Propagation of Acoustic Waves

Introduction – basic terms and quantities

Acoustics is the science of audible sound, ultrasound and infrasound. By audible sound we mean sound with a frequency of **16–20,000 Hz**, by ultrasound values above 20 kHz and by infrasound values up to 16 Hz.

Sound is a mechanical wave of the material environment, so it propagates in gases, liquids and solids (sound does not propagate in a vacuum).

Sound sources are bodies in which vibrations are generated, which are transmitted to the surrounding environment and propagate in it as a gradual wave of mechanical waves. An example would be a string, rod, membrane, etc.

Sound pressure, particle velocity and sound intensity are used to describe a sound wave.

The basic quantities that describe the propagation of acoustic waves are: *the frequency of oscillatory movement f* (Hz) and *the speed of propagation c* (m/s). From these two quantities we can further derive the *wavelength* λ (m). It is given by the relation: **$\lambda = c/f$ or $\lambda = cT$**.

Periodic sounds are called **tones** or musical sounds. If the sound has a harmonic progression, it is a simple tone. We refer to periodic sounds of a more complex progression as compound tones. Musical sounds include not only the sounds of musical instruments, but also, for example, the vowels of speech, the sound of which is periodic but not harmonic. The difference in the time course of sounds from different sources allows us to distinguish them from each other (e.g. recognizing the voices of different people, different musical instruments). Musical tones are made up of a series of harmonic oscillations of different **frequency** and **amplitude**, the superposition of which creates the resulting composite tone. We perceive non-periodic sounds as noise (a special case is noise accompanying auditory sensations practically constantly). Consonants also have a non-periodic progression.

See the Audio Properties page for more detailed information.

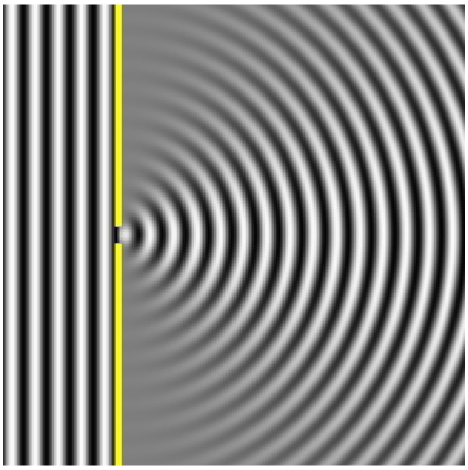
Acoustic field

The acoustic signal propagates from the sources in the form of **wavefronts**, which are dependent on the dimensions of the source. Sound propagates through an acoustic field according to Huygens' principle.

Huygens' principle

Each point of the wavefront reached at a certain moment by successive waves in an isotropic medium can be regarded as a **point source** of elementary waves. This is further propagated from it in elemental wavefronts. The wavefront of a progressive wave is the surface whose points oscillate with the **same phase**, that is, the surface on which the points that arrived from the source in the same time lie. The wavefront at the next moment in time is the "envelope" of all elementary wavefronts in the direction of wave propagation. Even sound propagates through this mechanism. Thanks to Huygens' principle, we can construct a wavefront at a certain moment if its position and shape at some previous moment are known.

See the Huygens' Principle page for more detailed information.



Huygens' principle for wave propagation

Propagation of sound in space

In free air, sound spreads freely from the source in all directions according to the mentioned Huygens principle. If the sound source is small, the wavefronts are spherical, if the sound source is, for example, a large plate, the wavefronts are flat. We also consider surfaces far from the source to be flat surfaces, when the radius of the "sphere" is so large that its section can be considered a flat surface.

Propagation in a plane wave

A plane wave occurs when points in space that have the same acoustic state at one instant form **a plane**. For a plane wave, there is **a constant ratio** between sound pressure and sound speed.

Propagation in a spherical wave

For a spherical wave, the previous knowledge does not apply, because there is no acoustic pressure with acoustic velocity in phase.

Propagation of sound in different environments

Sound propagates mainly by successive **longitudinal** waves, the exception being solid substances, in which sound can also propagate by successive transverse waves. The molecules of the environment then deviate from their central position either in the direction of wave propagation (longitudinal waves) or perpendicular to the direction of wave propagation (transverse waves). Liquid surfaces are a special case, where transverse waves propagate, while longitudinal waves propagate inside the liquid.

Sound propagation speed

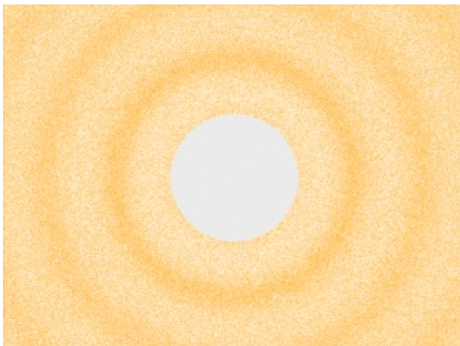
The speed of propagation of a sound wave depends on the given environment and also on immediate conditions such as temperature, pressure and, in the air, humidity. For gases, for an adiabatic process, the speed of air propagation can be derived from the gas equation of state. The dependence of the speed of sound v in air on the temperature t in degrees Celsius is expressed as follows:

$$v = (331 + 0.6\ t)\ \text{m/s}$$

The speed of sound in dry air increases approximately linearly with **increasing temperature**. The speed of sound also increases slightly with increasing air humidity. It spreads faster in liquids and solids than in gases.

Sound propagation in selected environments

Environment	Speed of sound (m/s)	Temperature (°C)
Air	331,8	0
Water	1500	25
Steel	5000	20
Ice	3250	-4
Glass	5200	20



Propagation of sound

Sound reflection

The propagation of sound is also affected by the obstacles that the sound waves hit. At the interface of two environments, sound **is reflected**. A special case of sound reflection from a large obstacle (a building, a rock face, etc.) is **an echo**. The characteristic of hearing is the distinction between two consecutive sounds, between which at least **0.1 s elapses**, which is the time it takes for the sound to travel a total distance of 34 m (17 m from the listener to the given obstacle and 17 m back). 1 s is also approximately the time we need to pronounce one syllable. At a distance of 17 m from the obstacle, a so-called monosyllabic echo is produced, at greater distances polysyllabic echoes can also be produced. If the obstacle is closer than 17 m, we can no longer distinguish the individual sounds, they partially overlap and the reflected sound merges with the original sound. This is manifested by an increase in the duration of the sound, i.e. even after the source has stopped outputting sound. We call this phenomenon reverberation. We call the reverberation time the time after which the **sound pressure** level decreases by 60 dB.

The reflection of sound from solid objects is used to measure the depths of the sea. In biophysics, we use ultrasound for ultrasonography. Some animals use it for spatial orientation, e.g. bats.

The course of the reflected wave depends on the nature of the obstacle. At a solid obstacle, the sound wave is reflected with the opposite phase. There is a folding of the waves - the so-called **wave interference**. A **standing wave** occurs, where some points are constantly at rest (nodes), some are constantly moving (in maximum movement - oscillations). This is also called **jitter**. If the obstacle is compliant, the ripples are reflected with the same phase. This is used, for example, in the organ.

Sound bending

A sound wave bends around objects that are comparable in length to it. For audible frequencies, it is a few centimeters to about 21 meters. Thanks to the bending, we can hear the sound even behind obstacles. If several waves occur simultaneously, interference occurs again. If the frequencies are inappropriate, or their ratio is not a whole number, so-called reverberations - shocks, which are fluctuations in the sound intensity, usually occur.

Links

Related Articles

- Huygens' Principle

External Links

- Sound on Wikipedia (https://en.wikipedia.org/wiki/Sound)
- Wave propagation on Wikipedia
- *Acoustic waves* on the websites of Physics FSv CTU (http://webfyzika.fsv.cvut.cz/PDF/prednasky/akustika.pdf%7CPřednáška)
- *Propagation of acoustic waves in free space* − Doc. Ing. Richard Nový, CSc., Institute of Environmental Technology, Czech Technical University (http://www.ib.cvut.cz/sites/default/files/Studijni_materialy/SHV/SHV_outdoor.pdf%7C)

References

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- ROSINA, Jozef, et al. *Biofyzika : Pro zdravotnické a biomedicínské obory.* 1. edition. Praha. 2013. ISBN 978-80-247-4237-3.

- LEPIL, Oldřich. *Fyzika pro gymnázia : mechanické kmitání a vlnění.* 4. edition. Praha : Prometheus, 2007. ISBN 978-80-7196-387-5.