Sound propagation and obstacles

Sound waves propagate from the sound source as circles or spheres, in a spatial context.
If the sound can spread uninterrupted, we talk of a free sound field. In everyday life, the sound field is normally obstructed by objects, such as walls or even people.
A sound can behave a number of ways when it encounters an obstacle:

- refraction,
- reflection,
- beaming,
- dissipation,
- absorption, and
- diffraction.

All these possibilities arise ultimately because of the wave nature of sound.

Sound refraction

Sound refraction arises because the speed of propagation of the sound wave differs in two media. Thus, if a sound wave traveling through medium 1 (for example, air) meets the boundary to a second medium, it always experiences refraction effects. (According to the laws of wave physics, these are exactly the same as for light – albeit in a different frequency range.)
Depending on the angle of incidence, the sound wave will enter the second medium but continue in a different direction, owing to the refraction.

Example: Football is louder during the day

A game of football is played once during the morning and once during the evening. During the morning, the ground is cool and the air layers warm. The sound reaches the warm air layers, is refracted downwards, and easily heard in the neighborhood of the stadium.

During the evening, the ground has warmed up, and the air layers have cooled down. The sound is refracted upwards in the cool air layers, and is not so easily heard in the neighborhood of the stadium.

Sound reflection

If a sound wave strikes a large, solid surface – i.e. the speed of sound in the two media differs extremely – the sound will be reflected. In these cases, the sound is reflected more or less completely or – depending on the angle of incidence and shape of the obstacle – redirected: The sound reflection is a special case of refraction and thus depends on the frequency. As a rule, high tones are more strongly reflected from stone walls than low ones, more of which penetrate the wall. That is why you can hear the bass from a music centre throughout the house.

The sound is reflected from the surface like light from a mirror.
If people talk in a room or play music on a stage with electronic sound equipment, the sound pattern is influenced by the properties of the reflecting surfaces of the walls and ceilings. “Sound sails” in concert halls are nothing other than sound reflectors.

Sound dissipation

Dissipation means reflection on many structures, with a very wide range of angles. In other words, the sound from a source transmitting the sound with a pronounced preferred direction will lose that preferred direction when it encounters such an obstacle.

The dissipation depends on the frequency, or wavelength. Dissipation arises when the obstacle's structure is smaller than the sound's wavelength.

Sound beaming

The opposite of sound dissipation is sound beaming. This relates to mechanical and electro-acoustic measures to concentrate the sound waves in a narrower sound field. This is similar to the use of mirrors and lenses in optics. If the reflecting surface has the right shape (for example, dome in a church), reflection bundles the sound, concentrating the reverberation or echo in a particular area of the nave. (Beaming can also occur when the sound is transmitted. This can be clearly seen in a loudspeaker shaped like a high-frequency horn.)

Sound absorption, sound reduction

In every medium (air and solid bodies), a certain percentage of the sound energy is “lost” through mechanical friction (converted into heat energy).

If the sound path is long enough, the sound will ultimately be swallowed up, or “absorbed”, by any medium.

Certain obstacles, such as sound-absorbing walls, are designed especially to absorb as much sound as possible. They are porous, and the resulting multiple reflection (dissipation) creates extremely long sound paths; the sound in these materials ends up as dissipated heat.

The absorption is dependent on the frequency, or wavelength. Absorption occurs when the obstacle's lattice constant is smaller than the sound's wavelength. The material's heat coefficient also plays a role.

Reverberation and resonance

Reverberation time

A short sound can be heard until most of the sound energy has been absorbed. This phenomenon is called “reverberation time”; in a normal living room, it is a matter of milliseconds, in a concert hall, on the other hand, it can be hundreds of milliseconds. A certain reverberation is perceived as normal by the human ear and may even improve audibility. Excessive reverberation has the opposite effect.

Resonance

Resonance is when the medium moves and only a part of the sound energy is absorbed. Although the resonance does not increase the total energy of the transmitted sound, it may boost it, i.e. improve its audibility. (Example: guitar string with, and without, resonance of the guitar body.)

Echo

Probably everybody has been in a tunnel or mountains and heard their echo.
If the sound is reflected from a distant object, the sound reflection can be heard as an echo. The reflected sound waves are only consciously perceived as an echo if there is a difference of 30 ms – 50 ms (sometimes stated as 100 ms) between the original and the reflected sound.

If the difference is shorter, there is a hearing impression in which the echo is subconsciously perceived as a reverberation. This hearing impression depends on the size, types, and number of items of furniture, etc. and gives the hearer an idea of the surrounding space. Blind people frequently make use of reverberation or echo from noises they themselves make, for example, their footsteps, for orientation.

Sound diffraction

For total reflection of sound, the reflecting structure must be large, compared with the wavelength. If, however, the wavelength is the same size as the diameter of the obstacle, the sound waves are diffracted, rather than reflected.

Example: You can still hear the traffic in your back garden

Diffraction means that the sound waves bend round the obstacle. If the obstacle is small, compared with the wavelength, the sound wave propagates behind the obstacle, almost like it did in front of it. (The explanation for this is that new elementary waves arise at the edges and spread out spherically in the shadow, as well.)

Example: Problems with hearing aids

One example of sound diffraction is the “head-shadow effect”: If a person wears a hearing aid in one ear only, the sound is weakened by the acoustic effect of the head (“head shadow”).

The head dampens the high tones because their wavelengths are relatively small, compared to the size of the head. In the case of the low tones, the low sound frequencies are relatively large, compared to the size of the head, and can bend round it.

When someone talks to the person with the hearing aid, their voice is sufficiently loud, but they are still hard to understand: they can only be understood if their consonants are clear, and consonants tend to be in the high frequency range.