Intensity and loudness of sound

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PHS-G-CC-4-4-TH

1 Intensity and loudness of sound

The characteristics of a musical sound are decided by the following factors:
(i) Intensity or loudness
(ii) Frequency or Pitch
(iii) Quality or timbre

Physically the intensity of a sound wave is the energy passing per second across unit area perpendicular to the direction of propagation. The subjective sensation of loudness is, however, not proportional to intensity. The range of audible frequency is from about 20 Hz to about 20 kHz and the sensitivity of normal ear is different at different frequencies. The maximum pressure vibration to produce a just audible sensation of sound at 25 Hz, is as large as 10 dynes/cm^2, while it is as low as 0.00076 dynes/cm^2 at 1000 Hz. The ear is most sensative to a sound of about 3500 Hz when the pressure at threshold of audibility is 0.00008 dynes/cm^2 only.

In fact, the intensity, the frequency and the quality refers to the quantitative aspects of a musical sound while the loudness, the pitch and the timbre corresponds to the qualitative aspects of a musical sound. The intensity of a sound depends
(i) on the square of the amplitude 'a'
(ii) on the size of the source
(iii) on the square of the frequency of the sound and
(iv) inversely on the square of the distance between the source and the listener.

Since the sensation of loudness depends upon intensity, a relationship has been decided between the intensity level and the sensation of loudness of a particular sound. This is known as Weber-Fechner's law.

The law states that the increase in loudness level of a sound depends upon the increase in intensity and inversely on the actual intensity of the sound,

$$\begin{aligned} \delta L &\propto \frac{\delta I}{I} \\ or\ \delta L &= k\frac{\delta I}{I} \end{aligned} \tag{1}$$

where k is a constant. Integrating both sides

$$\begin{aligned} L &= k \ln I + C \\ or\ L &= C_1 \log_{10} I + C \end{aligned} \tag{2}$$

$\Rightarrow$ Weber-Fechner's law.

2 Threshold of audibility

The sound having a frequency 1000 Hz and absolute intensity of 10^{-16} watt/cm^2 corresponding to an average acoustic pressure of 0.0002 dynes/cm^2 is called the standard reference tone or the threshold of audibility. It is usually denoted by I_0. Thus the intensity level of a given sound having an absolute intensity I_0 is given by

$$I.L. = log_{10}\frac{I}{I_0}$$

This intensity is defined in bel unit. Hence, a sound having an intensity level of 1 bel has an absolute intensity $I = 10 \times 10^{-16} = 10^{-15}$ watt/sec.

2.1 Decibel

This is a small unit of sound intensity level. It is one tenth of a bel. $\therefore 1\ bel\ = 10d.b.$.

3 Loudness level

The loudness level of a given sound is measured in phon unit. If the sound has an intensity level of $n\ d.b.$ s, its equivalent loudness level is given by $n\ phons$.

3.1 What is sone

A higher unit of equivalent loudness level is 'sone'. If a sound has an intensity level of 40 $d.b.$ (at a frequency of 1000 Hz) the equivalent loudness level of sound is given by 1 $sone$. $[\because 1\ sone = 40\ phon]$.

4 Quality or timbre

It is that property of musical sound by which one can distinguish different tones of same frequency and intensity, emitted from different musical instruments. Helmholtz has pointed out that the waveforms of this tones will be different and it is this difference in waveforms which is responsible for imparting different qualities to the tones.

5 Solved problems

5.1 Problem 1

The power of a source is 1 $watt$. Calculate the amount of energy received per minute per area at a distance 1 m away from the source.

Solution
$P = 1\ watt = 1\ joule/sec$. The souce is emitting 1 $Joule$ energy per second. The energy is distributed as a spherical wavefront.
$\therefore$ energy received per unit area per second at a distance of 100 cm from the source is

$$E' = \frac{10^7}{4\pi \times (100)^2}\ erg$$

Hence the required energy received per unit area per minute is

$$E = E' \times 60 = \frac{10^3}{4\pi}60\ erg$$

5.2 Problem 2

An orchetra rises to an equivalent loudness level of 1 *sona*. calculate the absolute intensity of the sound in $\mu w/cm^2$.

Solution:

The equivalent loudness level of the sound = 1 *sona* = 40 *phon*. $\therefore$ the intensity level of the sound = 40 *d.b.* = 4 *bel*. If I be the required absolute intensity of the sound,

$$\begin{aligned} 4 &= log_{10}\frac{I}{I_0} \\ or\ \frac{I}{I_0} &= 10^4 \\ or\ I &= I_0 \times 10^4 \\ &= 10^{-16} \times 10^4\ watt/cm^2 \\ &= 10^{-6}\mu w/cm^2 \end{aligned}$$

5.3 Problem 3

A sound has an intensity twice that of the standard reference tone. Calculate its intensity level in *d.b.*

Solution:

Here $I = 2I_0$.

$$\begin{aligned} \therefore I.L. &= log_{10}\frac{I}{I_0}\ bel \\ &= 10log_{10}\frac{I}{I_0}\ d.b. \\ &= 10log_{10}\frac{2I_0}{I_0} \\ &= 10 \times 0.3010\ d.b. \\ &= 3.010\ d.b. \end{aligned}$$

$I = 10^{-10}watt/cm^2$.

$$\therefore I.L. = log_{10}\left(\frac{10^{-10}}{10^{-16}}\right) = log_{10}10^6 = 6\ bel$$

5.4 Problem 4

A source of sound has a power of $10watt$. How much amount of energy is received per unit area at a distance of $1m$ from the source per sec.

Solution:

10 *watt* = 10 *Joule/sec*. Thus the source emits 10 *Joule* energy per sec. This energy travels as a spherical wavefront. Hence the intensity at a point 1 m apart from the source is

$$I = \frac{10}{4\pi(100)^2}\ watt/cm^2 = 0.8 \times 10^{-4}\ watt/cm^2$$