Pitch, Loudness, Quality/Timbre, Intensity of sound, decibel.

The pitch of a sound wave is determined by its frequency. A female voice is usually at a higher pitch than the voice of a man. We say a woman's voice has a higher pitch and a man's voice a lower pitch. Soprano is at the highest pitch of all the parts sung in a choir.

Loudness is a factor of the amplitude of the wave. The Intensity of a sound wave is directly proportional to the square of its amplitude. If we double the amplitude of a wave, the sound is 4 times louder. The Bel expresses the logarithmic ratio between two levels of signal power, voltage, or current in electronics and communications. It is named after Alexander Graham Bell, who invented the telephone. The decibel (dB), one-tenth of a Bel, is more often used as the unit of measurement. This is because the smallest difference that can be detected by a human ear is a one-decibel difference in loudness between two sounds. It is worthy of note that the ear is more sensitive to sound of very small amplitude than it is to sound of very large amplitude. Thus, a nonlinear scale is appropriate. This is provided by the logarithmic measure

$$L = 10\log_{10}\left(\frac{I}{I_0}\right)$$

L is the loudness in decibels corresponding to a sound of intensity I in Watts per square metre and I_0 is the reference intensity. When $I = I_0$,

$$L = 10\log_{10}\left(\frac{I}{I_0}\right) \text{ dB}$$

The loudness at this intensity is zero decibel. I_0 is about $10^{-12} W/m^2$. Now, consider an intensity of 10^{-11} W/m^2.

$$L = 10\log_{10}\left(\frac{10^{-11}}{10^{-12}}\right) = 10\log_{10}10 = 10 \text{ dB}$$

What about an increase from 10^{-1} to 1 W/m^2? This is an increase of 10 in the value of L.

$$L(10^{-1} W/m) = 10\log_{10}\left(\frac{10^{-1}}{10^{-12}}\right) = 10\log_{10}10^{11} = 110 \text{ dB}$$

$$L(1 W/m) = 10\log_{10}\left(\frac{1}{10^{-12}}\right) = 10\log_{10}10^{12} = 120 \text{ dB}$$

You could also get this increase as

$$L(10^{-1} \rightarrow 1 W/m) = 10\log_{10}\left(\frac{1}{10^{-1}}\right) = 10\log_{10}10 = 10 \text{ dB}$$

Other units of sound intensity are, the neper (np) and the bel (B).

$$L = \frac{1}{2}\ln\left(\frac{I}{I_0}\right) np = \log_{10}\left(\frac{I}{I_0}\right) B = 10\log_{10}\left(\frac{I}{I_0}\right) dB$$

The decibel is a tenth of the bel. Notice that all these units are dimensionless.

1 bel = $\frac{1}{2}\ln 10$. I dB = $\frac{1}{20}\ln 10$

Example: Convert 10 decibel to neper.

$$1 \text{ decibel} = \frac{1}{20}\frac{\ln\left(\frac{I}{I_0}\right)}{\log_{10}\left(\frac{I}{I_0}\right)} = \frac{1}{20}\times\frac{\log_e 10}{\log_{10} 10} = \frac{1}{20}\times 2.3026 = 0.115\ np$$

10 decibel = 1.15 np = 1 bel

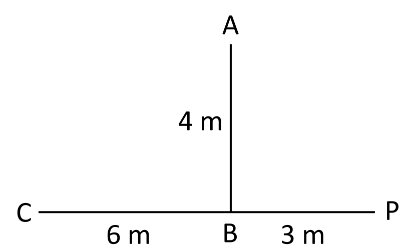
Variation of Intensity of Sound with distance from the source

The intensity of a sound wave falls with distance in an inverse-square manner. That is, $I \propto \frac{I_0}{r^2} \Rightarrow I = k\frac{I_0}{r^2}$. Very much like the behaviour of the electric field of a charge. This is because the charge is constant, just as the energy sent out at the source is constant at the source. The energy spreads out spherically very much as the electric field of a point charge or the gravitational field of a mass spread out. You must have come across this in the form of Gauss's law in electrostatics. Indeed, Sound intensity or acoustic intensity, is the power carried by sound waves per unit area in a direction perpendicular to the area.

Problem

A sound source is at P in the diagram. Calculate the ratio of the sound intensity at A, B and C.

$$I_A = k\frac{I_0}{5^2}, I_B = k\frac{I_0}{3^2},\ I_C = k\frac{I_0}{9^2} \Rightarrow I_A : I_B : I_C = k\frac{I_0}{5^2} : k\frac{I_0}{3^2} : k\frac{I_0}{9^2} = \frac{1}{25} : \frac{1}{9} : \frac{1}{81} = 729 : 2025 : 225$$



Quality/Timbre

This depends on the number of overtones present in the sound and their relative intensities. This enables you to differentiate between two musical instruments having the same fundamental frequency. For instance, a tube opened at one end has only odd harmonics while a tube opened at both ends has both odd and even harmonics. The waveform of the latter is more complex than that of the former.