Chapter 17: PHYSICS OF HEARING

# 17.2 SPEED OF SOUND, FREQUENCY, AND WAVELENGTH

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| 1. | *When poked by a spear, an operatic soprano lets out a 1200-Hz shriek. What is its wavelength if the speed of sound is 345 m/s?* |
| Solution | , so that |
| 2. | *What frequency sound has a 0.10-m wavelength when the speed of sound is 340 m/s?* |
| Solution |  |
| 3. | *Calculate the speed of sound on a day when a 1500 Hz frequency has a wavelength of 0.221 m.* |
| Solution |  |
| 4. | *(a) What is the speed of sound in a medium where a 100-kHz frequency produces a 5.96-cm wavelength? (b) Which substance in Table 17.1 is this likely to be?* |
| Solution | (a)  (b) steel (from value in Table 17.1) |
| 5. | *Show that the speed of sound in  air is 343 m/s, as claimed in the text.* |
| Solution |  |
| 6. | *Air temperature in the Sahara Desert can reach  (about ). What is the speed of sound in air at that temperature?* |
| Solution |  |
| 7. | *Dolphins make sounds in air and water. What is the ratio of the wavelength of a sound in air to its wavelength in seawater? Assume air temperature is .* |
| Solution | We know  (from Table 17.1) and  at  from Problem 17.5, since  and  , we know |
| 8. | *A sonar echo returns to a submarine 1.20 s after being emitted. What is the distance to the object creating the echo? (Assume that the submarine is in the ocean, not in fresh water.)* |
| Solution |  |
| 9. | *(a) If a submarine’s sonar can measure echo times with a precision of 0.0100 s, what is the smallest difference in distances it can detect? (Assume that the submarine is in the ocean, not in fresh water.) (b) Discuss the limits this time resolution imposes on the ability of the sonar system to detect the size and shape of the object creating the echo.* |
| Solution | (a)  (b) This means that sonar is good for spotting and locating large objects, but it isn’t able to resolve smaller objects, or detect the detailed shapes of objects. Objects like ships or large pieces of airplanes can be found by sonar, while smaller pieces must be found by other means. |
| 10. | *A physicist at a fireworks display times the lag between seeing an explosion and hearing its sound, and finds it to be 0.400 s. (a) How far away is the explosion if air temperature is  and if you neglect the time taken for light to reach the physicist? (b) Calculate the distance to the explosion taking the speed of light into account. Note that this distance is negligibly greater.* |
| Solution | (a)  (b) The time for the light to travel is approximately    The distance is the same to six significant figures. |
| 11. | *Suppose a bat uses sound echoes to locate its insect prey, 3.00 m away. (See Figure 17.10.) (a) Calculate the echo times for temperatures of  and . (b) What percent uncertainty does this cause for the bat in locating the insect? (c) Discuss the significance of this uncertainty and whether it could cause difficulties for the bat. (In practice, the bat continues to use sound as it closes in, eliminating most of any difficulties imposed by this and other effects, such as motion of the prey.)* |
| Solution | (a)  (b) % uncertainty =  (c) This uncertainty could definitely cause difficulties for the bat, if it didn’t continue to use sound as it closed in on its prey. A 5% uncertainty could be the difference between catching the prey around the neck or around the chest, which means that it could miss grabbing its prey. |
| 17.3 SOUND INTENSITY AND SOUND LEVEL | |
| 12. | *What is the intensity in watts per meter squared of 85.0-dB sound?* |
| Solution |  |
| 13. | *The warning tag on a lawn mower states that it produces noise at a level of 91.0 dB. What is this in watts per meter squared?* |
| Solution | , where , so that , and |
| 14. | *A sound wave traveling in  air has a pressure amplitude of 0.5 Pa. What is the intensity of the wave?* |
| Solution |  |
| 15. | *What intensity level does the sound in the preceding problem correspond to?* |
| Solution | Using the sound intensity level equation ,. |
| 16. | *What sound intensity level in dB is produced by earphones that create an intensity of ?* |
| Solution |  |
| 17. | *Show that an intensity of  is the same as .* |
| Solution |  |
| 18. | *(a) What is the decibel level of a sound that is twice as intense as a 90.0-dB sound? (b) What is the decibel level of a sound that is one-fifth as intense as a 90.0-dB sound?* |
| Solution | (a) From Table 17.3,  (b)  Thus, |
| 19. | *(a) What is the intensity of a sound that has a level 7.00 dB lower than a  sound? (b) What is the intensity of a sound that is 3.00 dB higher than a  sound?* |
| Solution | (a) Using Table 17.3,  (b) |
| 20. | *(a) How much more intense is a sound that has a level 17.0 dB higher than another? (b) If one sound has a level 23.0 dB less than another, what is the ratio of their intensities?* |
| Solution | (a) One factor of 10 (10.0 dB) and one factor of 5 (7.0 dB) make an overall factor of 50.1, i.e.  (b) Two 10-decibel losses give two factors of , or a total factor of The remaining 3 decibels give an additional factor of . So the ratio is a factor of  i.e. |
| 21. | *People with good hearing can perceive sounds as low in level as  at a frequency of 3000 Hz. What is the intensity of this sound in watts per meter squared?* |
| Solution |  |
| 22. | *If a large housefly 3.0 m away from you makes a noise of 40.0 dB, what is the noise level of 1000 flies at that distance, assuming interference has a negligible effect?* |
| Solution | A factor of 1000 in intensity corresponds to an increase of 30.0 dB, i.e.,  . Thus, |
| 23. | *Ten cars in a circle at a boom box competition produce a 120-dB sound intensity level at the center of the circle. What is the average sound intensity level produced there by each stereo, assuming interference effects can be neglected?* |
| Solution | A decrease of a factor of 10 in intensity corresponds to a reduction of 10 dB in sound level. |
| 24. | *The amplitude of a sound wave is measured in terms of its maximum gauge pressure. By what factor does the amplitude of a sound wave increase if the sound intensity level goes up by 40.0 dB?* |
| Solution | The intensity  is proportional to where  is the amplitude. We know that 40 dB is equivalent to an increase of a factor of in intensity. |
| 25. | *If a sound intensity level of 0 dB at 1000 Hz corresponds to a maximum gauge pressure (sound amplitude) of , what is the maximum gauge pressure in a 60-dB sound? What is the maximum gauge pressure in a 120-dB sound?* |
| Solution | We know that 60 dB corresponds to a factor of  increase in intensity. Therefore,    120 dB corresponds to a factor of  increase . |
| 26. | *An 8-hour exposure to a sound intensity level of 90.0 dB may cause hearing damage. What energy in joules falls on a 0.800-cm-diameter eardrum so exposed?* |
| Solution |  |
| 27. | *(a) Ear trumpets were never very common, but they did aid people with hearing losses by gathering sound over a large area and concentrating it on the smaller area of the eardrum. What decibel increase does an ear trumpet produce if its sound gathering area is  and the area of the eardrum is , but the trumpet only has an efficiency of 5.00% in transmitting the sound to the eardrum? (b) Comment on the usefulness of the decibel increase found in part (a).* |
| Solution | (a) so for a 5.00% efficiency:  . Now, using :    (b) This increase of approximately 20 dB increases the sound of a normal conversation to that of a loud radio or classroom lecture (see Table 17.2). For someone who cannot hear at all, this will not be helpful, but for someone who is starting to lose their ability to hear, it may help. Unfortunately, ear trumpets are very cumbersome, so even though they could help, the inconvenience makes them rather impractical. |
| 28. | *Sound is more effectively transmitted into a stethoscope by direct contact than through the air, and it is further intensified by being concentrated on the smaller area of the eardrum. It is reasonable to assume that sound is transmitted into a stethoscope 100 times as effectively compared with transmission though the air. What, then, is the gain in decibels produced by a stethoscope that has a sound gathering area of , and concentrates the sound onto two eardrums with a total area of  with an efficiency of 40.0%?* |
| Solution |  |
| 29. | *Loudspeakers can produce intense sounds with surprisingly small energy input in spite of their low efficiencies. Calculate the power input needed to produce a 90.0-dB sound intensity level for a 12.0-cm-diameter speaker that has an efficiency of 1.00%. (This value is the sound intensity level right at the speaker.)* |
| Solution |  |
| 17.4 DOPPLER EFFECT AND SONIC BOOMS | |
| 30. | *(a) What frequency is received by a person watching an oncoming ambulance moving at 110 km/h and emitting a steady 800-Hz sound from its siren? The speed of sound on this day is 345 m/s. (b) What frequency does she receive after the ambulance has passed?* |
| Solution | (a) Given    (b) |
| 31. | *(a) At an air show a jet flies directly toward the stands at a speed of 1200 km/h, emitting a frequency of 3500 Hz, on a day when the speed of sound is 342 m/s. What frequency is received by the observers? (b) What frequency do they receive as the plane flies directly away from them?* |
| Solution | (a) Given    (b) |
| 32. | *What frequency is received by a mouse just before being dispatched by a hawk flying at it at 25.0 m/s and emitting a screech of frequency 3500 Hz? Take the speed of sound to be 331 m/s.* |
| Solution |  |
| 33. | *A spectator at a parade receives an 888-Hz tone from an oncoming trumpeter who is playing an 880-Hz note. At what speed is the musician approaching if the speed of sound is 338 m/s?* |
| Solution |  |
| 34. | *A commuter train blows its 200-Hz horn as it approaches a crossing. The speed of sound is 335 m/s. (a) An observer waiting at the crossing receives a frequency of 208 Hz. What is the speed of the train? (b) What frequency does the observer receive as the train moves away?* |
| Solution | (a)  (b) |
| 35. | *Can you perceive the shift in frequency produced when you pull a tuning fork toward you at 10.0 m/s on a day when the speed of sound is 344 m/s? To answer this question, calculate the factor by which the frequency shifts and see if it is greater than 0.300%.* |
| Solution | Yes. The shift is just at 3% so it is audible by a factor of 10. |
| 36. | *Two eagles fly directly toward one another, the first at 15.0 m/s and the second at 20.0 m/s. Both screech, the first one emitting a frequency of 3200 Hz and the second one emitting a frequency of 3800 Hz. What frequencies do they receive if the speed of sound is 330 m/s?* |
| Solution | The first eagle hears:    The second eagle hears: |
| 37. | *What is the minimum speed at which a source must travel toward you for you to be able to hear that its frequency is Doppler shifted? That is, what speed produces a shift of 0.300% on a day when the speed of sound is 331 m/s?* |
| Solution | An audible shift occurs when . |
| 17.5 SOUND INTERFERENCE AND RESONANCE: STANDING WAVES IN AIR COLUMNS | |
| 38. | *A “showy” custom-built car has two brass horns that are supposed to produce the same frequency but actually emit 263.8 and 264.5 Hz. What beat frequency is produced?* |
| Solution | The beat frequency is |
| 39. | *What beat frequencies will be present: (a) If the musical notes A and C are played together (frequencies of 220 and 264 Hz)? (b) If D and F are played together (frequencies of 297 and 352 Hz)? (c) If all four are played together?* |
| Solution | (a) Using the equation :    (b)  (c) We get beats from every combination of frequencies, so in addition to the two beats above, we also have: |
| 40. | *What beat frequencies result if a piano hammer hits three strings that emit frequencies of 127.8, 128.1, and 128.3 Hz?* |
| Solution |  |
| 41. | A piano tuner hears a beat every 2.00 s when listening to a 264.0-Hz tuning fork and a single piano string. What are the two possible frequencies of the string? |
| Solution | so the other frequency is 263.5 Hz or 264.5 Hz. |
| 42. | *(a) What is the fundamental frequency of a 0.672-m-long tube, open at both ends, on a day when the speed of sound is 344 m/s? (b) What is the frequency of its second harmonic?* |
| Solution | (a)  (b) |
| 43. | *If a wind instrument, such as a tuba, has a fundamental frequency of 32.0 Hz, what are its first three overtones? It is closed at one end. (The overtones of a real tuba are more complex than this example, because it is a tapered tube.)* |
| Solution |  |
| 44. | *What are the first three overtones of a bassoon that has a fundamental frequency of 90.0 Hz? It is open at both ends. (The overtones of a real bassoon are more complex than this example, because its double reed makes it act more like a tube closed at one end.)* |
| Solution |  |
| 45. | *How long must a flute be in order to have a fundamental frequency of 262 Hz (this frequency corresponds to middle C on the evenly tempered chromatic scale) on a day when air temperature is ? It is open at both ends.* |
| Solution | so that  Since we know the air temperature:    Therefore, |
| 46. | *What length should an oboe have to produce a fundamental frequency of 110 Hz on a day when the speed of sound is 343 m/s? It is open at both ends.* |
| Solution |  |
| 47. | *What is the length of a tube that has a fundamental frequency of 176 Hz and a first overtone of 352 Hz if the speed of sound is 343 m/s?* |
| Solution |  |
| 48. | *(a) Find the length of an organ pipe closed at one end that produces a fundamental frequency of 256 Hz when air temperature is . (b) What is its fundamental frequency at ?* |
| Solution | (a)  (b) |
| 49. | *By what fraction will the frequencies produced by a wind instrument change when air temperature goes from  to ? That is, find the ratio of the frequencies at those temperatures.* |
| Solution |  |
| 50. | *The ear canal resonates like a tube closed at one end. (See Figure 17.39.) If ear canals range in length from 1.80 to 2.60 cm in an average population, what is the range of fundamental resonant frequencies? Take air temperature to be , which is the same as body temperature. How does this result correlate with the intensity versus frequency graph (Figure 17.37) of the human ear?* |
| Solution | For this frequency range, the graph shows a dip in the intensity of sound needed to pass the hearing threshold, presumably because these frequencies are resonances. |
| 51. | *Calculate the first overtone in an ear canal, which resonates like a 2.40-cm-long tube closed at one end, by taking air temperature to be . Is the ear particularly sensitive to such a frequency? (The resonances of the ear canal are complicated by its nonuniform shape, which we shall ignore.)* |
| Solution | Next, so that:    The ear is not particularly sensitive to this frequency, so we don’t hear overtones due to the ear canal. |
| 52. | *A crude approximation of voice production is to consider the breathing passages and mouth to be a resonating tube closed at one end. (See Figure 17.30.) (a) What is the fundamental frequency if the tube is 0.240-m long, by taking air temperature to be ? (b) What would this frequency become if the person replaced the air with helium? Assume the same temperature dependence for helium as for air.* |
| Solution | (a)  (b) |
| 53. | *(a) Students in a physics lab are asked to find the length of an air column in a tube closed at one end that has a fundamental frequency of 256 Hz. They hold the tube vertically and fill it with water to the top, then lower the water while a 256-Hz tuning fork is rung and listen for the first resonance. What is the air temperature if the resonance occurs for a length of 0.336 m? (b) At what length will they observe the second resonance (first overtone)?* |
| Solution | (a)  First resonance is at the fundamental, so , and    (b) The second resonance occurs at three times the first resonance: |
| 54. | *What frequencies will a 1.80-m-long tube produce in the audible range at  if: (a) The tube is closed at one end? (b) It is open at both ends?* |
| Solution | (a)  Since  must be an odd number,  is 419 or 421 (depending on the individual).  (b) |
| 17.6 HEARING | |
| 55. | *The factor of  in the range of intensities to which the ear can respond, from threshold to that causing damage after brief exposure, is truly remarkable. If you could measure distances over the same range with a single instrument and the smallest distance you could measure was 1 mm, what would the largest be?* |
| Solution |  |
| 56. | *The frequencies to which the ear responds vary by a factor of . Suppose the speedometer on your car measured speeds differing by the same factor of , and the greatest speed it reads is 90.0 mi/h. What would be the slowest nonzero speed it could read?* |
| Solution |  |
| 57. | *What are the closest frequencies to 500 Hz that an average person can clearly distinguish as being different in frequency from 500 Hz? The sounds are not present simultaneously.* |
| Solution | We know that we can discriminate between two sounds if their frequencies differ by at least 0.3%, so the closest frequencies to 500 Hz that we can distinguish are . |
| 58. | *Can the average person tell that a 2002-Hz sound has a different frequency than a 1999-Hz sound without playing them simultaneously?* |
| Solution | difference. However, the required difference is 0.3% of 2000.5 Hz or 6 Hz. Thus, an average person would not be able to distinguish the sounds. |
| 59. | *If your radio is producing an average sound intensity level of 85 dB, what is the next lowest sound intensity level that is clearly less intense?* |
| Solution | Although 1 dB sound level changes can be discerned, 3 dB changes are the threshold for most people to notice. |
| 60. | *Can you tell that your roommate turned up the sound on the TV if its average sound intensity level goes from 70 to 73 dB?* |
| Solution | . Such a change in sound level is easily noticed. |
| 61. | *Based on the graph in Figure 17.36, what is the threshold of hearing in decibels for frequencies of 60, 400, 1000, 4000, and 15,000 Hz? Note that many AC electrical appliances produce 60 Hz, music is commonly 400 Hz, a reference frequency is 1000 Hz, your maximum sensitivity is near 4000 Hz, and many older TVs produce a 15,750 Hz whine.* |
| Solution | From Figure 17.36, |
| 62. | *What sound intensity levels must sounds of frequencies 60, 3000, and 8000 Hz have in order to have the same loudness as a 40-dB sound of frequency 1000 Hz (that is, to have a loudness of 40 phons)?* |
| Solution | From Figure 17.36, |
| 63. | *What is the approximate sound intensity level in decibels of a 600-Hz tone if it has a loudness of 20 phons? If it has a loudness of 70 phons?* |
| Solution | From Figure 17.36: a 600 Hz tone at a loudness of 20 phons has a sound level of about 23 dB, while a 600 Hz tone at a loudness of 70 phons has a sound level of about 70 dB. |
| 64. | *(a) What are the loudnesses in phons of sounds having frequencies of 200, 1000, 5000, and 10,000 Hz, if they are all at the same 60.0-dB sound intensity level? (b) If they are all at 110 dB? (c) If they are all at 20.0 dB?* |
| Solution | (a) From Figure 17.36,    (b) From Figure 17.36,    (c) From Figure 17.36, |
| 65. | *Suppose a person has a 50-dB hearing loss at all frequencies. By how many factors of 10 will low-intensity sounds need to be amplified to seem normal to this person? Note that smaller amplification is appropriate for more intense sounds to avoid further hearing damage.* |
| Solution | 50 dB is five factors of 10. |
| 66. | *If a woman needs an amplification of  times the threshold intensity to enable her to hear at all frequencies, what is her overall hearing loss in dB? Note that smaller amplification is appropriate for more intense sounds to avoid further damage to her hearing from levels above 90 dB.* |
| Solution | = five factors of 10 plus one factor of 5. In decibels, this is (see Table 17.3). |
| 67. | *(a) What is the intensity in watts per meter squared of a just barely audible 200-Hz sound? (b) What is the intensity in watts per meter squared of a barely audible 4000-Hz sound?* |
| Solution | (a) At 200 Hz,  Using Table 17.3, 23 dB is twice (2.00) the intensity of 20 dB. From Table 17.2,  (b) At 4000 Hz,  –7 dB is  the intensity of 0 dB. Thus, |
| 68. | *(a) Find the intensity in watts per meter squared of a 60.0-Hz sound having a loudness of 60 phons. (b) Find the intensity in watts per meter squared of a 10,000-Hz sound having a loudness of 60 phons.* |
| Solution | (a) Using Figure 17.36, a 60.0 Hz sound at 60 phons has a sound level of 5.00 times the intensity of 70 dB.    (b) Using Figure 17.36,  times the intensity of 70 dB. |
| 69. | *A person has a hearing threshold 10 dB above normal at 100 Hz and 50 dB above normal at 4000 Hz. How much more intense must a 100-Hz tone be than a 4000-Hz tone if they are both barely audible to this person?* |
| Solution | From Figure 17.36, the 0 phons line is normal hearing. So, this person can barely hear a 100 Hz sound at 10 dB above normal, requiring a 47 dB sound level (). For a 4000 Hz sound, this person requires 50 dB above normal, or a 43 dB sound level () to be audible. So, the 100 Hz tone must be 4 dB higher than the 4000 Hz sound. To calculate the difference in intensity, use the equation  and convert the difference in decibels to a ratio of intensities.    So the 100 Hz tone must be 2.5 times more intense than the 4000 Hz sound to be audible by this person. |
| 70. | *A child has a hearing loss of 60 dB near 5000 Hz, due to noise exposure, and normal hearing elsewhere. How much more intense is a 5000-Hz tone than a 400-Hz tone if they are both barely audible to the child?* |
| Solution | From Figure 17.36, hearing at 60 dB above normal (0 phons) at 5000 Hz requires a 55 dB sound level (). Normal hearing at 400 Hz requires a 10 dB sound level (). |
| 71. | *What is the ratio of intensities of two sounds of identical frequency if the first is just barely discernible as louder to a person than the second?* |
| Solution | A 1 dB difference can barely be discerned. |
| 17.7 ULTRASOUND | |
| 72. | *What is the sound intensity level in decibels of ultrasound of intensity , used to pulverize tissue during surgery?* |
| Solution | By Table 17.2, 160 dB corresponds to , so  has a sound level of 170 dB. |
| 73. | *Is 155-dB ultrasound in the range of intensities used for deep heating? Calculate the intensity of this ultrasound and compare this intensity with values quoted in the text.* |
| Solution | Yes, this is in the range used for deep heating. |
| 74. | *Find the sound intensity level in decibels of  ultrasound used in medical diagnostics.* |
| Solution |  |
| 75. | *The time delay between transmission and the arrival of the reflected wave of a signal using ultrasound traveling through a piece of fat tissue was 0.13 ms. At what depth did this reflection occur?* |
| Solution | . |
| 76. | *In the clinical use of ultrasound, transducers are always coupled to the skin by a thin layer of gel or oil, replacing the air that would otherwise exist between the transducer and the skin. (a) Using the values of acoustic impedance given in Table 17.5 calculate the intensity reflection coefficient between transducer material and air. (b) Calculate the intensity reflection coefficient between transducer material and gel (assuming for this problem that its acoustic impedance is identical to that of water). (c) Based on the results of your calculations, explain why the gel is used.* |
| Solution | Use Table 17.5 for values and the equation for .  (a) , so 100% reflected.  (b)  (c) Gel is used to facilitate the transmission of the ultrasound between the transducer and the patient's body. |
| 77. | *(a) Calculate the minimum frequency of ultrasound that will allow you to see details as small as 0.250 mm in human tissue. (b) What is the effective depth to which this sound is effective as a diagnostic probe?* |
| Solution | (a)  so that .  (b) We know that the accepted rule of thumb is that you can effectively scan to a depth of about into tissue, so the effective scan depth is: |
| 78. | *(a) Find the size of the smallest detail observable in human tissue with 20.0-MHz ultrasound. (b) Is its effective penetration depth great enough to examine the entire eye (about 3.00 cm is needed)? (c) What is the wavelength of such ultrasound in  air?* |
| Solution | (a) Let = velocity of sound in tissue.    (b) Effective penetration depth =  Yes, it is enough.  (c) |
| 79. | *(a) Echo times are measured by diagnostic ultrasound scanners to determine distances to reflecting surfaces in a patient. What is the difference in echo times for tissues that are 3.50 and 3.60 cm beneath the surface? (This difference is the minimum resolving time for the scanner to see details as small as 0.100 cm, or 1.00 mm. Discrimination of smaller time differences is needed to see smaller details.) (b) Discuss whether the period  of this ultrasound must be smaller than the minimum time resolution. If so, what is the minimum frequency of the ultrasound and is that out of the normal range for diagnostic ultrasound?* |
| Solution | (a)  (b) The wavelength of the ultrasound must be larger than the size of the detail, so since  the period of the ultrasound must be smaller than the difference in time found in part (a). The minimum frequency of ultrasound is therefore:  Since 7 MHz ultrasounds are possible, this frequency is attainable. |
| 80. | *(a) How far apart are two layers of tissue that produce echoes having round-trip times (used to measure distances) that differ by ? (b) What minimum frequency must the ultrasound have to see detail this small?* |
| Solution | (a)  (b) |
| 81. | *(a) A bat uses ultrasound to find its way among trees. If this bat can detect echoes 1.00 ms apart, what minimum distance between objects can it detect? (b) Could this distance explain the difficulty that bats have finding an open door when they accidentally get into a house?* |
| Solution | (a) Assume  and therefore since    (b) No, since doors are wider than 17 cm, this does not explain why bats cannot get out of houses since their resolution is great enough to find the opening. |
| 82. | *A dolphin is able to tell in the dark that the ultrasound echoes received from two sharks come from two different objects only if the sharks are separated by 3.50 m, one being that much farther away than the other. (a) If the ultrasound has a frequency of 100 kHz, show this ability is not limited by its wavelength. (b) If this ability is due to the dolphin’s ability to detect the arrival times of echoes, what is the minimum time difference the dolphin can perceive?* |
| Solution | (a)  Since , the ability to resolve the two sharks is not limited by its wavelength.  (b) |
| 83. | *A diagnostic ultrasound echo is reflected from moving blood and returns with a frequency 500 Hz higher than its original 2.00 MHz. What is the velocity of the blood? (Assume that the frequency of 2.00 MHz is accurate to seven significant figures and 500 Hz is accurate to three significant figures.)* |
| Solution | At first, the blood is like a moving observer, so the equation  gives the frequency it receives (with the plus sign used because the blood is approaching):  (where  is the blood velocity)  Next, this frequency is reflected from the blood, which now acts as a moving source. The equation  (with the minus sign used because the blood is still approaching) gives the frequency received by the scanner:    Solving for the speed of blood gives: |
| 84. | *Ultrasound reflected from an oncoming bloodstream that is moving at 30.0 cm/s is mixed with the original frequency of 2.50 MHz to produce beats. What is the beat frequency? (Assume that the frequency of 2.50 MHz is accurate to seven significant figures.)* |
| Solution | By Example 17.8,    Note: extra digits were retained in order to show the difference. |

# Test Prep For AP® Courses

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| 1. | *A teacher wants to demonstrate that the speed of sound is not a constant value. Considering her regular classroom voice as the control, which of the following will increase the speed of sound leaving her mouth?*  I. Submerge her mouth underwater and speak at the same volume. II. Increase the temperature of the room and speak at the same volume. III. Increase the pitch of her voice and speak at the same volume.   1. I only 2. I and II only 3. I, II and III 4. II and III 5. III only |
| Solution | (b) |
| 2. | *All members of an orchestra begin tuning their instruments at the same time. While some woodwind instruments play high frequency notes, other stringed instruments play notes of lower frequency. Yet an audience member will hear all notes simultaneously, in apparent contrast to the equation.*  *Explain how a student could demonstrate the flaw in the above logic, using a slinky, stopwatch, and meter stick. Make sure to explain what relationship is truly demonstrated in the above equation, in addition to what would be necessary to get the speed of the slinky to actually change. You may include diagrams and equations as part of your explanation.* |
| Solution | The medium in which the wave travels is the only factor that affects the wave velocity. Because all musical notes are traveling through the same medium before reaching the audience member’s ear, they will all reach the ear at the same time. The equation demonstrates the relationship between frequency and wavelength, but should not be interpreted as having any influence on the wave velocity.  As a demonstration, students could shake the slinky with various frequencies and note that, while the wavelength constructed will change, the time it takes each wave to reach the opposite end of the slinky will remain the same. |
| 3. | *In order to waken a sleeping child, the volume on an alarm clock is tripled. Under this new scenario, how much more energy will be striking the child’s ear drums each second?*   1. twice as much 2. three times as much 3. approximately 4.8 times as much 4. six times as much 5. nine times as much |
| Solution | (e) |
| 4. | *A musician strikes the strings of a guitar such that they vibrate with twice the amplitude.*   1. *Explain why this requires an energy input greater than twice the original value.* 2. *Explain why the sound leaving the string will not result in a decibel level that is twice as great.* |
| Solution | 1. The energy transported by a sound wave is proportional to the square of the wave amplitude. As a result, a sound wave with twice its original amplitude requires an energy input equal to four times its original value. 2. Decibel levels are related to sound amplitude through the logarithmic scale. By setting up a ratio of the two sound amplitudes, it can be found that the sound level will only increase by 3 dB. (see Example 17.3) |
| 5. | *A baggage handler stands on the edge of a runway as a landing plane approaches. Compared to the pitch of the plane as heard by the plane’s pilot, which of the following correctly describes the sensation experienced by the handler?*   1. The frequency of the plane will be lower pitched according to the baggage handler and will become even lower pitched as the plane slows to a stop. 2. The frequency of the plane will be lower pitched according to the baggage handler but will increase in pitch as the plane slows to a stop. 3. The frequency of the plane will be higher pitched according to the baggage handler but will decrease in pitch as the plane slows to a stop. 4. The frequency of the plane will be higher pitched according to the baggage handler and will further increase in pitch as the plane slows to a stop. |
| Solution | (c) |
| 6. | *The following graph represents the perceived frequency of a car as it passes a student.*  [Figure 17\_02\_Ch17\_graph\_img]     1. *If the true frequency of the car’s horn is 200 Hz, how fast was the car traveling?* 2. *On the graph above, draw a line demonstrating the perceived frequency for a car traveling twice as fast. Label all intercepts, maximums, and minimums on the graph.* |
| Solution | a. Approximately 30 m/s.  b. The graph should shrink in vertical direction, with a changing slope between 0.3 and 0.35 s. The maximum of the graph should be between 240 Hz and 245 Hz. The minimum of the graph should be between 170 Hz and 165 Hz. |
| 7. | *A common misconception is that two wave pulses traveling in opposite directions will reflect off each other. Outline a procedure that you would use to convince someone that the two wave pulses do not reflect off each other, but instead travel through each other. You may use sketches to represent your understanding. Be sure to provide evidence to not only refute the original claim, but to support yours as well.* |
| Solution | Answers vary. Students could include a sketch showing an increased amplitude when two waves occupy the same location. Students could also cite conceptual evidence such as sound waves passing through each other. |
| 8. | *Two wave pulses are traveling toward each other on a string, as shown below. Which of the following representations correctly shows the string as the two pulses overlap?*  [Figure 17\_05\_wavese1\_img]    Two sinusoidal waves of the same magnitude but opposite phase with only one full period are approaching each other.  (a) [Figure 17\_05\_wavese1a\_img]  A sinusoidal wave with the same magnitude as the two waves but showing one and a half periods.  (b) [Figure 17\_05\_wavese1b\_img]  A shape formed by joining the two sinusoidal waves at the point at which they first touch.  (c) [Figure 17\_05\_wavesec\_img]  A straight line.  (d) [Figure 17\_05\_wavesed\_img]  A sinusoidal wave with double the magnitude but the phase of one of the waves. |
| Solution | (c) |
| 9. | *A student sends a transverse wave pulse of amplitude A along a rope attached at one end. As the pulse returns to the student, a second pulse of amplitude 3A is sent along the opposite side of the rope. What is the resulting amplitude when the two pulses interact?*   1. 4*A* 2. *A* 3. 2*A*, on the side of the original wave pulse 4. 2*A*, on the side of the second wave pulse |
| Solution | (d) |
| 10. | *A student would like to demonstrate destructive interference using two sound sources. Explain how the student could set up this demonstration and what restrictions they would need to place upon their sources. Be sure to consider both the layout of space and the sounds created in your explanation.* |
| Solution | Destructive interference will occur where the node of one speaker and the anti-node of the second speaker align. The sources need to play sounds of the same amplitude and same frequency. |
| 11. | *A student is shaking a flexible string attached to a wooden board in a rhythmic manner. Which of the following choices will decrease the wavelength within the rope?*  I. The student could shake her hand back and forth with greater frequency.  II. The student could shake her hand back in forth with a greater amplitude.  III. The student could increase the tension within the rope by stepping backwards from the board.  (a) I only  (b) I and II  (c) I and III  (d) II and III  (e) I, II, and III |
| Solution | (c) |
| 12. | *A ripple tank has two locations (L1 and L2) that vibrate in tandem as shown below. Both L1 and L2 vibrate in a plane perpendicular to the page, creating a two-dimensional interference pattern.*  [Figure 17\_07\_rippletnk\_img]    *Describe an experimental procedure to determine the speed of the waves created within the water, including all additional equipment that you would need. You may use the diagram below to help your description, or you may create one of your own. Include enough detail so that another student could carry out your experiment.* |
| Solution | Equipment needed should include a ruler and stopwatch. Students should cite measuring the period of the vibrating object’s oscillation and the distance between locations of constructive interference. |
| 13. | [Figure 17\_08\_strngosc\_img]    *A string is vibrating between two posts as shown above. Students are to determine the speed of the wave within this string. They have already measured the amount of time necessary for the wave to oscillate up and down. The students must also take what other measurements to determine the speed of the wave?*   1. the distance between the two posts. 2. the amplitude of the wave 3. the tension in the string 4. the amplitude of the wave and the tension in the string 5. the distance between the two posts, the amplitude of the wave, and the tension in the string |
| Solution | (a) |
| 14. | *The accepted speed of sound in room temperature air is 346 m/s. Knowing that their school is colder than usual, a group of students are asked to determine the speed of sound in their room. They are permitted to use any materials necessary; however, their lab procedure must utilize standing wave patterns. The students collect the information collected in the table below.*  [Table 17\_05\_01]   |  |  |  |  | | --- | --- | --- | --- | | Trial Number | Wavelength (m) | Frequency (Hz) |  | | 1 | 3.45 | 95 |  | | 2 | 2.32 | 135 |  | | 3 | 1.70 | 190 |  | | 4 | 1.45 | 240 |  | | 5 | 1.08 | 305 |  |  * 1. *Describe an experimental procedure the group of students could have used to obtain this data. Include diagrams of the experimental setup and any equipment used in the process.*   2. *Select a set of data points from the table and plot those points on a graph to determine the speed of sound within the classroom. Fill in the blank column in the table for any quantities you graph other than the given data. Label the axes and indicate the scale for each. Draw a best-fit line or curve through your data points.*   3. *Using information from the graph, determine the speed of sound within the student’s classroom, and explain what characteristic of the graph provides this evidence.*   4. *Determine the temperature of the classroom.* |
| Solution | 1. Experimental procedure must include an air column, a device to measure the frequency of sound created, and a meter stick to measure the length of the air column. The appropriate procedure should also cite whether the air column is open or closed on one end. 2. The students should select either the frequency or wavelength for their graph. In the blank column, they should record the inverse values of the other variable (1/f or 1/λ). The axes chosen should match the dependence of the relationship described in the experimental procedure. As the points do not fully support a linear relationship, a best-fit line should be drawn. 3. A slope of the best-fit line should be taken. The speed of sound is approximately 340 m/s. 4. Approximately 293 K (20°C or 67°F) |
| 15. | *A tube is open at one end. If the fundamental frequency f is created by a wavelength λ, then which of the following describes the frequency and wavelength associated with the tube’s fourth overtone?*  f λ  a. 4f λ/4  b. 4f λ  c. 9f λ/9  d. 9f λ |
| Solution | (c) |
| 16. | *A group of students were tasked with collecting information about standing waves. Below is a series of their data, showing the length of an air column and a resonant frequency present when the column is struck.*   |  |  | | --- | --- | | Length (m) | Resonant Frequency (Hz) | | 1 | 85.75 | | 2 | 43 | | 3 | 29 | | 4 | 21.5 |  1. *From their data, determine whether the air column was open or closed on each end.* 2. *Predict the resonant frequency of the column at a length of 2.5 meters.* |
| Solution | 1. Open on each end. 2. Approximately 34.5 Hz |
| 17. | *When a student blows across a glass half-full of water, a resonant frequency is created within the air column remaining in the glass. Which of the following can the student do to increase this resonant frequency?*  I. Add more water to the glass. II. Replace the water with a more dense fluid. III. Increase the temperature of the room.   1. I only 2. I and III 3. II and III 4. all of the above |
| Solution | (b) |
| 18. | *A student decides to test the speed of sound through wood using a wooden ruler. The student rests the ruler on a desk with half of its length protruding off the desk edge. The student then holds one end in place and strikes the protruding end with his other hand, creating a musical sound, and counts the number of vibrations of the ruler.*  *Explain why the student would not be able to measure the speed of sound through wood using this method.* |
| Solution | Striking the end of a protruding ruler would create transverse waves, not sound waves. Any measurable, audible sound would come from the repetitive striking of the ruler against the desk. The student is confused about the speed of sound through solids versus the speed of sound in air. |
| 19. | *A musician stands outside in a field and plucks a string on an acoustic guitar. Standing waves will most likely occur in which of the following media? Select two answers.*  (a) The guitar string  (b) The air inside the guitar  (c) The air surrounding the guitar  (d) The ground beneath the musician |
| Solution | (a), (b) |
| 20. | [Figure 17\_10\_spkr\_img]    *The figure above shows two tubes that are identical except for their slightly different lengths. Both tubes have one open end and one closed end. A speaker connected to a variable frequency generator is placed in front of the tubes, as shown. The speaker is set to produce a note of very low frequency when turned on. The frequency is then slowly increased to produce resonances in the tubes. Students observe that at first only one of the tubes resonates at a time. Later, as the frequency gets very high, there are times when both tubes resonate.*  *In a clear, coherent, paragraph-length answer, explain why there are some high frequencies, but no low frequencies, at which both tubes resonate. You may include diagrams and/or equations as part of your explanation.* |
| Solution | In order to resonate, the length of the tube must be an odd multiple of a quarter wavelength of the sound (λ/4, 3 λ/4, 5 λ/4, etc.). Examples are shown below.  [Figure 17\_12\_tube\_resonate]    For resonance at low frequencies, the wavelength of the sound will be so small that only ¼ wavelengths will fit in the tube. Because the difference in tube lengths is much smaller than a half wavelength, resonance will only occur for one tube at a time.  As the frequency increases, wavelength will decrease and many more wavelengths will be able to fit inside the tube. At this time, both tubes may be able to resonate simultaneously. However, this will only be able to occur when the difference in length between the two tubes is precisely ½ wavelengths in size. For example, both tubes can resonate if one tube contains 17 quarter wavelengths while the other contains 19 quarter wavelengths. |
| 21. | [Figure 17\_11\_osc\_img]      *A student connects one end of a string with negligible mass to an oscillator. The other end of the string is passed over a pulley and attached to a suspended weight, as shown above. The student finds that a standing wave with one antinode is formed on the string when the frequency of the oscillator is f0. The student then moves the oscillator to shorten the horizontal segment of string to half its original length. At what frequency will a standing wave with one antinode now be formed on the string?*  (A) *f*0/2  (B) *f*0  (C) 2*f*0  (D) There is no frequency at which a standing wave will be formed. |
| Solution | (c) |
| 22. | *A guitar string of length L is bound at both ends. The table below shows the string’s harmonic frequencies when struck.*  [Table 17\_05\_02]   |  |  | | --- | --- | | Harmonic Number | Frequency | | 1 | 225/L | | 2 | 450/L | | 3 | 675/L | | 4 | 900/L |  1. *Based on the information above, what is the speed of the wave within the string?* 2. *The guitarist then slides her finger along the neck of the guitar, changing the string length as a result. Calculate the fundamental frequency of the string and wave speed present if the string length is reduced to 2/3 L.* |
| Solution | (a) 450 m/s; (b) 337.5/*L* Hz, 450 m/s |

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