

THE SCIENCE OF MUSIC

EXERCISES FOR CHAPTER 3

- 3.1** A sound reaching your ear has intensity 10^{-6} W/m^2 . A typical human eardrum has area about 60 mm^2 . About how much sound energy, in joules, will hit your eardrum per second?
- 3.2** A sound is measured to have mean-square sound pressure of 0.001 Pa^2 . What is its intensity?
- 3.3** What would be a typical value for the mean-square sound pressure indoors in a public place, such as store or restaurant? What about a loud outdoor space, such as a construction site?
- 3.4** Using the rules in Table 3.2 give rough decibel equivalents for the following intensities: (a) 10^{-7} W/m^2 , (b) $4 \times 10^{-7} \text{ W/m}^2$, (c) $8 \times 10^{-7} \text{ W/m}^2$, (d) $3.2 \times 10^{-6} \text{ W/m}^2$.
- 3.5** Using the rules in Table 3.2 give rough intensity values for the following sound levels in decibels: (a) 60 dB, (b) 63 dB, (c) 67 dB, (d) 72 dB.
- 3.6** A house is about 10 meters high and wide. What frequency must sound have in order to flow around the house unimpeded?
- 3.7** You hear music coming from the other side of a small forest of trees with trunks about 50 cm across. What effect would you expect the trees to have on the sound as it passes through the forest?
- 3.8** The lowest frequency we can hear is about 20 Hz. How wide therefore would an object need to be to block sound at all audible frequencies? Give an example of an object that is about this size.
- 3.9** As we have seen, sound reaches the human ear unobstructed by the head when the frequency is lower than about 1700 Hz, but will be attenuated above this frequency. Give a rough estimate of the corresponding frequency above which sound will be attenuated for a mouse and for an elephant.
- 3.10** The legendary marching band in the song *Seventy-Six Trombones* (see Example 3.7) is said to have had 110 cornets. By how many decibels would 110 cornets be louder than just a single cornet, assuming they are all playing the same thing?
- 3.11** A sound source produces a sound intensity level of 70 dB when heard from a distance of 5 meters. What is the sound intensity level at 10 meters, 20 meters, and 50 meters? (You should be able to work out the answers, at least roughly, without using a calculator.)
- 3.12** A large crowd of 100 000 people in a sports stadium are all cheering at once.

- a) A single person cheering loudly creates a sound intensity level of about 75 dB at a distance of 1 meter. What would the sound intensity level be at 50 meters?
- b) A player in the middle of the field is about 50 meters away from the people in the crowd (some a little more, some a little less). Given that there are 100,000 people in the crowd, what roughly is the sound intensity level for the player?
- c) How far would you have to be from the stadium for the sound intensity level to drop to a more reasonable 40 dB, assuming there are no obstacles in the way of the sound?

3.13 The sound level from the launch of NASA's Artemis 1 moon rocket on November 16, 2022 was measured to be a stupendous 136 dB at a distance of 1.48 km from the launch site.

- a) Using Eq. (3.47), calculate how far away you would have to be for the sound to drop to a more reasonable 60 dB.
- b) In practice, one does not need to be this far away. Why not?

3.14 You are listening to an open-air music concert.

- a) If you triple your distance from the stage, how many decibels does the sound intensity level go down by?
- b) The music has a sound intensity level of 80 dB for concertgoers 10 meters from the stage. Based on your answer to part (a), roughly how many times would you have to triple that distance to reduce the sound intensity level to a mellow 40 dB?
- c) About how far from the stage would you then be?

3.15 Three sounds are played one after another.

- a) Sound 2 is 25 dB louder than sound 1. How many sones louder is it?
- b) The intensity of sound 3 is 400 times that of sound 1. How many decibels is this?
- c) How many sones louder is sound 3 than sound 1?

3.16 The perceived loudness of a sound roughly doubles when the sound intensity level goes up by 10 dB.

- a) If the sound intensity level increases by S decibels, by what factor will the perceived loudness increase?
- b) By how many decibels does the sound intensity level of a sound increase when you half your distance from the sound source?
- c) Hence calculate the percentage by which the perceived loudness of a sound increases when you half your distance from its source.

3.17 A fifty-voice choir is singing in unison (i.e., they are all singing the same thing at the same time).

- a) How much greater is the intensity of the full choir than that of just one voice?
- b) How many decibels is this?
- c) How much greater will be the apparent loudness of the full choir be in sones than the apparent loudness of one voice?

3.18 Two tones are played at 60 dB, one with frequency 100 Hz and one with frequency 1000 Hz. Which will sound louder and by about how many decibels?

3.19 A 200 Hz tone is played at a sound intensity level of 40 dB. At what sound intensity level must a 50 Hz tone be played to sound 10 dB louder?

3.20 Two sine-wave tones are played one after another.

- a) The first has frequency 1000 Hz and sound intensity level 90 dB. The second has frequency 50 Hz and sounds the same loudness as the first. What is the sound intensity level of the second tone?
- b) Tones of these same two frequencies (50 Hz and 1000 Hz) are played 40 dB quieter. Which one will now sound louder, and by how many decibels?
- c) Explain briefly the relevance of the result in part (b) for recorded music. Why does it matter that sounds that are equally loud at one volume level are no longer equally loud when played at a quieter volume level?

3.21 Two sine-wave tones are played at a sound intensity level of 70 dB. Their pitches are D2 and C6.

- a) Though they are played at the same intensity they will not sound equally loud. Which one will sound louder?
- b) By about how many decibels would you have to turn up the volume on the quieter one to make it sound as loud as the louder one?

3.22 The limit of audibility for quiet sounds is usually taken to be 0 dB sound intensity level, which is a good general figure for a sound around 1000 Hz. At lower frequencies, however, the ear is less sensitive. Based on the Fletcher-Munson diagram of Fig. 3.6, what would you estimate to be the sound intensity level of the quietest audible sound at 20 Hz?

3.23 What is the apparent loudness in sones of a tone played at (a) 100 Hz and 40 dB, and (b) 4000 Hz and 70 dB?

3.24 What is the ratio of the apparent loudness in sones for a pair of tones at:

- a) 500 Hz and 2000 Hz, both played at 90 dB
- b) 200 Hz/60 dB and 50 Hz/90 dB