and now, the answers.

Most answers come with solutions, which 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. If a solution doesn't make sense, don't hesitate to ask for help—from your friends, your teachers, me (the test writer), or the vast fields of human knowledge called the Internet.

Multiple choice

1. B – the beat frequency is $216\text{ Hz} - 212\text{ Hz} = 4\text{ Hz}$.

2. D – pressure is a measure of force per area. The SI unit of force is the newton, and the SI unit of area is m^2. By Newton's Second Law, the newton is equal to $\text{kg} \cdot \text{m/s}^2$. Therefore, one newton per meter squared is

$$\frac{\text{N}}{\text{m}^2} = \frac{\text{kg} \cdot \text{m} / \text{s}^2}{\text{m}^2} = \frac{\text{kg}}{\text{m} \cdot \text{s}^2}.$$

(A) is wrong because millimeters of mercury is not an SI unit.

3. A – decibels are a type of *logarithmic* unit, where 10 times a quantity corresponds to an increase of 10 dB. That is, a sound of 30 dB has 10 times the intensity of a sound of 20 dB, and a sound of 40 dB has 10 times the intensity of one of 30 dB, and one of 50 dB has 10 times that of 40 dB, and so forth. Unlike normal linear units, a value of zero doesn't mean "absolutely none." While a length of zero means absolutely no length, or a charge of zero means absolutely no charge, an intensity level of 0 dB just means "10 times less than 10 dB," so it is possible to have an intensity greater than zero, but an intensity *level* of 0 dB. By convention, we define 10^{-12} W/m^2 to correspond to an intensity level of 0 dB.

4. E – on a standing wave, a node is a region where no oscillation of a quantity occurs, while an antinode is a region where a quantity can reach its maximum value. Because the problem asks for displacement, it must be either a displacement node or a displacement antinode. So, (E) is the correct answer. Why isn't (B) correct? A trough is a region of maximum *negative* displacement, so it can't be a place where zero displacement occurs; in other words, a crest and trough are the same thing, but one of them is upside down relative to the other. Antinodes cycle between crests and troughs over time, bobbing up and down, while nodes remain at zero displacement forever.

5. D – this question tested your recognition of common methods used by scientists, although you don't need to understand the mathematics behind them.

6. B – resonance occurs when an object vibrates at certain frequencies at which it can sustain standing waves. In this example, the vibration of one string is inducing another string to vibrate, so this is known as *induced resonance*, or *driven resonance*. As a fun fact, a small number of instruments are purposefully built with resonance in mind: some instruments have extra strings that are never played by the musician, and the sole purpose of these strings is to resonate when other strings are played, changing the final sound heard by the listener. These extra strings are called sympathetic strings, and they're mostly found in instruments from South Asian cultures.

7. D – I shows a descending major scale, while II is an ascending major scale. III is missing the syllable *la* while repeating the syllable *mi*, and so it cannot be a major scale.

8. E – one half step is equal to 100 cents, so 350 cents is equivalent to 3.5 half steps. As all of these intervals consist of an integer number of half steps, so choice (E) is the answer. (You also could eliminate choices (C) and (D) because an augmented sixth has the same size as a minor seventh.)

9. C – a major scale is a sequence of notes where the intervals between consecutive notes follows the pattern of W–W–h–W–W–W–h, where W represents a whole step, and h represents a half step. If each note gets transposed down by three half steps, then the *intervals* between two consecutive notes remains the same: each note would be lowered by the same amount, so the interval between any two notes wouldn't change. As a result, the major scale remains a major scale, and because A

is three half steps lower than C, this is an A major scale.

10. D – from left to right, these notes are A_4, B_4, G_4, F_5, and A_5.

11. B – $\frac{2}{2}$ is a valid time signature because it says that each measure must consist of two half notes, and each half note is equal in duration to two quarter notes. $\frac{4}{4}$ is also a valid time signature, as the bottom number indicates that the quarter note is the beat, and the top number indicates there should be four beats per measure. $\frac{3}{4}$ is incorrect because it only allows for three quarter notes per measure, but we have four quarter notes.

12. D – the viola is the only pitched instrument in these five choices.

13. B – upon contact with the guitarist's hand, the molecules in the soundboard begin to move. Some of these wood molecules collide with air molecules, thereby transferring their energy into the air, which results in a sound that resembles a drum. (A) is incorrect because the guitar's soundboard is made from wood and several other materials, rather than an elastic membrane. Choice (C), a mellophone, is a brass instrument that sometimes substitutes for French horns. A guitar is definitely not a French horn, and so (C) is incorrect. (D) is incorrect as an aerophone is an instrument where sound comes from movement of columns of air. (E) is incorrect because electrophones are instruments where electricity is converted directly into vibrations. Even if a robot were playing the guitar, it still wouldn't be classified as an electrophone because it is the vibration of the wood in the guitar, not electricity, that most directly produces the drum-like sound. Choice (B) is the best answer because it is the vibration of a part of the guitar itself producing the drum-like sound, but it is neither a membrane nor a string. This matches the definition of an idiophone.

14. B – the synthesizer produces sound through electricity, so it is not an aerophone.

Short answer

15. The frequency of the nth harmonic of a pipe closed at exactly one end (also known as a *closed pipe*) is $nv/(4L)$, where v is the speed of sound and L is the length of the pipe. Therefore, the fundamental frequency is

$$f_1 = \frac{(1)(343\text{ m/s})}{4(1.75\text{ m})} = 49.0\text{ Hz}.$$

16. For a pipe open at both ends (called simply an *open pipe*), the frequency of the nth harmonic is $f_n = \dfrac{nv}{2L}$. So, the frequency of f_6 for the pipe in the problem is

$$f_6 = \frac{(6)(343\text{ m/s})}{2(0.820\text{ m})} = 1250\text{ Hz}$$

which is correct to three significant figures. (Without significant figures, the calculation would have returned 1254.88 Hz. This was accepted for credit as well.)

17. Because $f_n = \dfrac{nv}{2L}$, we see find the length of the pipe to be

$$L = \frac{nv}{2f_n} = \frac{(10)(343\text{ m/s})}{2(3431\text{ Hz})} = 0.500\text{ m}.$$

18. Because $f_n = \dfrac{nv}{4L}$, it follows that

$$n = \frac{4Lf_n}{v} = \frac{4(1.40\text{ m})(551\text{ Hz})}{343\text{ m/s}} = 9.00$$

which is correct to three significant figures. So, the pipe plays the 9th harmonic.

19. If x cycles of a wave pass by a point in one second, the frequency is defined to be x Hz. Conversely, the duration for one full cycle of the wave to pass by is $1/x$ seconds. So, the frequency f of a wave is simply one divided by its period. Using the values given in the problem,

$$f = \frac{1}{0.00102\text{ s}} = 980.\text{ Hz}.$$

20. Because $v = \lambda f$, and because we're told that $v = 704$ m/s and $\lambda = 0.766$ m, we have it that

$$f = \frac{704\text{ m/s}}{0.766\text{ m}} = 919\text{ Hz}.$$

Hold on a moment, what if I got an answer of 460. Hz instead by using $f_1 = v/(2L)$? Why doesn't this work? It's because in the second formula, L is the length of the string, rather than the wavelength of the wave. A string can carry waves of multiple different wavelengths, even though the string clearly can only have one length.

21. Solution 1: because the wave is a sine wave, the displacement $x(t)$ at a point at some time t is given by $x_{\max}\cos(2\pi ft + \phi)$, where ϕ is some constant. You should try convincing yourself this equation is correct—because the cosine function repeats itself once when its input is increased by 2π, we see that its input must increase by $2\pi(559)$ to repeat itself 559 times. To make it repeat 559 times per *second*, we make its input $2\pi ft$, plus some phase shift ϕ. Because the problem tells us the wave is at a maximum displacement at $t = 0$, we know that $x(0) = x_{\max}$, so we can let $\phi = 0$. Now, we can solve for the displacement at time $t = 120$ s as

$$(1.2\text{ m})\cos\Big(2\pi(559\text{ Hz})(120.0\text{ s})\Big) = 1.2\text{ m}.$$

Solution 2: the frequency in hertz and time in seconds are both integers. Therefore, the number of cycles that pass the observer must also be an integer, so the wave at $t = 120.0$ s must look as it was when it started. We therefore see the displacement must be the same as it was initially, or 1.2 m.

22. For a string with a linear mass density μ (mass per length) and under tension T, the speed of waves v is $\sqrt{\dfrac{T}{\mu}}$. Rearranging, we have it that

$$T = v^2\mu = (364\text{ m/s})^2\left(\frac{5.00\times10^{-4}\text{ kg}}{0.500\text{ m}}\right) = 132\text{ N}.$$

23. Any two notes that could be separated by a perfect fourth (five half steps), in either descending or ascending order, receives full credit. Correct answers include the notes C and F (ascending) or C and G (descending).

24. For full credit, students must mention or imply in their response both that (1) tuning pegs change the tension in a string, and (2) an increase (or decrease) in tension is related to an increase

(or decrease) in wave speed. No additional points are awarded for explanations involving changes in the length of the string or its density.

25. The notation of ♩ = 144 means that there are 144 quarter notes every minute. A half rest is equal in duration to two quarter notes. Therefore, 72 half rests occur each minute. The aliens must self-quarantine for a total of

$$(14 \text{ days}) \left(24 \frac{\text{hours}}{\text{day}}\right) \left(60 \frac{\text{minutes}}{\text{hour}}\right) \left(72 \frac{\text{half rests}}{\text{minute}}\right) = 1451520 \text{ half rests.}$$

26. Acceptable answers include *allegro*, *presto*, as well as any variations, such as *molto allegro*, *allegretto*, or *prestissimo*.

27. **3 points**

1 point is awarded for a correct ranking

$f_B < f_A < f_C$ or f_B, f_A, f_C or $B < A < C$ or B, A, C

If a student writes $f_C > f_A > f_B$, they receive full credit, even though the instructions ask them to rank from lowest to highest rather than highest to lowest. No credit is awarded for C, A, B.

1 point is awarded for a correct justification for cars A and C

Example: Car C is moving faster than car A, so the frequency of car C must be higher

1 point is awarded for a correct justification for car B and the other two cars

Example: Car B is neither approaching nor getting farther away from the observer, so its frequency does not change. However, the other cars are approaching the observer, so their frequencies must increase.

28. For all three comparisons, the new frequency is equal to the frequency from the question 27. One point is awarded for a correct response for each comparison.

While you didn't have to justify your answer for this question, why are the new, reflected frequencies all equal to their corresponding non-reflected frequency? When the sound hits the cars, their frequencies are shifted by the Doppler Effect after reflection. As a result, there is functionally no difference between the sound reflected by the car, and the sound emitted by the car, because the sound sources are identical, and their Doppler shifts are identical. So, the observer would not be able to distinguish between frequencies that were sent and returned by the cars, and frequencies emitted by the cars themselves.

29. The wavelength is $\dfrac{1480 \text{ m/s}}{512 \text{ Hz}} = 2.89 \text{ m}$.

30. The frequency is 512 Hz. This is because the frequency of a wave never changes from one medium to another. Intuitively, every time air molecules slam into the water, the water molecules will start moving too. Consequently, if air molecules strike the water back and forth 512 times each second, then the water molecules will begin shoving other molecules too, also at 512 times per second. As a result, the frequency remains the same.

31. Assuming $A_4 = 440$ Hz as stated on the cover of this test, the sound has a frequency between that of B_4 (493.88 Hz) and C_5 (523.25 Hz). Because humans perceive pitches as ratios of frequen-

cies, we compare these frequencies with 512 Hz in ratio, giving us $\frac{512}{493.88} = 1.04$ and $\frac{523.25}{512} = 1.02$. Since the ratio is smaller between C_5 and the sound than the sound and B_4, the sound would be closer to C_5 in pitch.

32. There was no rubric for this question to ensure that we could break a tie in the unlikely case that the Pitch Score, Song Score, and other test questions could not break a tie. Here are the jokes I came up with:

- Why did the chicken cross the trombone?
- What's the difference between a land drummer and a pirate drummer?

Share your thoughts!

How was this test? Did anything confuse you? Did you uncover any ~~typoos~~ typos or errors? If you'd like to discuss, I'd appreciate it if you could post a message on the Scioly.org forums! You can find the Sounds of Music forum discussion at https://scioly.org/forums/viewtopic.php?f=284&t=18297, and I'll respond as soon as I can. You're also welcome to discuss questions with me even if you didn't compete at this invitational.

You can also anonymously give your feedback at the link below.

`https://scioly.web.unc.edu/rate-my-tests-gz839918`

Errata

This version differs from the original version in that I correct minor typographical errors in the key. I made no other changes from the original version.

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

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