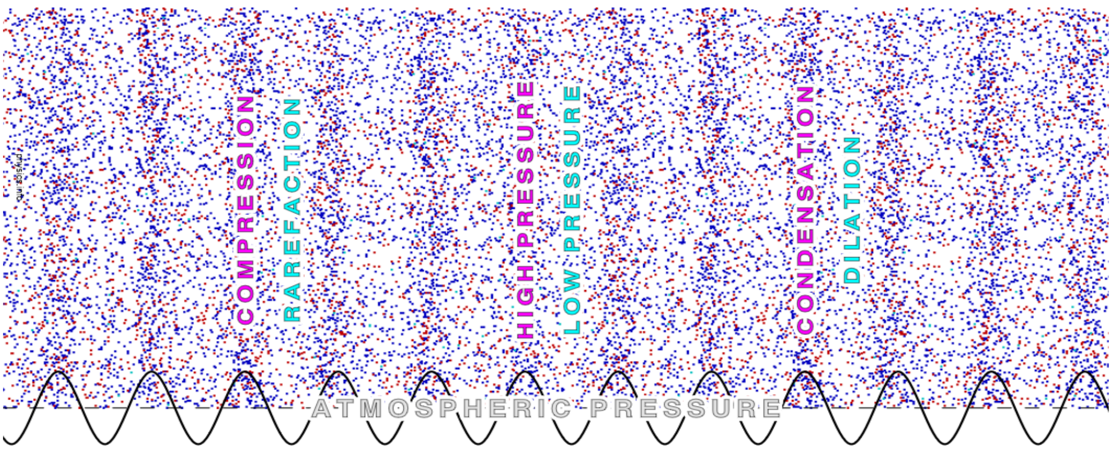
# Lecture 8

## Sound, Intensity and Level; Sources

sound in air or other fluids is a good example of longitudinal, mechanical or condensation (A region of increased pressure on a waves compression sound wave )and rarefaction or dilation (A region of decreased pressure on a sound wave) occur along the propagation direction when the disturbance reaches our eardrums it is detected and perceived in our brains according to its loudness(Intensity), pitch(frequency) and other factors.

**Sound cannot travel through a vacuum**.

snapshot of a longitudinal wave in air




instantaneous local pressure

**Speed of Sound**

Air at $0^o$ C , $v$ =331 m/s

Air at $20^o$ C , $v$ =343 m/s (value used in most problems)

In gases with lighter molecules, the speed is even greater :

Helium at $20^o$ C , $v$ =1005 m/s

Hydrogen at $20^o$ C , $v$ =1300 m/s

Speed of Sound is also very large in solids, due to their strong elastic properties Table (8.1)

| **Medium** | ***v* (m/s)** |
|---|---|
| Solids (longitudinal or bulk) ***at 20$^o$C*** | |
| Vulcanized rubber | 54 |
| Polyethylene | 920 |
| Marble | 3810 |
| Glass, Pyrex | 5640 |
| Lead | 1960 |
| Aluminum | 5120 |
| Steel | 5960 |

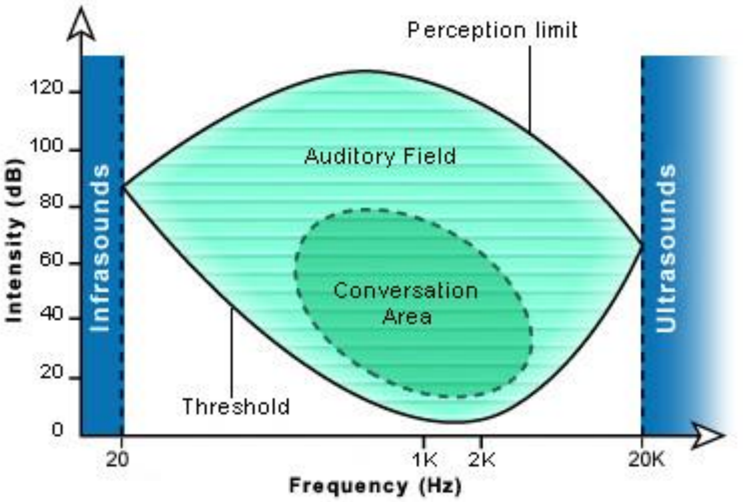
Table 8.1

The time between seeing lightning and hearing thunder can always use $\boldsymbol{d} = \boldsymbol{vt}$ figure out the time delay for when sound from any source reaches a detector or observer. Time for sound to travel **1 mile =1609 m** is

$$t = \frac{d}{v} = \frac{1609\,m}{343 m/s} = 4.7s \sim 5s$$

commonly used to estimate distance to lightning strikes.

**Human auditory field: frequency-intensity curves**




The human auditory field corresponds to a specific band of frequencies between **20 Hz** (lowest pitch) to **20 kHz** (highest pitch) and a specific range of intensities, perceived by our ear. Acoustic vibrations outside of this field are not considered as "sounds", even if they can be perceived by other animals.

## Sound, Intensity and Level

defined intensity as 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 $\boldsymbol{I}$ is:

where $\boldsymbol{P}$ is the power through an area $\boldsymbol{A}$. Threshold of human hearing is: $I = \frac{P}{A}$

This is taken as a standard of extremely faint sound intensity $I_O = 10^{-12}\ \frac{W}{m^2}$

The **SI** unit for $\boldsymbol{I}$ is $(\frac{W}{m^2})$

If we assume that the sound wave is spherical, and that no energy is lost to thermal processes, the energy of the sound wave is spread over a larger area as distance increases, so the intensity decreases. The area of a sphere is: $A = 4\pi r^2$

But our hearing physiology works on a logarithmic scale. when $\boldsymbol{I}$ increases by **10** , to as it only sound ***2x loud***. So define sound level in decibels, **(dB)**

$$\beta = (10\ dB)\log\left(\frac{I}{I_O}\right)\ This\ uses\ \log 10$$

| Sound intensity level $\beta$ (dB) | Intensity $I$ ($W/m^2$) | Example / effect |
|---|---|---|
| 0 | $1\times 10^{-12}$ | Threshold of hearing at 1000 Hz |
| 10 | $1\times 10^{-11}$ | Rustle of leaves |
| 20 | $1\times 10^{-10}$ | Whisper at 1 m distance |
| 30 | $1\times 10^{-9}$ | Quiet home |
| 40 | $1\times 10^{-8}$ | Average home |
| 50 | $1\times 10^{-7}$ | Average office, soft music |
| 60 | $1\times 10^{-6}$ | Normal conversation |
| 70 | $1\times 10^{-5}$ | Noisy office, busy traffic |
| 80 | $1\times 10^{-4}$ | Loud radio, classroom lecture |
| 90 | $1\times 10^{-3}$ | Inside a heavy truck; damage from prolonged exposure |
| 100 | $1\times 10^{-2}$ | Noisy factory, siren at 30 m; damage from 8 h per day exposure |
| 110 | $1\times 10^{-1}$ | Damage from 30 min per day exposure |
| 120 | 1 | Loud rock concert, pneumatic chipper at 2 m; threshold of pain |
| 140 | $1\times 10^{2}$ | Jet airplane at 30 m; severe pain, damage in seconds |
| 160 | $1\times 10^{4}$ | Bursting of eardrums |

**Table 8. 2.** Sound Intensity Levels and Intensities.

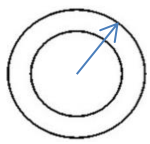
An observation readily verified by examining (**Table 8.2**) or by using equation $\boldsymbol{\beta = (10\ dB)\log\left(\frac{I}{I_0}\right)}$ is that each factor of **10** in intensity corresponds to **10 dB**. For example, a **90 dB** sound compared with a **60 dB** sound is **30 dB** greater, or three factors of **10** (that is,$\mathbf{10^3}$ times) as intense. Table 8.3.

| $I_2 / I_1$ | $\beta_2$-$\beta_1$ |
|---|---|
| 2.0 | 3 dB |
| 5.0 | 7.0 dB |
| 10.0 | 10.0 dB |
| 100.0 | 20.0 dB |
| 1000.0 | 30.0 dB |

Table 8.3. Ratios of Intensities and Corresponding Differences in Sound Intensity Levels

**Example:** a loudspeaker emits total power of **75 W** equally in all direction (isotropically) what are the intensity and sound level at **r=3m** away?

**Solution:**



Approach the power is spread out over a spherical surface, radius $r$ whose area is $A = 4\pi r^2$, $I = \frac{P}{A} = \frac{P}{4\pi r^2} = \frac{75W}{4\pi(3)^2} = 0.663\,\frac{W}{m^2}$

$$\beta = (10\ dB)\log\left(\frac{I}{I_O}\right) = (10\ dB)\log\left(\frac{0.663\ W/m^2}{10^{-12}\ W/m^2}\right)$$

$$= 118\ dB\ very\ loud$$

**Example:** A baby cries on seeing a dog and the cry is detected at a distance of **3.0 m** such that the intensity of sound at this distance is **$10^{-2}$ $W$ $m^{-2}$**. Calculate the intensity of the baby's cry at a distance **6.0 *m***.

**Solution:**

$I_1$ is the intensity of sound detected at a distance **3.0 m** and it is given as **$10^{-2}$ $W$ $m^{-2}$**. Let $I_2$ be the intensity of sound detected at a distance **6.0 m**. Then,

$r_1$ = 3.0 m, $I_1 = 10^{-2}\ W\,m^{-2}$

$r_2$ = 6.0 m, $I_2$=?

$I = \frac{P}{A} = \frac{P}{4\pi r_1^2}$, $P = I \times 4\pi {r_1}^2 = 10^{-2} \times 4\pi \times (3^2) = 36\,\pi \times 10^{-2}\ W$

$$I = \frac{P}{4\pi r_2^2} = \frac{36\,\pi \times 10^{-2}\ W}{4\pi(6 \times 6)m^2} = 0.25 \times 10^{-2}\ \frac{W}{m^2}\ \text{and since}, I \propto \frac{1}{r^2}$$

the power output does not depend on the observer and depends on the baby. Therefore,

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}\ , I_2 = I_1\frac{r_1^2}{r_2^2} = 0.25 \times 10^{-2}\frac{W}{m^2}$$

## Sources of sound-musical instruments

The physics behind musical instruments is beautifully simple. The sounds made by musical instruments are possible because of standing waves, which come from the constructive interference between waves traveling in both directions along a string or a tube..

**string instruments:**

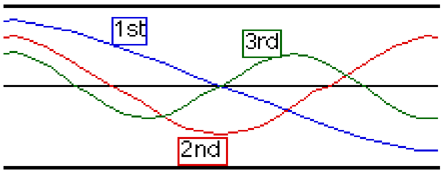
. Applies to guitar, violins, cello's, etc. $\boldsymbol{f_n = nf_1}$, $\boldsymbol{f_1 = \frac{v}{2L}}$, $\boldsymbol{v = \sqrt{\frac{\tau}{m/L}}}$

But note wavelength on the string is different from the wavelength in the air because there are different wave speeds in the two.

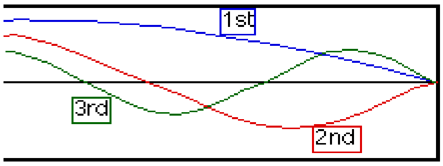
**Wind instruments and longitudinal standing waves(use a vibrating column of air ):**

Pipes work in a similar way as strings, so we can analyze everything from organ pipes to flutes to trumpets. The big difference between pipes and strings is that while we consider strings to be fixed at both ends, the tube is either free at both ends (if it is open at both ends) or is free at one end and fixed at the other (if the tube is closed at one end). In these cases the harmonic frequencies are given by:

tube open at both ends : $f_n = n (v/2L)$ (n = 1, 2, 3, 4, ...)




tube open at one end : $f_n = n (v/4L)$ (n = 1, 3, 5, ...)




A pipe organ has an array of different pipes of varying lengths, some open-ended and some closed at one end. Each pipe corresponds to a different fundamental frequency. For an instrument like a flute, on the other hand, there is only a single pipe. Holes can be opened along the flute to reduce the effective length, thereby increasing the frequency. In a trumpet, valves are used to make the air travel through different sections of the trumpet, changing its effective length; with a trombone, the change in length is a little more obvious.

**Example:** A tube open at one end has a length of **25.0 cm**. The temperature is **20°C**. What is the fundamental frequency of this tube? What is the frequency of the fifth harmonic?

**Solution:**

If we blow through the tube, it will make a musical tone, and that's what we're talking about here. The velocity involved in the frequency equation is therefore the speed of sound, which is **343 m/s at 20°C**. The fundamental frequency is then:

$f_n = n (v/4L)$ with n = 1

So the fundamental is **343/(4 x 0.25) = 343 Hz**.

A tube like this, closed at one end, only has odd harmonics (**n = 1, 3, 5, etc**.).

The fifth harmonic is five times the fundamental, and it's also given by:

$f_n = n (v/4L)$ with n = 5

So the fifth harmonic is **1715 Hz.**

## Beats

When two waves which are of slightly different frequency interfere, the interference cycles from constructive to destructive and back again. This is known as beats; two sound waves producing beats will generate a sound with an intensity that continually cycles from loud to soft and back again. The frequency of the sound you hear will be the average of the frequency of the two waves; the intensity will vary with a frequency (known as the beat frequency) that is the difference between the frequencies of the two waves.