Answers on the following page.

Solutions match the problem in level of difficulty. You don't need much prior knowledge to understand solutions to easy problems; more scientific background is assumed for solutions to harder problems.

All questions are worth 1 point except for 37, which is 12 points.

1. B – the only thing that matters is the relative velocities of each vehicle. Y is getting further away from X at 10 m/s, so X hears a lower pitch, eliminating choice (A). Y is also getting more distant from Z (because Y moving 10 m/s faster than Z is), so we can eliminate (C). Choices (D) and (E) are wrong by extension. The correct answer is then (B).

2. C – the first overtone is the second harmonic, which is $2f$.

3. C – one half step is 100 cents. A major third consists of four half steps.

4. C – an increase in sound intensity level (SIL) by 10 dB means the intensity was multiplied by 10. Therefore, you'd need 10 times fewer people to achieve a decrease of 10 dB SIL. If you chose (D), you may have confused SIL with sound pressure level (SPL). Because decibels are logarithmic units, we use them as a ratio of two amounts; for SIL, this is the ratio of I to I_{ref}, and for SPL, the ratio of p to p_{ref}. Since pressure p is proportional, to $\sqrt{I}$, this is probably how you got (D) if you didn't random guess. If you didn't choose (D), you are safe mostly ignoring the previous explanation: most scientists don't use anything other than sound intensity level when referring to decibels in the context of sound. (Audio engineers are an exception who do pay attention to both SIL and SPL.)

5. B – because sound is being used to reduce sound, this is destructive interference. Particles above atmospheric pressure meet particles below atmospheric pressure, combining to form a region with no fluctuations of pressure, or a region of silence.

6. A – sound localization is how you know whether a sound is close by or far away, whether it is to your left and to your right. Critical-band perception is something I invented; the Fletcher-Munson effect is the tendency of certain frequencies to sound louder than others when played at the same intensity; kinesthetic sense is the ability to sense where your limbs are relative to your body (even if your eyes are closed, you know which of your hands is at a higher elevation, whether your right foot is to the left of your nose, etc.); the vestibular sense is your sense of balance.

7. E – $E\flat_6$ is a perfect fifth below $B\flat_6$. Perfect fifths are seven half steps, and a half step is a ratio of $\sqrt[12]{2}$ between two notes. The ratio is then $\sqrt[12]{2}^{\,7} = 1.50$

8. E – 759 Hz and 763 Hz are both possible, so it's not (A) or (B). But you can't play both at once—otherwise, you'd get beats of $f_{\text{beat}} = 763\text{ Hz} - 759\text{ Hz} = 4\text{ Hz}$, and four definitely doesn't equal two. So the answer has to be (E). (If you find a pitch generator online or on your computer, such as Audacity, try it yourself!)

9. D

10. C – in the equation, n is an exact constant, because pipes only have integer numbered harmonics. The number 4 in the equation also is exact, because exactly one fourth of a wavelength of the fundamental fits into a closed pipe. These are derived from theory, and therefore have an infinite number of significant figures. L has 3 significant figures, and v has 4 significant figures. The final computation should then have 3 significant figures.

11. A – frequency never changes from one medium (low-density string) to another (high-density string). Intuitively, every time a wave cycle from one string hits the other string, the other string will get a wave too (i.e. the wave gets transmitted). Consequently, if n wave cycles come from the low-density string in t time, then n cycles will arrive at the boundary of the two strings in t time, so all n of those cycles will transmit onto the high-density string in t time, and therefore the frequency does not change.

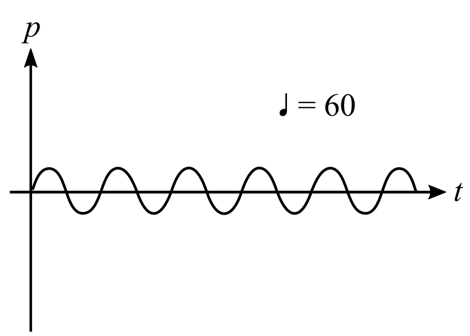
12. C – you may have heard of the general rule that smaller instruments have higher pitches. Translating this rule to average frequencies, this rule provides the correct ranking, as violins are the smallest and basses are the largest in size. Even though overlap exists between the viola and the violin, you don't actually need to compute the average to answer this question: the viola's strings are a perfect fifth lower than each analogous violin string, which you would soon realize in the case you had the tunings listed in your notes.

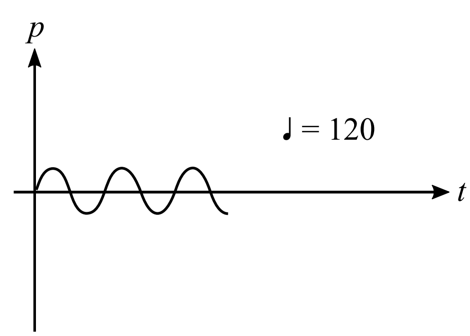
13. E – for a string, $v = \lambda f = 2Lf$. Bigger instruments have lower pitches, so if you increase either f or L, the other one decreases. Because orchestral string instruments do not have a standard size (there are 16.5″ violas, there are 15.5″ violas, etc.), we cannot tell what the length of the strings are, so some violins (or violas or cellos) will have strings with higher wave speeds than other violins, to account for the fact that all modern violins are tuned to the same pitches, but may differ in size.

14. E – noise is incoherent sound, in contrast to music or speech, for which frequencies are non-random. Since frequencies have intensity, noise is described by colors to tell us what frequencies are most abundant.

15. C – Solution 1: by definition, $P = W/t$, where P is the power usage of some process (such as playing a musical piece) over a time t. Because you're not using more energy per time to send out more wavefronts of a musical note, P doesn't change. (For example, to play note C_4 for 1 second you need x energy; to play it for two seconds, you'll need $2x$ energy; for three seconds, $3x$ energy, and so forth.) At twice the tempo, you'll finish the piece in half the time. So, you'll only be doing half the amount of work on the air.

Solution 2: you may not think solution 1 is a fair treatment of the question. "Hold on," you might say, "but I feel more tired when I play the piece twice as fast. My body is converting chemical energy from food into the mechanical energy used to move my finger on the piano, but it's doing it *twice as fast* now that the tempo is doubled." In fact, you may feel more tired. But we care about the work done on the air by the musical piece (actually the piano), not the work done by *you* on the piano. If you wanted to expend more of your body's stored energy from food, you could play the piano while simultaneously also singing, dancing, screaming, or taking a sounds of music test. This may motivate us to develop an alternative explanation for this question. Let's examine the wave structure of a generic note of pressure over time:





Notice that when we double the tempo, our frequency doesn't change. (C major is still C major no matter how fast you play it.) But now each wave is half as long in time—there are half as many peaks on the wave. So half as much work is done per note. And without loss of generality, this is true for every note in the piece, so half as much work is done by the piece.

Remarks:

- Note that the beats per minute are not standardized, so *largo* isn't always ♩ = 60.
- In the limiting case, a composition played at a tempo of infinity has a duration of zero seconds; in other words, an infinite tempo is equivalent to not playing a piece at all. It takes zero energy to not even play a piece, so increasing the tempo must lead to a decrease in energy emitted into the air. This eliminates choices (D) and (E).
- A small caveat is that all sound decays over time. For a piece at half tempo on piano, guitar, harpsichord, or any instrument not receiving a constant power input, the sound will slightly decay and the power decreases. This means that the true amount of work done at *allegretto* is a small, but negligible amount greater than $W/2$. But you don't need to know that much to find the correct answer ;)

16. B – bassoons, clarinets, and oboes are closed pipes; bells are not wind instruments at all (they are struck).

17. E – a psaltery and mandolin don't have keyboards; a piano and clavichord are struck, not plucked. Only a harpsichord matches all parts of the description.

18. A

19. A – harmonicas produce sound by blowing into a reed.

20. C – the Moog was one of the pioneering instruments in electronic synthesizers.

21. B

22. D – neither electricity nor air columns are involved, so it isn't an electrophone or aerophone. Because the music comes from bumps and bulges on the instrument itself, as opposed to a string or a membrane, the instrument must be an idiophone.

23. D – when identifying unknown notes on a staff, it's easy to count by thirds or fifths, because a major third will be the interval from one bar to the next (and a fifth will be every other bar). Starting on middle C, you can move your pencil down every bar, from C, to A, to F, and finally to D (which is D_3). We also should check the key signature, and see that there are no sharps nor flats on D, so we see this choice is good.

24. B – note that (C) and (D) are completely implausible. Anything that isn't in the time signature position of a staff shouldn't indicate time signature; anything that doesn't divide the octave into 12 half steps can't be displayed on a normal staff, much less a clef used on the staff.

25. E – to learn about solfège in sounds of music, see https://youtu.be/drnBMAEA3AM (no lie)

26. A – this is E major, or simply "E" in chord symbols.

27. C – frets are a half step apart. Guitars are string instruments, so the length of string from the bridge to the fret must be $\sqrt[12]{2}$ greater for each subsequent fret. (C) is the only choice that shows increasing distances between frets. (E) comes close, but $\sqrt[12]{2}$ is the ratio of distances from frets to the bridge, as shown in (B), and not the ratio of distances from fret to fret, which is what (E) shows.

28. The speed of a wave v is given by $\lambda f = v$. So, we have it that $f = \frac{v}{\lambda} = \frac{300.\text{ m/s}}{40.0\text{ m}} = 7.50$ Hz.

29. By definition of frequency and hertz, if x cycles of a wave pass by a point in one second, the frequency is x Hz. Conversely, 1 cycle will pass by every $\dfrac{1}{x}$ seconds, as you are "dividing both sides” by x. Therefore, the period of time T between cycles (which we usually just call the *period* of a wave) is equal to the reciprocal of frequency, or $\frac{7.00\text{ m}}{450.\text{ m/s}} = 0.0175$ s.

30. Minim means half note.

31. This is $\genfrac{}{}{0pt}{}{2}{2}$ time, or ¢ (both answers are acceptable)

32. In a snare drum, high frequencies carry most of the energy. In a bass drum, low frequencies have most of the energy. Students may write “intensity” or “pressure amplitude” instead of energy for full credit.

33. Absolute pitch

34. Any of these answers are acceptable:

- Dog whistles can produce sounds with high energy/power/intensity (1 point), which can damage human ears
- Dog whistles cause sound pollution (1 point) which may interfere with technology using sound and cause unintended damage

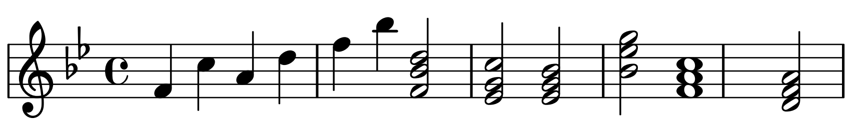
Credit will be given for only one of these answers. Even though both of these possibilities are equal to 1 point in value, the first is preferred as it is most direct.

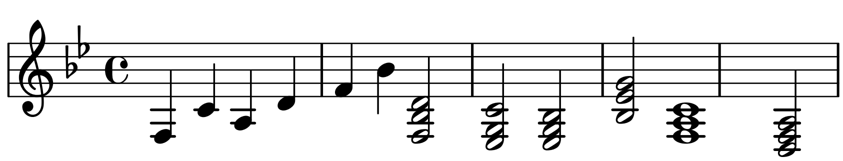
35. This chord contains notes B, D♯, F♯, and A♭.

36. Accept any of these: flutist, flautist, flutenist, fluter, flute player/performer, aulete. Do not accept flaut<u>en</u>ist. One point is awarded for having at least one item, but additional items may be used to break ties in the unlikely case that multiple teams have the same score.

37. 0.5 points for each correct note. In other words, each correct triad is worth 1.5 points, because a triad has three notes.

Either of these will be accepted (the first is preferred):





Credit will be awarded regardless of whether bar lines are drawn.

Errata

The original version of this test and key included several errors. For question 7, I mistakenly used the word “above” instead of “below” in the first sentence of the solution. For question 15, I had mistakenly swapped ♩ = 120 and ♩ = 60 in the diagram of the two waves in the solution. Because the typos in questions 7 and 15 only affected the answer explanations, no teams were misscored. In addition, the original answer key for question 31 included only the two stacked numbers, when it should have also included the symbol. This version of the answer key has corrected these errors.