maximum altitude is ***7370 meters.***

Here's an extremely professional drawing of a pipe setup. The pipes are cylindrical with a constant diameter of 0.250 meters. Note the arrows. (The light-blue rectangular sections are all connected to each other.)




20. (2.00 points) A tone is played through the pipe at the location marked “IN”. What is the lowest frequency that the tone can be in order for the waves to still remain in phase at the location marked out?

    In order for the waves to remain in phase, the difference between the length of the straight-line path (1.75 m) and the length of the detour (5.25 m) needs to be a non-negative integer number of wavelengths. They’re obviously different lengths, so zero wavelengths doesn’t make sense, but what about one? That means the largest possible wavelength (which leads to the lowest possible frequency) is equal to 5.25 - 1.75 m, or 3.50 m. Divide the speed of sound 343 m/s by the wavelength to get ***98.0 Hz***.

21. (2.00 points) What is the highest wavelength that the tone can be in order for the waves to be completely out of phase with each other at the location marked “OUT”?

    This is similar to the last one, except if the waves are completely out of phase, it means they’re half a wavelength apart, so the difference between lengths is equal to $n + 0.5$ wavelengths, where *n* is a non-negative integer. The smallest possible value of $n$ is 0, so the wavelength is $\frac{5.25-1.75}{0.5}$ = ***7.00 meters***.

22. (4.00 points) A certain solid has density $\rho$ = 2720 kg/m$^3$, bulk modulus *B* = 67.2 GPa and shear modulus *G* = 45.0 GPa. Calculate its speed of sound given that it is homogeneous and isotropic.

    OK, this is a bit misleading, since there are actually two speeds of sound in a solid - one for the pressure (P) wave and one for the shear (S) wave. Either correct answer will get full credit. Let’s start with the P wave velocity:

    $$c = \sqrt{\frac{E}{\rho}}$$

    *E* is Young’s modulus, while *rho* is the density - but wait, we don’t have *E*! Well, there’s another formula for that:

    $$2G(1 + v) = E = 3B(1 - 2v)$$

    *v* is Poisson’s ratio - another value we don’t have - but we can find it with some substitution and algebra:

$$2(4.50 \times 10^{10})(1 + v) = 3(6.72 \times 10^{10})(1 - 2v)$$
$$9.00 \times 10^{10} + 9.00 \times 10^{10}v = 2.016 \times 10^{11} - 4.032 \times 10^{11}v$$
$$4.932 \times 10^{11}v = 1.116 \times 10^{11}$$
$$v = 0.226$$

Now substitute *v* in and solve for *E*:

$$2G(1 + 0.226) = E = 3B[1 - 2(0.226)] = 1.104 \times 10^{11}$$

Back to our initial equation, putting in our density and new Young's modulus:

$$c = \sqrt{\frac{1.104 \times 10^{11}}{2720}} = 6369.88$$

So our P-wave velocity is ***6370 m/s***. What about the S-wave? That's a similar equation:

$$c = \sqrt{\frac{G}{\rho}}$$

We already have both of those values, so just substitute and solve:

$$c = \sqrt{\frac{4.50 \times 10^{11}}{2720}} = 4067.47$$

The S-wave velocity is ***4070 m/s***.

23. (3.00 points) Why can't decibels be used as a unit of loudness?

    The answer to this is that ***loudness is dependent on perception*** - I might perceive a noise as being rather loud, while you might not. In addition, ***different frequencies can cause different loudnesses even when they have the same decibel intensity***. However, that hasn't stopped the creation of units to measure loudness, such as sones and phons.

24. (3.00 points) This is a table relating phons and sones, which are both units of loudness. Calculate a function *s*(*p*) that returns the loudness of a sound in sones when given its loudness in phons.

| Phons | Sones |
|---|---|
| 100 | 64 |
| 90 | 32 |
| 80 | 16 |
| 70 | 8 |
| 60 | 4 |
| 50 | 2 |
| 40 | 1 |

You'll notice that as the phons increase by ten, the sones double, which means we can make an exponential function out of this:

$$s(p) = 2^{f(p)},$$

where $f(p)$ is some expression that will give the correct exponent. A good first step to coming up with the expression would be to divide *p* by 10 (or multiply by 0.1), so that each increase in *p* of one doubles *s*:

$$f(p) = 0.1p$$

If you look at the graph of $s(p) = 2^{0.1p}$, you'll now notice that it's basically just $2^p$ shifted four units to the right. Let's just subtract for from $f(p)$! That makes our equation ***s(p) = 2*** $^{\mathbf{0.1p - 4}}$.

25. (3.00 points) I'm trying to analyze some audio. I decided to use a spectrogram, but then I discovered a mel-spectrogram, and now I'm confused. What's the difference between a mel-spectrogram and a regular one?

    Instead of using Hertz as the unit for the y-axis, a mel-spectrogram ***converts frequencies to the mel scale***, which tries to create a "linear" scale such that pitches the same perceptual "distance" apart are the same physical distance apart on a mel-spectrogram. In practice, this looks a lot like a logarithmic transformation, so answers that mention the transformation but not the mel scale receive one point (the important part is the mel scale - regular spectrograms can be logarithmic too).

For questions 26-40, you'll be analyzing score 1 (located at [this URL]).

26. (2.00 points) What time signature is this piece in? What is the name of the meter of this piece?

    We can count the beats in the first measure: three triplet eighth notes equal a quarter note and so do two eighth notes, and when we add in the three quarter notes we end up with five quarter-note beats in a measure, making the time signature ***5/4***. 5/4 is a quintuple meter, meaning that it has five beats per measure, and it's a ***simple quintuple meter*** because the beats are divided into halves (unlike a compound meter, where the beats are divided into thirds, i.e. a dotted quarter note in 15/8 that gets split into three eighth notes).

27. (1.00 points) What's the Italian term for the type of repeated rhythm played by the string section at the beginning of the piece?

    The term here is ***ostinato***, which comes from the Italian for "stubborn" (think English "obstinate") and refers to a sequence of notes played repeatedly, often by the same voice.

28. (2.00 points) Both of the harps alternate between two notes for the first few measures of the piece. State the names of these two notes (e.g. C4 and D4) as well as the interval between them.

    The two notes are ***G1*** and ***G2***, and there is an interval of an ***octave*** between them.

29. (1.00 points) You'll notice at the bottom of the first page that the strings are instructed to play *col legno*. What does this style marking mean?

*Col legno* is a special technique where ***string players make contact with the strings using the backs of their bows***. The specific type of *col legno* used in this piece is *col legno battuto*, which entails striking the string with the bow (there's also *col legno tratto*, in which the wood of the bow is actually drawn across the string).

Let's look at the first and third notes played by the Bassoon 2 part. (Ties are considered to be one note.)

30. (1.00 points) What is the interval between these two notes?

    The two notes are G2 and D♭3, leading to an interval of a ***diminished 5th*** between them. (An augmented 4th is the same in practice, but diminished 5th is the technically correct answer, so only that receives full points.)

31. (1.00 points) What is the width of the interval between these notes (in cents) in equal temperament?

    The notes are six semitones apart, for an interval of ***600 cents***.

32. (2.00 points) What is the width of the interval in Pythagorean tuning, if the first note played by the bassoon is the tonic?

    The ratio between a tonic and its diminished fifth in Pythagorean tuning is 1024/729. Let's convert that to cents:

$$cents = 1200\log_2(\frac{F_2}{F_1}) \rightarrow 1200\log_2(\frac{1024}{729}) = 588.27$$

    The width is ***588 cents***.

33. (2.00 points) Given that the tempo is quarter note = 160. beats per minute, how long (in seconds) does it take Horn 6 in F to play their first three notes? (Again, ties count as one note.)

34. (2.00 points) Four types of instruments (according to the Hornbostel-Sachs system) are represented on the second page. Name each of them as well as how many of the parts listed on the page fall into each category.

    From top to bottom, there are ***11 aerophones***, ***1 membranophone***, ***1 idiophone***, and ***7 chordophones***.

35. (2.00 points) There are three lines intersecting the stems of the tam-tam's notes throughout the second page. What musical effect does this represent? What does it mean to change the number of intersecting lines?

    The effect represented is ***tremolo***, which involves rapidly playing a note over and over again. ***More lines equal greater frequency of tremolo*** - three lines mean that the tremolo should be a rapid sequence of 32nd notes, for instance, while two lines indicate to use 16ths instead. ("Roll" was also accepted in place of "tremolo", since this was a percussion instrument.)

36. (2.00 points) In measure 14, the words *con sordino* are written above the 1st Trumpet in C part. What does *con sordino* mean? What is another instrument that can be played *con sordino*?

*Con sordino* is Italian for ***with a mute***. Other instruments may vary; examples include ***pretty much every standard Western brass instrument*** as well as ***the violin***.

37. (2.00 points) What clef is marked for the Tenor Trombone 1 part in measure 18? What note (in concert pitch) is written in the last two beats of that measure?

    That clef right there is the ***tenor clef***. The note is ***B♭3***.

38. (1.00 points) At measure 25, the piece modulates into a new key, spearheaded by a horn melody. What key is this, in concert pitch?

    When I say "piece", I mean "brass instruments" - the ostinato remains unchanged. The new key is ***A♭ major***, as indicated by the unison B♭ (concert E♭) in the horns that switches to an E♭ (concert A♭) major chord, all over concert E♭ and C in the trombones.

39. (3.00 points) The score concludes with the woodwinds and upper brass sustaining a chord over a low brass/strings ostinato. What slash chord (in concert pitch) represents the conclusion of the score? (A slash chord is written in the format $C^7$/D, where $C^7$ is the upper chord and D is the bass note.)

    Looking at the upper chord, we notice that all the notes are either A♭, F, or D♭, meaning that we're dealing with a D♭ major chord. (While a C# major chord is the same thing in practice, it's technically considered a separate key signature from D♭ with its own set of notes, so D♭ is the only one that receives full credit.)

    Heading over to the low brass and strings, it should be somewhat obvious what the bass note is - they're all playing a concert C! Therefore, we can write this in slash chord notation as ***D♭/C***.

40. (2.00 points) (Tiebreaker 4) Name that tune! What piece have you been looking at this whole time? (P.S. you get half credit for simply writing anything here…)

    The piece here is none other than ***"Mars, the Bringer of War"***, the first movement in Gustav Holst's multi-work suite *The Planets*. If you've never heard of it before but the music sounds familiar, that's likely because John Williams drew heavy inspiration from it when composing the score for *Star Wars* (see: the D♭/C slash chord, which is literally in Williams's score, orchestrated similarly, just with a different rhythm).

Time for score number 2! This piece is a two-piano arrangement of a song. You can find it [here].

41. (1.00 points) The first measure is marked as 4/4 time signature, but that's a bit misleading… What's the measure's actual time signature? (Format your answer similar to "4/4" without the quotes.)

    There are only two quarter notes' worth of beats in this measure, so the time signature is ***2/4***.

42. (2.00 points) The last beat of the first measure is eight 32nd notes running up a scale. What mode (e.g. C ionian) is this run in?

    The notes are F-G-A-B♭-C-D-E-F, which matches the pattern of an ***F major mixolydian*** scale.

43. (2.00 points) Measures 2-4 in the first piano part are played by a melodica in the actual song. What Hornbostel-Sachs category does a melodica fall under? How does it produce sound and change between notes?

    A melodica is an ***aerophone***. ***Air is blown in past a reed, causing it to vibrate*** and make sound. You can change between notes by ***pressing keys*** on the melodica's body.

44. (1.00 points) What Italian term describes the small eighth note with a slash through it in measure 7 of the 2nd piano part? (Don't worry too much about spelling.)

    The word is ***acciaccatura***, from the Latin verb meaning "to crush". Full credit should be given as long as spelling is close enough that it can be distinguished as meaning acciaccatura, which I copy-pasted from Wikipedia because I don't trust myself to spell it correctly either.

45. (2.00 points) Measures 14 and 16 include octave intervals in the piano 1 part. Are the intervals likely tuned to be 1200 cents apart, wider, or narrower? Why?

    The intervals are likely to be ***wider*** apart than 1200 cents. Pianos often exhibit inharmonicity due to the fact that strings aren't perfect, causing octave intervals to sound closer than they really are. Consequently, ***octave intervals are often "stretched"***, making them wider than they should be to sound correct.

46. (1.00 points) What two-word phrase describes the new key signature (starting from measure 22) in relation to the previous one?

    The new key signature is G major, which is the ***parallel major*** of the previous key signature (G minor).

47. (2.00 points) (Tiebreaker 5) What song is this? (Like the last one, you get half credit for writing anything here…)

    This piece is ***Baka Mitai***, a piece from the *Yakuza* video game series OST that gained popularity in humorous deepfakes back in 2020. The first three words of the chorus, "Dame Da Ne", are also acceptable.

You have your melodica-player friend handle the first piano part while you play the second part on an actual piano.

48. (3.00 points) You're playing outside as night falls and it gets colder. How does the intonation of each instrument change due to the temperature (sharper/flatter/unaffected) and why?

    The piano would get ***sharper*** as the instrument technically physically contracts from the lower temperature, leading to shorter string lengths and higher pitch. The melodica, however, would become ***flatter*** since the air coming from the player's mouth is colder, so the speed of sound in it is also lower.

49. (4.00 points) (Tiebreaker 2) Your friend holds out the G4 in the last measure while approaching you from behind at 2.75 m/s, and you play a G4 at the same time. However, this leads to some weird-sounding beats. It's harder to tune a piano than it is to tune a melodica, so you ask them to play the last note with slightly different intonation so that someone standing in front of both of you hears the same (in-tune) frequency from both instruments. Should they play sharper or flatter, and by how many cents?

Time for the Doppler effect once again! If your friend is approaching you from behind, then they're also approaching the person standing in front of you both, so let's figure out what frequency to play so that the perceived frequencies match an in-tune G4 (frequency: 392.00 Hz).

$$392.00 = \frac{343}{343-2.75} f_0$$

Use algebra to solve:

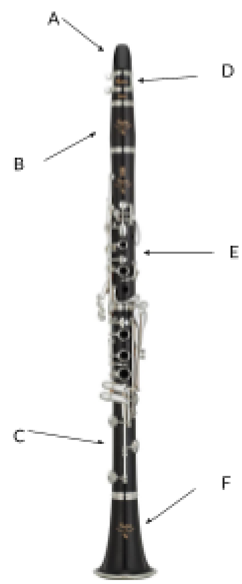
$$f_0 = \frac{(392.00)(343-2.75)}{343} = 388.85$$

And now calculate the number of cents between $f_0$ and the actual frequency of G4:

$$cents = 1200\log_2\left(\frac{388.85}{392.00}\right) = -13.94$$

The negative sign indicates that it should be flatter, so the answer here is to play ***flatter by 13.9 cents***.

This is a Yamaha YCL-CSVR B♭ soprano clarinet.




50. (3.00 points) Identify the six components of the instrument pointed out on the diagram. (The arrows are not pointing to keys or holes.)

    A: ***mouthpiece***
    B: ***barrel***
    C: ***lower joint***
    D: ***ligature***
    E: ***upper joint***
    F: ***bell***

51. (1.00 points) "Crossing the break" is a comparatively difficult task for a beginning clarinetist. While they may know the fingerings for higher notes, they struggle to actually get the notes out and often end up making painful squeaking noises. What concept in acoustics causes this difficulty?

This would be an example of ***acoustic impedance*** - the opposition that the instrument presents to flow coming from applied pressure (in this case, the player blowing into the clarinet). Inexperienced players aren't very skilled at handling the higher acoustic impedance of higher notes, and they often end up sending their air off the rails and getting weird overtones (squeaking noises) instead.

52. (2.00 points) I tried learning flute a few years ago. (Spoiler alert: I was known for having absolutely horrible tone.) I was trying to get the hang of high notes, but whenever I tried playing G6 I would end up playing the D below. What was causing that to happen? (Hint: the lowest G on a standard flute is G4.)

    A flute is a cylinder open at both ends, meaning that it can play odd and even harmonics. Whenever I tried to play G6 (G4's fourth harmonic), I ***kept missing the note and playing D6 (the third harmonic) instead***.

53. (2.00 points) Trumpets and cornets are relatively interchangeable instruments. What is the main difference between the two, and how does it affect the tonal characteristics of the two instruments?

    The main difference is that ***trumpets have cylindrical bores, while cornets have conical bores***. Tonal characteristics are subjective, but in general, ***trumpets are perceived to sound brighter and more piercing while cornets sound warmer and rounder***.

54. (5.00 points) (Tiebreaker 2) It's quite disappointing that due to the limitations of virtual Science Olympiad, you can't share your Sounds of Music devices with everyone. Write about a device you would have brought to the competition had it been in-person. What Hornbostel-Sachs category is it? How do you operate it? How does it make sound? What advantages do your specific design have over other devices? What disadvantages might it have?

    Answers may vary. Example below, for a vibraphone:

    Hornbostel-Sachs category: ***idiophone***
    How to operate it: ***hit a bar with a mallet***
    How it makes sound: ***the bar vibrates and the sound is amplified by a resonator***
    Advantages of the design: ***intonation is more stable than on a string or wind instrument, more durable***
    Disadvantages of the design: ***bulky, expensive, hard to construct and tune***