

## Decibels

A *decibel* (abbreviated dB) is defined as one tenth of a *bel*. The bel<sup>F.1</sup> is an amplitude unit defined for sound as the log (base 10) of the *intensity* relative to some *reference intensity*,<sup>F.2</sup> i.e.,

$$\text{Amplitude\_in\_bels} = \log_{10} \left( \frac{\text{Signal\_Intensity}}{\text{Reference\_Intensity}} \right)$$

The choice of reference intensity (or power) defines the particular choice of *dB scale*. Signal intensity, power, and energy are always proportional to the *square* of the signal *amplitude*. Thus, we can always translate these energy-related measures into squared amplitude:

$$\text{Amplitude\_in\_bels} = \log_{10} \left( \frac{\text{Amplitude}^2}{\text{Amplitude}_{\text{ref}}^2} \right) = 2 \log_{10} \left( \frac{|\text{Amplitude}|}{|\text{Amplitude}_{\text{ref}}|} \right)$$

Since there are 10 decibels to a bel, we also have

$$\begin{aligned} \text{Amplitude}_{\text{dB}} &= 20 \log_{10} \left( \frac{|\text{Amplitude}|}{|\text{Amplitude}_{\text{ref}}|} \right) = 10 \log_{10} \left( \frac{\text{Intensity}}{\text{Intensity}_{\text{ref}}} \right) \\ &= 10 \log_{10} \left( \frac{\text{Power}}{\text{Power}_{\text{ref}}} \right) = 10 \log_{10} \left( \frac{\text{Energy}}{\text{Energy}_{\text{ref}}} \right) \end{aligned}$$

## DB SPL Scale:

Table F.1 gives a list of common sound levels and their dB equivalents [48]:

**Table F.1:** Approximate dB-SPL level of common sounds. (Information from S. S. Stevens, F. Warshofsky, and the Editors of Time-Life Books, *Sound and Hearing*, Life Science Library, Time-Life Books, Alexandria, VA, 1965, p. 173.)

Sound	dB-SPL
Jet engine at 3m	140
Threshold of pain	130
Rock concert	120
Accelerating motorcycle at 5m	110
Pneumatic hammer at 2m	100
Noisy factory	90
Vacuum cleaner	80
Busy traffic	70
Quiet restaurant	50
Residential area at night	40
Empty movie house	30
Rustling of leaves	20
Human breathing (at 3m)	10
Threshold of hearing (good ears)	0

In my experience, the "threshold of pain" is most often defined as 120 dB.

The relationship between sound amplitude and actual *loudness* is complex [67]. Loudness is a perceptual dimension while sound amplitude is physical. Since loudness sensitivity is closer to logarithmic than linear in amplitude (especially at moderate to high loudnesses), we typically use *decibels* to represent sound amplitude, especially in spectral displays.

The *sones amplitude scale* is defined in terms of actual loudness perception experiments [67]. At 1kHz and above, loudness perception is approximately logarithmic above 50 dB SPL or so. Below that, it tends toward being more linear.

The *phon amplitude scale* is simply the *dB scale* at 1kHz [67, p. 111]. At other frequencies, the amplitude in phons is defined by following the *equal-loudness* curve over to 1 kHz and reading off the level there in dB SPL. In other words, all pure tones have the same loudness at the same phon level, and 1 kHz is used to set the reference in dB SPL. Just remember that one phon is one dB-SPL at 1 kHz. Looking at the Fletcher-Munson equal-loudness curves [67, p. 124], loudness in phons can be read off along the vertical line at 1 kHz.

Classically, the *intensity level* of a sound wave is its dB SPL level, measuring the peak time-domain *pressure-wave* amplitude relative to  $10^{-16}$  watts per centimeter squared (*i.e.*, there is no consideration of the *frequency domain* here at all).

Another classical term still encountered is the *sensation level* of pure tones: The sensation level is the number of dB SPL above the *hearing threshold* at that frequency [67, p. 110].