**Sound Intensity and Sound Level**



Figure 1. Noise on crowded roadways like this one in Delhi makes it hard to hear others unless they shout. (Credit: Lingaraj G J, Flickr)

In a quiet forest, you can sometimes hear a single leaf fall to the ground. After settling into bed, you may hear your blood pulsing through your ears. But when a passing motorist has his stereo turned up, you cannot even hear what the person next to you in your car is saying. We are all very familiar with the loudness of sounds and aware that they are related to how energetically the source is vibrating. In cartoons depicting a screaming person (or an animal making a loud noise), the cartoonist often shows an open mouth with a vibrating uvula, the hanging tissue at the back of the mouth, to suggest a loud sound coming from the throat Figure 2. High noise exposure is hazardous to hearing, and it is common for musicians to have hearing losses that are sufficiently severe that they interfere with the musicians’ abilities to perform. The relevant physical quantity is sound intensity, a concept that is valid for all sounds whether or not they are in the audible range.

Intensity is defined to be the power per unit area carried by a wave. Power is the rate at which energy is transferred by the wave. In equation form, ***intensity*** *I* is I= =P/A, where *P* is the power through an area *A*. The SI unit for *I* is W/m2. The intensity of a sound wave is related to its amplitude squared by the following relationship:

I = (Δp)2/2ρvw

Here Δ*p* is the pressure variation or pressure amplitude (half the difference between the maximum and minimum pressure in the sound wave) in units of Pascals (Pa) or N/m2. (We are using a lower case *p* for pressure to distinguish it from power, denoted by *P* above.) The energy (as kinetic energy mv2/2) of an oscillating element of air due to a traveling sound wave is proportional to its amplitude squared. In this equation, *ρ* is the density of the material in which the sound wave travels, in units of kg/m3, and *v*w is the speed of sound in the medium, in units of m/s. The pressure variation is proportional to the amplitude of the oscillation, and so *I* varies as (Δ*p*)2 (Figure 2). This relationship is consistent with the fact that the sound wave is produced by some vibration; the greater its pressure amplitude, the more the air is compressed in the sound it creates.

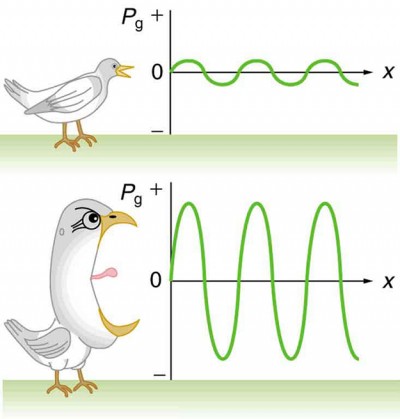


Figure 2. Graphs of the gauge pressures in two sound waves of different intensities. The more intense sound is produced by a source that has larger-amplitude oscillations and has greater pressure maxima and minima. Because pressures are higher in the greater-intensity sound, it can exert larger forces on the objects it encounters.

Sound intensity levels are quoted in decibels (dB) much more often than sound intensities in watts per meter squared. Decibels are the unit of choice in the scientific literature as well as in the popular media. The reasons for this choice of units are related to how we perceive sounds. How our ears perceive sound can be more accurately described by the logarithm of the intensity rather than directly to the intensity. The *sound intensity level β* in decibels of a sound having an intensity *I* in watts per meter squared is defined to be β(dB)=10log10 (I/I0), where I0 = 10−12 W/m2 is a reference intensity. In particular, I0 is the lowest or threshold intensity of sound a person with normal hearing can perceive at a frequency of 1000 Hz. Sound intensity level is not the same as intensity. Because *β* is defined in terms of a ratio, it is a unitless quantity telling you the *level* of the sound relative to a fixed standard (10−12 W/m2, in this case). The units of decibels (dB) are used to indicate this ratio is multiplied by 10 in its definition. The bel, upon which the decibel is based, is named for Alexander Graham Bell, the inventor of the telephone.

| **Table 1. Sound Intensity Levels and Intensities** | | |
| --- | --- | --- |
| **Sound intensity level *β* (dB)** | **Intensity *I*(W/m2)** | **Example/effect** |
| 0 | 1 × 10–12 | Threshold of hearing at 1000 Hz |
| 10 | 1 × 10–11 | Rustle of leaves |
| 20 | 1 × 10–10 | Whisper at 1 m distance |
| 30 | 1 × 10–9 | Quiet home |
| 40 | 1 × 10–8 | Average home |
| 50 | 1 × 10–7 | Average office, soft music |
| 60 | 1 × 10–6 | Normal conversation |
| 70 | 1 × 10–5 | Noisy office, busy traffic |
| 80 | 1 × 10–4 | Loud radio, classroom lecture |
| 90 | 1 × 10–3 | Inside a heavy truck; damage from prolonged exposure[**[1]**](https://courses.lumenlearning.com/physics/chapter/17-3-sound-intensity-and-sound-level/#footnote-3592-1) |
| 100 | 1 × 10–2 | Noisy factory, siren at 30 m; damage from 8 h per day exposure |
| 110 | 1 × 10–1 | Damage from 30 min per day exposure |
| 120 | 1 | Loud rock concert, pneumatic chipper at 2 m; threshold of pain |
| 140 | 1 × 102 | Jet airplane at 30 m; severe pain, damage in seconds |
| 160 | 1 × 104 | Bursting of eardrums |

The decibel level of a sound having the threshold intensity of 10−12 W/m2 is *β* = 0 dB, because log101 = 0. That is, the threshold of hearing is 0 decibels. Table 1 gives levels in decibels and intensities in watts per meter squared for some familiar sounds.

One of the more striking things about the intensities in Table 1 is that the intensity in watts per meter squared is quite small for most sounds. The ear is sensitive to as little as a trillionth of a watt per meter squared—even more impressive when you realize that the area of the eardrum is only about 1 cm2, so that only 10–16 W falls on it at the threshold of hearing! Air molecules in a sound wave of this intensity vibrate over a distance of less than one molecular diameter, and the gauge pressures involved are less than 10–9 atm.

Another impressive feature of the sounds in Table 1 is their numerical range. Sound intensity varies by a factor of 1012 from threshold to a sound that causes damage in seconds. You are unaware of this tremendous range in sound intensity because how your ears respond can be described approximately as the logarithm of intensity. Thus, sound intensity levels in decibels fit your experience better than intensities in watts per meter squared. The decibel scale is also easier to relate to because most people are more accustomed to dealing with numbers such as 0, 53, or 120 than numbers such as 1.00 × 10–11.

One more observation readily verified by examining Table 1 or using I = (Δp)2/2ρvw is that each factor of 10 in intensity corresponds to 10 dB. For example, a 90 dB sound compared with a 60 dB sound is 30 dB greater, or three factors of 10 (that is, 103 times) as intense