Sound – basics

1 What is sound?

1.1 Definitions

Like light, sound is a physical phenomenon defined via human perception. Light is the visible section of electromagnetic vibrations (waves). Similarly, **sound is the audible section of mechanical vibrations or waves**.
The **sound source** is always a mechanically vibrating material, for example gases (wind instruments), solids (string, vocal chord), or liquids.
The **sound is transmitted** to the ear via the **sound carrier** air:
The vibrations of a solid, for example, are transferred to the surrounding air and transmitted in the form of periodic pressure fluctuations as a longitudinally vibrating sound wave. Longitudinal means that the wave is vibrating in the direction of propagation.
Sound perception and sound transduction: In the human ear, the sound waves are first beamed and amplified ("force amplification") and then in the inner ear converted into a cochlear travelling wave, which, in turn, generates electric impulses and thus, neuronal activity.

1.2 Categorization by frequency

Sound waves are categorized by their frequencies into the following ranges:

- **Audible sound**
  Sound waves with frequencies between 16 Hz and 20,000 Hz that can be heard by the human ear.
- **Infrasound**
  Sound vibrations with frequencies of less than 16 Hz , which occur as ground or building vibrations and are not registered by the human ear. They can, however, be felt subconsciously by the human body. Elephants, for example, communicate in this range.
- **Ultrasound**
  Frequencies between approx. 20 kHz and 10^7 kHz. Ultrasonic waves are used in medicine, for example, for diagnostics. In the animal world, bats, for example, use this range as "acoustic radar".
- **Hyper sound**
  Frequencies above 10^7 kHz are in the thermal motion range of material (for example, used to determine physical properties such as hardness, elasticity, etc.).

Although these frequency ranges differ with respect to human perception, they nevertheless always involve mechanical waves. (Analogy to light: ultraviolet, infrared, microwaves).

2 Sound types

In an ideal form, sound waves are based on sine-shaped waves (sine curve). In principle, several waves, each of a different frequency, could overlap to form an envelope, which is regarded as "enveloping" all the waves involved. The following sound types can be differentiated by total duration, amplitude, and shape of the enveloping sound curve:

- **Tone**
  A **pure tone** is the physically most simple type of sound vibration, namely, a sine wave of a single frequency. In other words, the pressure fluctuations of a pure tone have a temporal and spatial sinusoidal pattern. Tones are characterized by their pitch (frequency) and level (amplitude).

  Examples: The only truly pure tone is a test tone from an electronic generator. Practically pure is the tone from a tuning fork (few overtones, additional tones only when struck).

- **Harmonic**
  Just like any other vibration, sound can also be formed by **overlapping sinusoidal waves of the same frequency**. Several tones in a set, "meaningful" relationship to each other produce a "harmonic": This set, "meaningful" relationship arises if the frequencies of the various tones are integer multiples of the frequency of a sinusoidal fundamental wave. The result, the harmonic, is a periodic, but no longer sinusoidal, overall wave.

  Examples: tone of a single (!) guitar string, violin string, etc.

- **Complex sound**
  Arises from **sinusoidal vibrations with any frequencies**.

  Example: Consonance of several violin strings

- **Harmonic mixture**
  A harmonic mixture comprises harmonics with fundamental tones of any frequencies.

  Example: Choir, orchestra, etc.

- **Noise**
  All of the above sound types are based on periodic pressure fluctuations. Sound events produced by pressure fluctuations without regularity (sine vibrations) are not tones or sounds, and are termed noise.
  Experts often use the term "tone" loosely in the sense of "audio". A practically-oriented definition of noise is thus: a sound event whose tones have no content-specific or aesthetically meaningful relationship to each other.

  Examples: Rustling leaves, waterfall, machine noises, etc.

- **Bang**
  This comprises a small number of vibrations differing widely in frequency, in which the amplitudes shoot up explosively and then rapidly decline.

  Example: Bursting balloon, explosion

3 Parameters of the individual sound wave

3.1 Basic physical parameters

Just like any other type of wave also:

- frequency (wavelength),
- oscillation, and
- amplitude.

3.2 Visible and audible parameters

Vibrations and waves are depicted as mathematical curves; hence, the shape of a vibration is also referred to as "curve form". This can be rendered visible in an oscilloscope, for example. (Note: Modern audio editing programs for computers also have an oscilloscope-like presentation function.)

Here

- The **amplitude** stands for the **volume.**
- The **frequency** defines the **pitch**.
- The **vibration form** determines the **harmonic**.

3.3 Electro-acoustics: Presentation with oscilloscope

High tones have tight, quickly repeating waveforms, for low tones the waveforms are broader and repeat themselves more slowly.

Note: You will also find a large number of typical sound samples as audio files or as a combined video (oscilloscope/tone presentation) on the media portal of the Siemens Stiftung.

3.4 Speed of sound in the air

Sound waves are longitudinal waves. In other words, the sound energy travels in parallel to the direction of displacement of the air particles. (Water waves, by comparison, are transverse!).

The speed c, at which sound energy travels, is called the speed of sound. At 0 °C and 1,013 mbar in air, it is 331 m/s (= approx. 1,200 km/h).

3.5 Speed of sound in other media

In a sound vibration, the smallest particles of a material (atoms, molecules, or ions) have to move against each other and pass on their movement.

How well an individual particle can move depends on its mass and how tightly connected it is to other particles. In addition, the distance between them also influences how "easily" the movement of the one particle can be transmitted to its neighbor.

On balance, the various physical properties combine in such a manner that the speed of sound ultimately depends only on the elasticity modulus and density of the material:

$$\boxed{c = \sqrt{\frac{E}{\rho}}}$$

Density we experience daily as “heavy and light materials”. The elasticity modulus is harder to experience because it is determined by the binding forces and atomic spatial structure of materials. (By the way, as only solid bodies have elasticity, an alternative parameter is used for gases and liquids: compressibility).

3.6 Values for the speed of sound in various materials

Gases [m/s]		Liquids [m/s]		Solids [m/s]	
Chlorine	206	Alcohol	1,168	Lead	1,200
Oxygen	313	Benzene	1,324	Steel	5,200
Nitrogen	336	Water	1,407	Crown glass	5,300
Hydrogen	1,261	Glycerin	1,900	Quartz glass	5,370

As density and elasticity are temperature-dependent, the speed of sound also changes with the temperature.