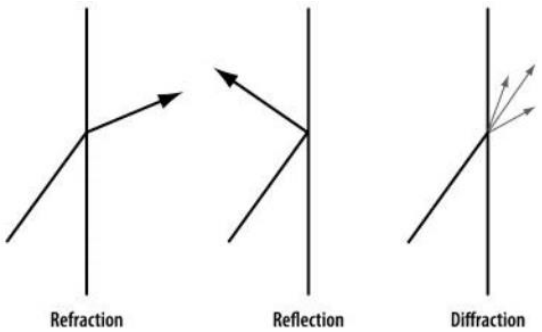
Deviation of sound waves

Waves in general can undergo alterations during propagation. In particular the sound waves can undergo deviations, which occur under different physical conditions.



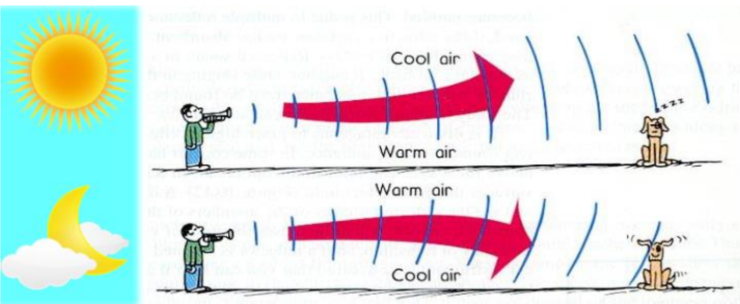
Refraction

The refraction is a physical phenomenon that consists in the deviation of a wave caused by a change in its propagation velocity.

A wave crossing two media of different densities changes direction in the transition from one to the other. The speed varies if the temperature changes or if the propagation medium changes.

Sound spreads faster in denser media.

In cold air the speed of sound is lower, while in hot air it is higher. This is because the molecules of air are moving faster, and the vibrations of the sound wave can therefore be transmitted faster. This means that when sound travels from hot air to cold air or from cold air to hot air it will **refract**.



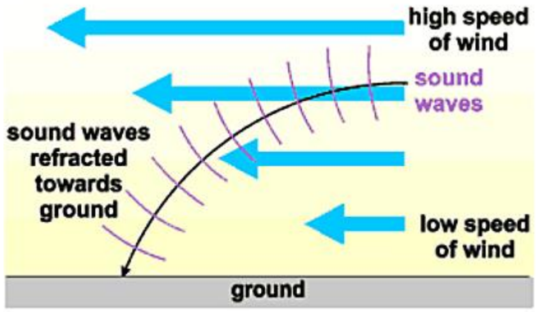
When the air near the ground is warm (during the day) and above cold, the waves are diverted upwards. Conversely, they are diverted downwards (during the night).

Because of the cold evenings, the sounds can be heard more easily for the same distance from the source.

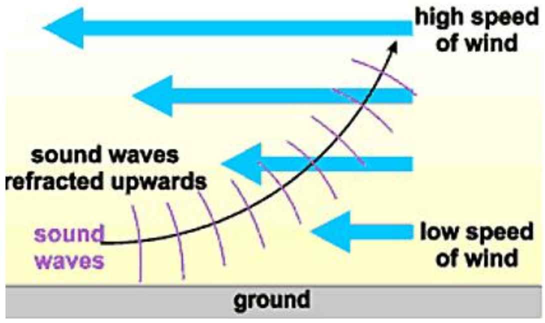
Can wind bring sound?

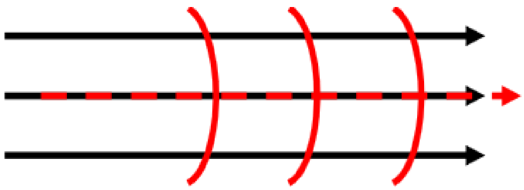
In reality waves are diverted and not transported.

Usually the wind blows at a lower speed near the ground and higher at high altitude. The difference between these two speeds induces a **refraction**.

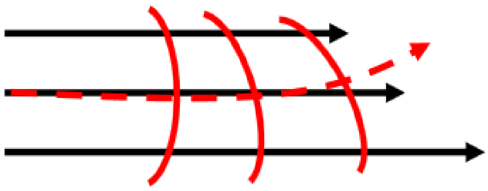


In the case in which the direction of the sound waves is equal to the direction in which the wind blows, these will be refracted downwards. If the direction is opposite, the waves will be refracted upwards. This gives the impression that the wind "transports" words.





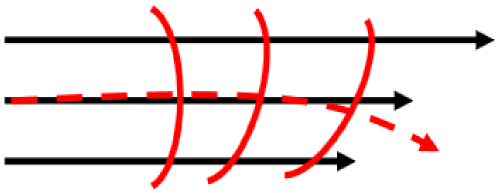
Normal condition



Slower waves at the top and faster at the bottom

→ The sound wave tends to rise

It will be less noticeable at the bottom



Slower waves at the bottom and faster at the top

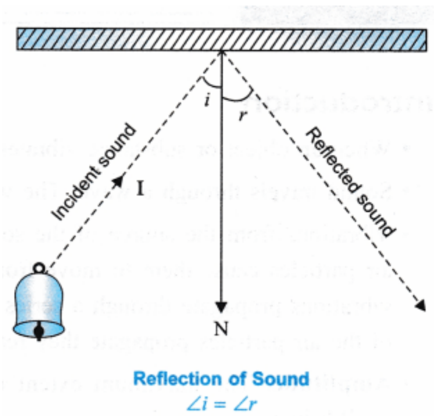
→ The sound wave tends to go down

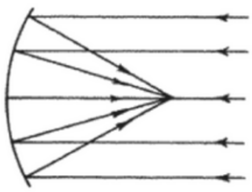
It will be more perceptible at the bottom

Reflection

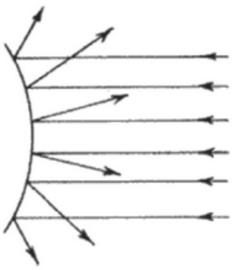
Reflection is the change in direction of a wavefront at an interface between two different media so that the wavefront returns into the medium from which it originated.

The acoustic phenomenon that occurs when the sound wave encounters an obstacle and comes back (it changes direction). The **law of reflection** says that for specular reflection the angle at which the wave is incident on the surface equals the angle at which it is reflected. A wave that affects a flat surface with an angle of incidence α (between the normal to the surface and the direction of propagation of the wave) is reflected with an angle of reflection equal to α (therefore the angles of incidence and reflection are equal).





Concave surfaces are avoided in acoustics as they tend to concentrate the sound at a precise point (focus) creating uneven sound distributions. Instead, they are used for the construction of directional microphones as they allow amplifying even very weak signals.

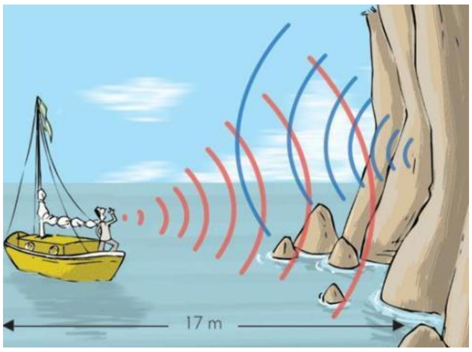


Conversely, convex surfaces have the property of spreading sound (dispersion) and are therefore widely used to improve the acoustics of environments.

Echo

The echo is an example of reflection: Reflected sound waves that hit an obstacle are "perceived" by the transmitter more or less unchanged and with a certain delay compared to the direct sound.

This delay must not be less than 1/10 of a second.



The human ear cannot distinguish echo from the original direct sound if the delay is less than 1/10 of a second. The velocity of sound in dry air is approximately 343 m/s at a temperature of 25 °C.

$$D = \frac{v \ \Delta t}{2} \qquad \boldsymbol{D \cong \frac{343 \times 0.1}{2} \cong 17\ m}$$

Therefore, the reflecting object must be more than 17m from the sound source for echo to be perceived by a person located at the source. When a sound produces an echo in two seconds, the reflecting object is 343m away. In nature, canyon walls or rock cliffs facing water are the most common natural settings for hearing echoes.

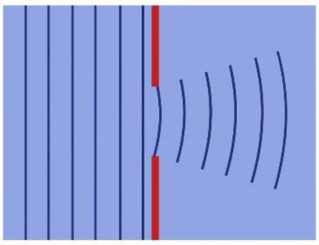
If the distance is lower than 17m, we can no longer speak of echo but of reverberation. Reverberation occurs when the incident wave merges into the listener's ear with the reflected wave, while an echo occurs when the two waves are distinct. We speak properly of echo when the individual reflections of the sound wave are perceived distinctly by the listener.

In more general terms, the echo can be defined as a wave that is reflected by a discontinuity in the propagation medium, and that returns with sufficient intensity and delay to be perceived. It can be "useful" (as in sonar) or "unwanted" (as in telephone systems).

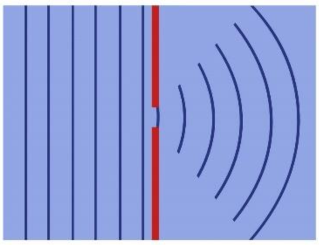
Diffraction

Diffraction is a physical phenomenon that consists in the deviation of a wave that meets an obstacle.

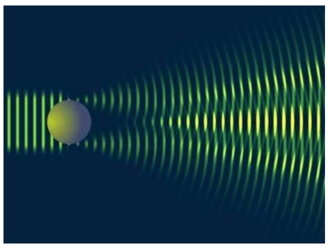
In trying to overcome it, the wave widens or "breaks".



Large Opening



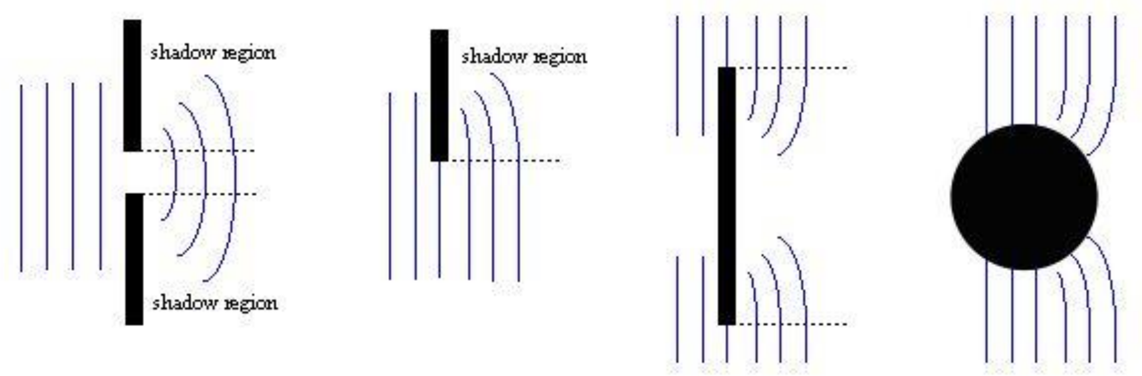
Small Opening



Obstacle

Change of direction of a sound wave due to an obstacle (pass it by turning around it).

If the aperture or obstacle is smaller than the wavelength, the diffraction will be significant, and the wave reconstitutes itself behind the obstacle after losing some energy. If instead the obstacle is large, the wave is largely reflected, and a shaded area is formed.



For a sound wave that meets an obstacle or a slit to be diffracted, it is necessary that its wavelength is much larger than the obstacle or slit.
The absence of sound diffraction in the case of wavelengths that are too small for an obstacle is called a sound shadow.

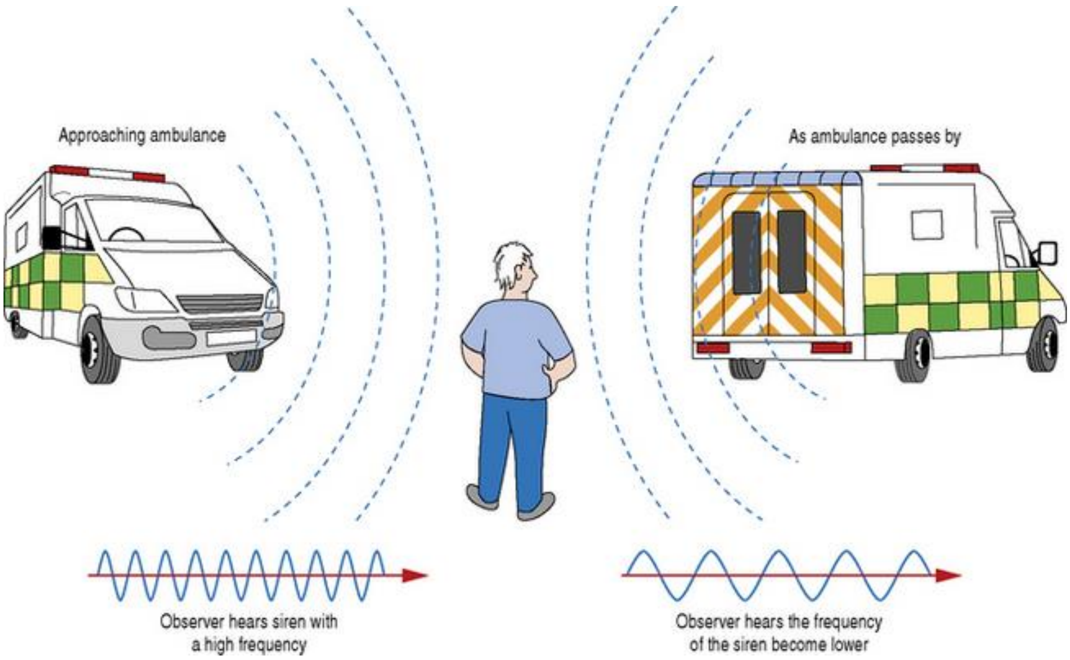
Everything depends on the frequency. Sounds with a large wavelength (and therefore low frequency) easily overcome obstacles with a size smaller than their wavelength. This is one of the reasons why the first frequencies that are attenuated are the high ones while the low ones propagate to much greater distances.

It is therefore more difficult for humans to identify the source of a severe sound. This is because they tend to get around the head by coming to both ears. Our mouth has the aim to improve the diffusion of sound by exploiting the diffraction caused by the passage from a slit.

Variation in perceived frequency due to motion

Doppler effect

The change in frequency of a wave in relation to an observer who is moving relative to the wave source.



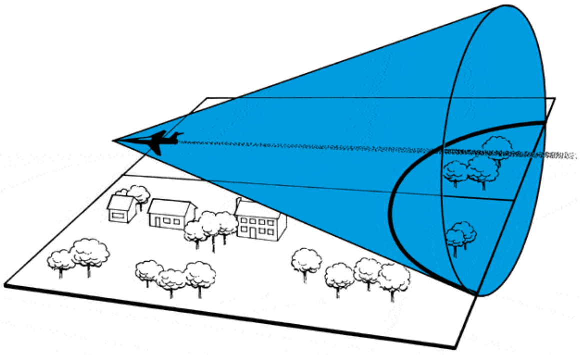
Compared to the emitted frequency, the received frequency is higher during the approach, identical at the instant of passing by, and lower during the recession.

The reason for the Doppler effect is that when the source of the waves is moving towards the observer, each successive wave crest is emitted from a position closer to the observer than the crest of the previous wave. Each wave takes slightly less time to reach the observer than the previous wave. Hence, the **time between the arrivals of successive wave crests at the observer is reduced, causing an increase in the frequency**. While they are traveling, the distance between successive wave fronts is reduced, so the waves "bunch together".
Conversely, if the source of waves is moving away from the observer, each wave is emitted from a position farther from the observer than the previous wave, so the arrival **time between successive waves is increased, reducing the frequency**. The distance between successive wave fronts is then increased, so the waves "spread out".

Sonic boom and Mach number

A sonic boom is the sound associated with the shock waves created whenever an object travelling through the air travels faster than the speed of sound.

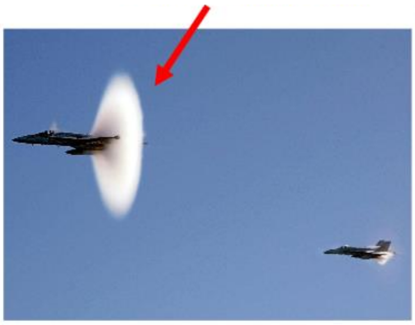
A sonic boom does not occur only at the moment an object crosses the speed of sound. The boom is a continuous effect that occurs while the object is travelling at supersonic speeds. The sound of a sonic boom depends largely on the distance between the observer and the aircraft shape producing the sonic boom.



It affects only observers that are positioned at a point that intersects a region in the shape of a geometrical cone behind the object. As the object moves, this conical region also moves behind it and when the cone passes over the observer, they will briefly experience the boom.

$$331{,}6\frac{m}{s} = 331{,}6 * 60 * 60\frac{m}{h} = 1.193.760\frac{m}{h} = 1.193\frac{km}{h}$$

Mach cone



Mach	Km/h
0	0
1	1226
2	2451,2
3	3675,4
4	4900,5
5	6125,3
6	7350,1
7	8575,4
8	9800,2
9	11.025,3
10	12.250,1

When an aircraft passes through the air it creates a series of pressure waves in front of the aircraft and behind it. These waves travel at the speed of sound and, as the speed of the object increases, the waves are forced together, or compressed, because they cannot get out of each other's way quickly enough. Eventually they merge into a single shock wave, which travels at the speed of sound, a critical speed known as **Mach 1**, and is approximately 1,235 km/h at sea level and 20 °C (68 °F).