

## 12-2 Intensity of Sound: Decibels

Like pitch, **loudness** is a sensation in the consciousness of a human being. It too is related to a physically measurable quantity, the **intensity** of the wave. Intensity is defined as the energy transported by a wave per unit time across a unit area perpendicular to the energy flow. As we saw in Chapter 11, intensity is proportional to the square of the wave amplitude. Intensity has units of power per unit area, or watts/meter<sup>2</sup> (W/m<sup>2</sup>).

The human ear can detect sounds with an intensity as low as  $10^{-12}$  W/m<sup>2</sup> and as high as 1 W/m<sup>2</sup> (and even higher, although above this it is painful). This is an incredibly wide range of intensity, spanning a factor of  $10^{12}$  from lowest to highest. Presumably because of this wide range, what we perceive as loudness is not directly proportional to the intensity. To produce a sound that sounds about twice as loud requires a sound wave that has about 10 times the intensity. This is roughly valid at any sound level for frequencies near the middle of the audible range. For example, a sound wave of intensity  $10^{-2}$  W/m<sup>2</sup> sounds to an average human being like it is about twice as loud as one whose intensity is  $10^{-3}$  W/m<sup>2</sup>, and four times as loud as  $10^{-4}$  W/m<sup>2</sup>.

### Sound Level

Because of this relationship between the subjective sensation of loudness and the physically measurable quantity “intensity,” sound intensity levels are usually specified on a logarithmic scale. The unit on this scale is a **bel**, after the inventor Alexander Graham Bell, or much more commonly, the **decibel** (dB), which is  $\frac{1}{10}$  bel (10 dB = 1 bel). The **sound level**,  $\beta$ , of any sound is defined in terms of its intensity,  $I$ , as

$$\beta \text{ (in dB)} = 10 \log \frac{I}{I_0}, \quad (12-1)$$

where  $I_0$  is the intensity of a chosen reference level, and the logarithm is to the base 10.  $I_0$  is usually taken as the minimum intensity audible to a good ear—the “threshold of hearing,” which is  $I_0 = 1.0 \times 10^{-12}$  W/m<sup>2</sup>. Thus, for example, the sound level of a sound whose intensity  $I = 1.0 \times 10^{-10}$  W/m<sup>2</sup> will be

$$\beta = 10 \log \left( \frac{1.0 \times 10^{-10} \text{ W/m}^2}{1.0 \times 10^{-12} \text{ W/m}^2} \right) = 10 \log 100 = 20 \text{ dB},$$

since  $\log 100$  is equal to 2.0. Notice that the sound level at the threshold of hearing is 0 dB. That is,  $\beta = 10 \log 10^{-12}/10^{-12} = 10 \log 1 = 0$  since  $\log 1 = 0$ . Notice too that an increase in intensity by a factor of 10 corresponds to a sound level increase of 10 dB. An increase in intensity by a factor of 100 corresponds to a sound level increase of 20 dB. Thus a 50-dB sound is 100 times more intense than a 30-dB sound, and so on.

Intensities and sound levels for a number of common sounds are listed in Table 12-2.

**EXAMPLE 12-3 Sound intensity on the street.** At a busy street corner, the sound level is 70 dB. What is the intensity of sound there?

**APPROACH** We have to solve Eq. 12-1 for intensity  $I$ , remembering that  $I_0 = 1.0 \times 10^{-12}$  W/m<sup>2</sup>.

**SOLUTION** From Eq. 12-1

$$\log \frac{I}{I_0} = \frac{\beta}{10},$$

so

$$\frac{I}{I_0} = 10^{\beta/10}.$$

With  $\beta = 70$ , then

$$I = I_0 10^{\beta/10} = (1.0 \times 10^{-12} \text{ W/m}^2)(10^7) = 1.0 \times 10^{-5} \text{ W/m}^2.$$

**NOTE** Recall (Appendix A) that  $x = \log y$  is the same as  $y = 10^x$ .

*Loudness*



**PHYSICS APPLIED**

*Wide range of human hearing*

*The dB unit*

*Sound level (decibels)*



**CAUTION**

*0 dB does not mean zero intensity*

*Each 10 dB corresponds to a 10-fold change in intensity*

**TABLE 12-2 Intensity of Various Sounds**

Source of the Sound	Sound Level (dB)	Intensity (W/m <sup>2</sup> )
Jet plane at 30 m	140	100
Threshold of pain	120	1
Loud rock concert	120	1
Siren at 30 m	100	$1 \times 10^{-2}$
Auto interior, at 90 km/h	75	$3 \times 10^{-5}$
Busy street traffic	70	$1 \times 10^{-5}$
Talk, at 50 cm	65	$3 \times 10^{-6}$
Quiet radio	40	$1 \times 10^{-8}$
Whisper	20	$1 \times 10^{-10}$
Rustle of leaves	10	$1 \times 10^{-11}$
Threshold of hearing	0	$1 \times 10^{-12}$