

Decibels, Phons, and Sones

The rate at which sound energy reaches a given cross-sectional area is known as the **sound intensity**. There is an abnormally large range of intensities over which humans can hear. Given the large range, it is common to express the sound intensity using a logarithmic scale known as the **decibel scale**. By measuring the intensity level of a given sound with a meter, the deciBel rating can be determined. Intensity values and decibel ratings for several sound sources listed in **Table 1**.

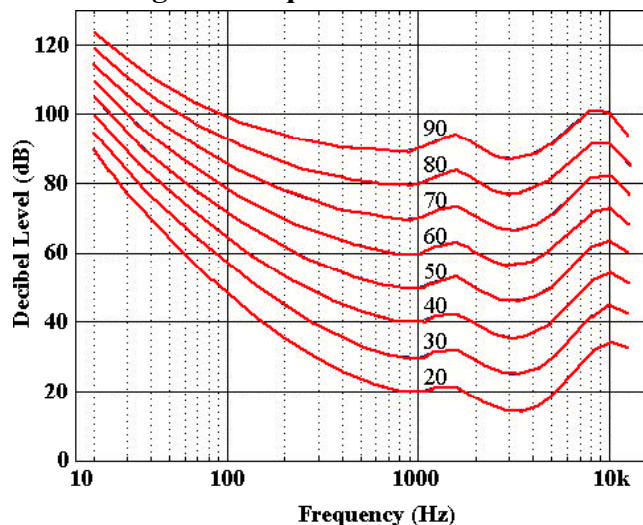
Table 1: deciBel Ratings of Several Sounds

Sound Source	Intensity	deciBel
Weakest Sound Heard	$1 \times 10^{-12} \text{ W/m}^2$	0.0
Rustling Leaves	$1 \times 10^{-11} \text{ W/m}^2$	10.0
Quiet Library	$1 \times 10^{-9} \text{ W/m}^2$	30.0
Average Home	$1 \times 10^{-7} \text{ W/m}^2$	50.0
Normal Conversation	$1 \times 10^{-6} \text{ W/m}^2$	60.0
Phone Dial Tone	$1 \times 10^{-4} \text{ W/m}^2$	80.0
Truck Traffic	$1 \times 10^{-3} \text{ W/m}^2$	90.0
Chainsaw, 1 m away	$1 \times 10^{-1} \text{ W/m}^2$	110.0

The decibel scale and the intensity values it is based on is an objective measure of a sound. While intensities and deciBels (dB) are measurable, the loudness of a sound is subjective. Sound loudness varies from person to person. Furthermore, sounds with equal intensities but different frequencies are perceived by the same person to have unequal loudness. For instance, a 60 dB sound with a frequency of 1000 Hz sounds louder than a 60 dB sound with a frequency of 500 Hz. The unit **phon** is used to indicate an individual's perception of loudness. By definition, 1 phon is equivalent to 1 deciBel at 1000 Hz (1 kHz).

Figure 1 shows several equal loudness curves. The curves were determined experimentally. Volunteers were subjected to a 1 kHz sound at 60 dB; this is a *loudness* of 60 phon. Sounds with different frequencies were then played; the volunteer adjusted the decibel level until it was perceived to have the same loudness as it had at 1000 Hz. This was repeated for varying frequencies to generate the entire 60-phon curve. To create an 80-phon curve, subjects were exposed to 1 kHz sounds at 80 dB. For other frequencies, they adjusted the decibel level until it was perceived to be of equal loudness as the 1 kHz sound. **Figure 1** represents an average of the results for many individuals.

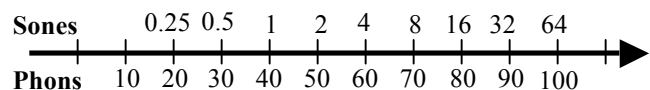
Figure 1: Equal Loudness Curves



The **sone scale** is a third scale associated with the loudness of a sound. The sone scale is based on the observation that a 10 phon increase in a sound level is most often perceived as a doubling of loudness.

According to the sone scale, a 1 sone sound is defined as a sound whose loudness is equal to 40 phons. **Figure 2** is generated based on these assumptions.

Figure 2: The Sone Scale



Questions:

1. Which statement accurately describes the mathematical relationship between the intensity of a sound and the decibel rating?
 - a. The decibel rating is the intensity value multiplied by 10.
 - b. The decibel rating doubles every time the intensity rating increases by 1000.
 - c. The decibel rating increases by 10 dB for every 10-fold increase in the intensity level.
 - d. The decibel rating is 10 times the absolute power of the exponent on 10 for the intensity level.
2. How is the decibel scale different than the phon scale?
 - a. All sounds have different decibel rating but the same phon rating.
 - b. The decibel scale is an objective measure of a sound; the phon scale is more subjective.
 - c. There is no limit on the decibel scale; the phon scale is limited to a smaller range of numbers.
 - d. The decibel scale measures the loudness of sound; the phon scale measures a person's perceptions.
3. What would be the phon rating of a 100 Hz sound that has a decibel rating of 60 dB?
 - a. 30 phons
 - b. 35 phons
 - c. 40 phons
 - d. 60 phons
4. Based on the information in **Figure 2**, how many times louder would a typical person perceive a 70 phon sound to be compared to a 40 phon sound?
 - a. 0.5 times louder
 - b. 3 times louder
 - c. 8 times louder
 - d. 30 times louder
5. A sound has an intensity level of $1 \times 10^{-2} \text{ W/m}^2$ and a frequency of 200 Hz. Use **Table 1**, **Figure 1**, and **Figure 2** to determine its rating on the Sone Scale.
 - a. Approximately 10 sones
 - b. Approximately 64 sones
 - c. Approximately 100 sones
 - d. Approximately 110 sones

Answers and Explanations

1. **Answer: C**

Explanation: The intensity value of rustling leaves and a quiet library is listed in the second column of **Table 1**. Scientific notation is used to express the intensity values. Consider the intensity and the decibel rating of an average home and of normal conversation. Normal conversation is 10 decibels greater than an average home; and the intensity level of normal conversation is 10 times greater (one power of 10) than an average home. The same trend is observed when comparing a phone dial tone and truck traffic. And so this data fits the statement that “the decibel rating increases by 10 dB for every 10-fold increase in the intensity level.” It also follows that a 100-fold increase in intensity level is equivalent to increasing the intensity by a factor of 10 on two consecutive occasions (i.e., $10 \times 10 = 100$). This translates into adding 10 dB to the decibel rating on two consecutive occasions. And so increasing the intensity level by a factor of 100 results in a new decibel rating that is 20 dB greater.

2. **Answer: B**

Explanation: The second paragraph of the passage is devoted to describing the difference between the decibel scale and the phon scale. The decibel scale is mathematically related to a measurable quantity that we refer to as decibels. The phon scale is subjective and associated with a person’s perception of how loud a sound is.

3. **Answer: B**

Explanation: The lines on the graph in **Figure 1** are referred to as equal loudness curves; each line is representative of a specific phon rating. The coordinate axes are the decibel rating and the frequency. To determine the phon rating of a sound with a given frequency and decibel rating, one must first locate the point on the graph with the given frequency-decibel coordinates. Then determine what line the coordinate point is on. The point with coordinates 60 dB and 100 Hz is in between the 30 phon line and the 40 phon line. And so the phon rating is in between 30 and 40 phons, making choice B the best answer.

4. **Answer: C**

Explanation: The sone scale is based on the observation that “a 10 phon increase in the sound level is most often perceived as a doubling of loudness.” A 40 phon sound is assigned a sone rating of 1. A 50 phon sound is 10 phons greater; so its sone rating is two times greater than 1 – thus a sone rating of 2. And a 60 phon sound is 10 phons greater than 50 phons; and so its sone rating must be double the sone rating of 50 phons. This makes a 60 phon sound have a sone rating of 4. The same reasoning would lead to the conclusion that a 70 phon sound would be twice as loud as a 60 phon sound and have a sone rating of 8. Putting these facts together, one concludes that a 70 phon sound (with a sone rating of 8) is eight times louder than a 40 phon sound (with a sone rating of 1).

5. **Answer: B**

Explanation: **Figure 2** can be used to determine the sone rating from the phon rating. But first the phon rating must be determined from the stated values of intensity and frequency. **Table 1** can be used to determine the decibel rating for the given intensity. Interpolating between the last two rows of the table allows one to conclude that a sound with an intensity

of $1.0 \times 10^{-2} \text{ W/m}^2$ has a decibel rating of 100.0 dB. Using **Figure 1**, this decibel rating can be combined with the frequency of 200 Hz to determine the phon rating. The coordinate point with values of 200 Hz and 100 dB lies above the 90 phon line. A reasonable estimate is that it is an approximately 100 phon sound. Now using **Figure 2**, a 100 phon sound has a sone rating of 64. This makes choice A the best choice.