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.

1. B – this occurs because of the Doppler Effect. In effect, as a source moves towards an observer, waves produced by the source such as sound waves. The frequency encountered by the observer only depends on (1) the speed of sound, (2) the velocity of the ambulance, and (3) whether the ambulance is getting nearer or farther from the observer. (1) and (2) are constant; (3) remains the same (nearer) until the ambulance passes by the observer, before changing (farther) and remaining that way. Therefore, the frequency as the ambulance approaches is constant, and the frequency as the ambulance drives away is constant, and the only time the apparent frequency changes is as the ambulances drives beside the observer and switches from growing nearer to going farther. At that time, the frequency seems to fall.

2. A – The intensity I of a sound equals $\dfrac{P}{4\pi r^2}$, where r is the distance from the source and P is the power output of the source. Whatever distance we are looking for, the intensity is 5 times less than it is at 2 m. That means it must be $\sqrt{5}$ times more distant, or at $(\sqrt{5})(2.0\text{ m}) = 4.5$ meters away, correct to two significant figures.

3. C – the fundamental frequency of a string f with length L and linear mass density μ under tension T is $\dfrac{1}{2L}\sqrt{\dfrac{T}{\mu}}$.

4. A – The tones will create beats of 1 Hz.

5. E – remember that for any type of simple harmonic motion or sinusoidal waveform, $\omega = 2\pi f$. In essence, 2π is the "angle" that you put next to your frequency f to get your angular frequency (literally true, because you multiply them).

6. E – a rarefaction is a region of a longitudinal wave, such as sound, which has the least concentration of medium, in this case particles of air.

7. D – iridescence is a property of light only. If you're curious, iridescence means the changing of color based on the direction at which an observer views an object. Iridescence isn't really a single phenomenon and could be a special case of interference/diffraction, reflection, etc. or a combination of these. However, the term only applies to light waves, and not to sound, so the correct answer is (D).

8. D – The resultant wave has a frequency of $\text{gcf}\,(f_1, f_2) = \text{gcf}\,(120, 180) = 60$ Hz. The period is then $1/f = \frac{1}{60}$ seconds.

9. C – this is known as timbre or *tone color*. Hint (not that you need it now that you know the answer): the question asks for a "phenomenon," and *rubato* or anything Italian probably isn't a phenomenon but instead a word for musical notation (e.g. *forte*, *coda*, *con forza*, *staccato*, etc.).

10. D – this is an auditory illusion known as the Yanny–Laurel illusion. For an explanation, see Pressnitzer et al. (2018, *Current Biology*, 28(13)). This source, as well as Bosker (2018, *Journal of the Acoustical Society of America*, 144(6)), show that (C) is also wrong, although you didn't have to know that in advance to get the right answer since you've probably met people who can hear both Yanny and Laurel. Basically, what these articles say is that the Yanny-Laurel illusion involves sounds with two formants: one higher and one lower. People are more likely to pick up one than the other (partly due to age and other individual differences), but factors like what you listened to previously may alter your likelihood of hearing one or the other, and it's possibly for scientists to

tinker with the acoustics until you hear half-Laurel, half-Yanny. (A) seems unlikely because the first time you ever heard the Yanny–Laurel illusion, you probably didn't encounter it at a location below typical atmospheric pressure. The premise of (B) is false: while it may be true that listeners can easily confuse open vowels with each other, Yanny (/jɑni/) and Yannik (/jɑnɪk/) contain only one open vowel.

11. E – psychophysics is the study of the relation between physical quantities, and the sensation and perception of those quantities. This includes the study of thresholds, which is a limit of what quantities a human can detect. In this case, the physical quantity is frequency (which we perceive as pitch). Organology is the study of the classification of musical instruments; phonology is the study of how we interpret and use speech; phonetics is the study of how we produce speech, so (B), (C), and (D) are incorrect. (A) would be the best answer if psychophysics weren't a choice, but the question asks for the most closely relevant discipline, and so the *typical* research done in acoustics is not as related to psychoacoustics as typical research in psychophysics is related to what is given in this question.

12. B

13. A – prongs and other beam-shaped parts of an instrument are called tines.

14. D – a common mistake is to believe that only the tines vibrate or that none of the tuning fork vibrates. Why aren't these true? Let's eliminate of (E) first: because sound is a vibration of the air, any physical object that creates sound must also vibrate because the object "hits" the air and causes the air to vibrate as well. Part III is a specialized resonator: it amplifies the sound of the tines, so for the same reason, it must vibrate too. (If you play a string instrument, part III is analogous to the soundboard.) How do we know part II, the handle, will vibrate too? Actually, it only vibrates a little bit, so don't feel bad if you missed it :) the handle resonates in higher order normal modes. Also, the handle is coupled to both the tines and the resonator, which vibrate, so the handle vibrates too. After all, if you had to make an educated guess, it's unlikely for any continuous mass of the handle to be entirely nodes—that would mean zero vibration, which seems like a contradiction since it's literally touching two vibrating objects. So, by guessing, it seems like the handle vibrates too—and that happens to be the correct answer.

15. A

16. D – the xylophone and glockenspiel are instruments with free bars and no specialized resonator, but the xylophone's bars are made from wood, while the glockenspiel's bars are made from metal. The marimba and vibraphone are instruments with free bars with a specialized resonator, but the marimba's bars are made from wood, while the vibraphone's bars are made from metal. (There are also a few range and tuning differences between these four instruments.) Also, depending on whom you ask, xylophones sometimes have a specialized resonator, but not always.

17. E – see previous explanation

18. A – a semitone is a half step, and so is the minor second.

19. D – C_4 is middle C and has a frequency of approximately 261.63 Hz.

20. A – a noninverted chord consists of three or more notes in consecutive thirds. The best known noninverted chord is the triad, such as C–E–G or D–F♯–A. The lowest of these notes is called the root. When a chord is *inverted*, that means we move a note, usually the root. To illustrate, C–E–G may be inverted as E–G–C or G–C–E. In the first case, the root has moved up an octave, and in the second, both the root C and the E have moved up an octave. Even so, the root is still the root; it still

forms the nucleus of the chord that determine its most atomic melodic qualities. Therefore, (B) and (C) can be eliminated. (D) is irrelevant and may be eliminated as well.

21. 1 tiebreaker point awarded for selecting any choice other than Troy, California

22. There are six strings on a guitar.

23. There are 88 keys on a piano.

24. Students should explain conservation of volume flow. The volume of fluid entering any cross section of a pipe is equal to the amount of fluid exiting any other cross section; fluid can't disappear in the middle. In a nutshell, the volume per second, which equals the cross-sectional area A multiplied by the fluid's speed v, is constant. Give full credit if student only writes "volume flow is conserved"/"conservation of volume flow"

25. There are two half steps: one from the mediant to subdominant, and another half step from the leading tone to the tonic. If you were playing in C major, this would be from E to F, and from B to C where C is an octave above the C you started on.

26. *Relative* refers to keys that have the same notes. That is, the relative minor of A major is a key that has the same notes as A major, but it starts on a different note such that when a scale is played, the key is minor. The notes, in order, are F♯, G♯, A, B, C♯, D, E (and F♯). Give full credit regardless of whether F♯ is repeated. Partial credit should be rounded to the nearest half point. If you are hungry for some food for thought, there is a method that always tells you what the starting note is for a relative minor—what is it? Can you tell why it always works, without checking it for every single major scale?

27. *Parallel* refers to keys that begin on the same note. The minor scale beginning on A has no accidentals; that is, its notes are A, B, C, D, E, F, G (and A). Give full credit regardless of whether A is repeated.

28. A cadence serves to provide the listener a sense of resolution/finality. Give full credit even if the student mentions that not all cadences are terminal, such as a deceptive/interrupted/evasive cadence

29. Common time, $\frac{4}{4}$, is a simple quadruple meter, as well as $\frac{4}{2}$ and $\frac{4}{8}$

30. The mediant is the third note in a key. (The first is the tonic.) The key of B♭ has notes B♭, C, D, E♭, F, G, and A, so the mediant is D.

31. 44100 Hz – give full credit regardless of whether units are included

32. Soprano Alto Tenor Bass

33. **8 points total**

(a) For stating that C_5 is the same frequency as an overtone of C_4 on the piano (student does not need to mention the piano for full credit) — 1 point

For explaining that playing C_4 will induce resonance — 1 point

(b) i. For the correct frequency and units, to two or more significant figures — 1 point
523.2511 Hz

ii. For a correct identification — 1 point
G_5, C_6, E_6, G_6, or C_7

(c) For a choice AND correct corresponding justification — 3 points

If "more" is checked, the justification should state that A_6 and A_7 have frequencies of 1760 Hz and 3520 Hz, which are loudest to human perception (compared to other frequencies played at the same intensity)

If "less" is checked, the justification should state that because A_6 and A_7 are so high, the strings for these notes must be very short, and therefore the strings will bend/the waves will not be a close approximation of transverse waves/particles on the strings will move in both vertical and horizontal directions. Therefore, the sequence of overtones is not every positive integer multiplied by the fundamental.

If "neither more nor less" is checked, the justification should state that both of the effects described above should counteract each other, so the overall effect cannot be determined

If the response shows a degree of understanding of the concept associated with the choice checked but the response is difficult to understand or not logically thorough, partial credit of 1 point may be awarded

(d) The piano is a true board zither with a resonator box, or 314.122 in Hornbostel Sachs numbering. 1 point is awarded for saying "chordophone" or anything more specific; tiebreaker points are awarded out of what the most specific answer is. For example, if the student responds "zither" and the most specific response is "board zither," award the student 2 out of the 4 tiebreaker points. If the student has the most specific response out of any other student, he or she deserves all 4 tiebreaker points. — 1 point

Errata

In the original version of this test, in question 16, the correct answer was not in (A) through (E). This version of the answer key has corrected these errors, as well as various minor grammatical errors.

This test is your test. This test is my test.

"Science knows no country, because knowledge belongs to humanity." –Louis Pasteur