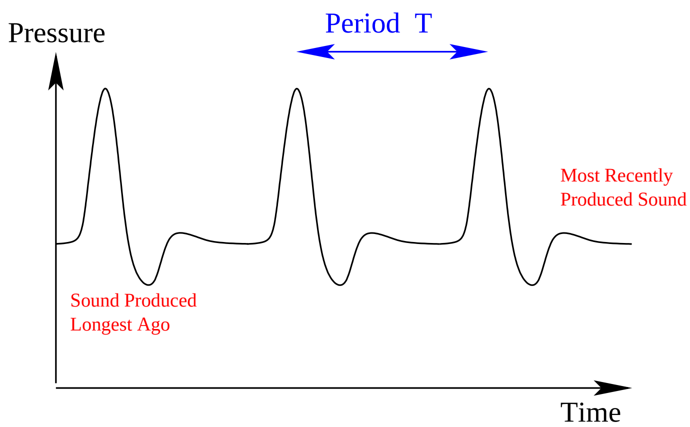
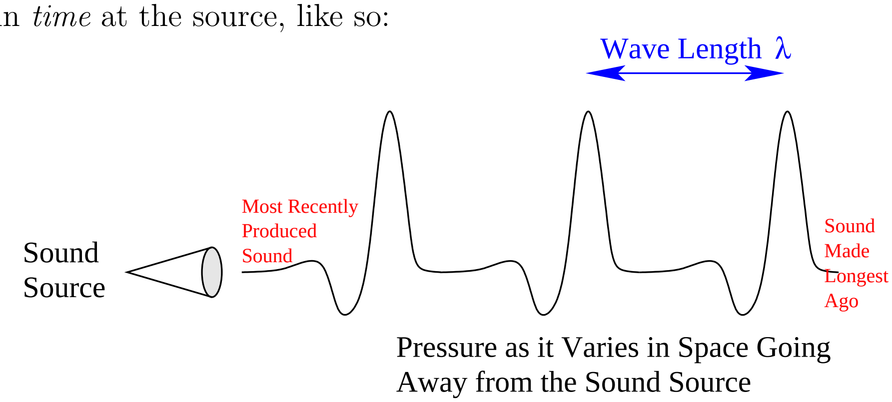
Lecture 8: Wavelength and Diffraction

Wavelength

Suppose that the pressure at the source of a sound looks like this as a function of time:



Then as the sound moves away from the thing that makes it, the pressure will vary in the air. The pressure furthest from the source is the pressure signal the source made the longest ago. Therefore, the distribution in *space* of the pressure, will be backwards from the production in *time* at the source, like so:



If the pressure produced at the source varies periodically in time, the pressure pattern in the air will vary periodically in space (ignoring the way the sound spreads out, reflects, etc). We can define the **wave length** to be the distance over which the sound wave is periodic.

It is easy to figure out the relation between the wave length and the period of the sound. If the source produces a pressure spike at time 0 and at time T (the period), then the wave length will be how far away the first pressure spike has made it by the time the second one was made. That is just

$$\lambda = v_{\rm sound} T = \frac{v_{\rm sound}}{f} \, .$$

The funny looking thing, λ, is the Greek lower-case letter lambda, which is always used by physicists to denote wavelength.

Complex tones are produced of multiple sounds of different wave lengths λ, just as they are of different frequencies f. For a periodic tone, the wave lengths of the sine wave (Fourier) components are 1, 1/2, 1/3, 1/4, ... times the wavelength of the sound, just as the periods are 1, 1/2, 1/3, 1/4, ... of the sound's period and the frequencies are 1, 2, 3, 4, ... times the sound's frequency.

Light also has a wave length. The difference is that the wave length of light is smaller than you can see, 0.4 to 0.7 μm (micrometers or microns), which is about 1/70 to 1/250 of the width of a human hair. The wave lengths of sound waves are in the range of common lengths we encounter in our everyday experience. For instance, sound at the lower threshold of our hearing has

$$\lambda_{\text{Lowest}} = \frac{344 \text{ m/s}}{20 \text{ Hz}} = \frac{344 \text{ m/s}}{20 \text{ /s}} = 17.4 \text{ m}$$

which is actually pretty huge. Sound at the upper threshold of our hearing has a wave length of

$$\lambda_{\text{Highest}} = \frac{344 \text{ m/s}}{17000 \text{ Hz}} = 0.02 \text{ m} = 2 \text{ cm}$$

which is just under an inch–about the width of one of my fingers. Musical sounds have wave lengths varying from about the width of the palm of your hand, to the height of a room.

To understand how sound propagates, there are two important things to realize. First, we are used to how light propagates, which is in straight lines. The reason light does that is, that its wave length is so much smaller than the things it is propagating through. Lots of cool effects happen when things are the same thinkness as the wavelength of light. For instance, the film of oil you sometimes see on water, making rainbow patterns, does that because it is around 1 μm thick. Since sound's wave length is comparable to everyday objects, it will *not always* move in straight lines and cast shadows like light does–but it also will sometimes, depending on the frequency and the size of the objects involved.

The other thing to realize is that, if the behavior depends on the wave length, then the different harmonics in a complex tone will behave differently. That means that the tone color you hear (relative loudness of the harmonics) can get affected by the propagation of the sound to reach you. To understand what you will hear, you have to

1. break up the sound which is produced into its harmonics,

2. determine how each harmonic propagates through its environment,

3. put the harmonics back together at the place where the sound will be heard (ear or microphone) to understand what sound will be received there.

One case where different frequencies behave differently is sound absorption. Most sound absorbing materials give a different fraction of absorption and reflection depending on frequencies. The general tendency is that most things absorb high frequencies more effectively than low frequencies. Very high frequencies are also absorbed as they propagate long distances through the air, which is why nearby lightning has thunder with a lot of high frequencies, but distant thunder only has the low frequency rumbling.

Diffraction

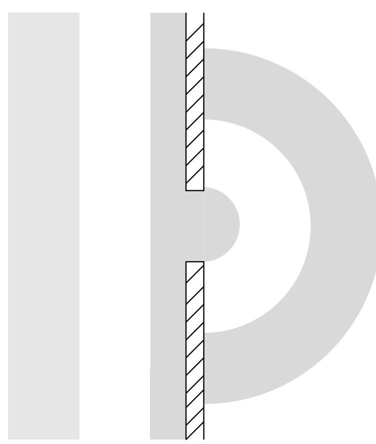
When sound moves around objects, it can "bend" to go around obstacles. This is called **diffraction**.

We are familiar with how light casts shadows and generally does not "bend around" objects. It can be reflected, but we rarely see it being diffrated. This will also be true for sound when the wave length is short compared to the objects it is moving around. In the opposite limit, it will bend around objects without any trouble:

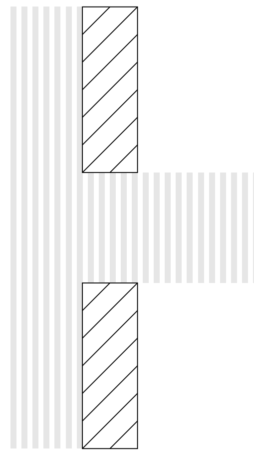
Wavelength $\ll$ Size of Objects: Straight Lines and Shadows, like Light

Wavelength $\geq$ Size of Objects: Bends Around Objects Without Difficulty

To see why, think about sound approaching a doorway, window, or other opening in a wall or other reflecting object. First, consider sound with a wave length larger than the size of the opening. Then, for a long time, all the room on the other side of the opening sees is that the pressure is high there. That will cause air to rush out in all directions. This leads to a sound wave which moves out from the opening in all directions. Showing high pressure in gray, this looks like,



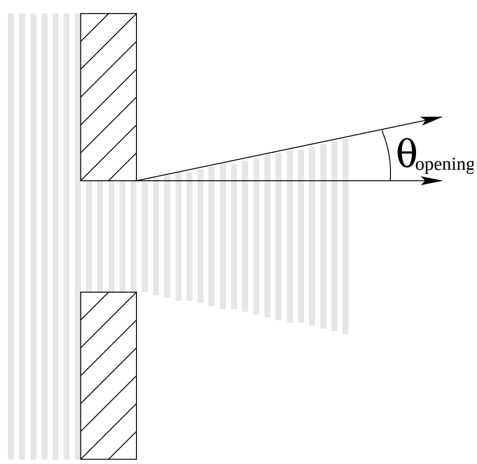
On the other hand, if the wave length of the sound is much shorter than the size of the opening, then the pressure peaks and troughs, the pattern of the sound wave, "barely sees" that there is wall so far away, and proceeds to move through the opening in the same direction it was moving in:



Actually, that was too quick. The wave which goes through the opening *will* spread out, but only gradually. The angle it spreads out by, is given roughly by

$$\theta_{\text{opening}} = \frac{\lambda}{L} \qquad \text{with } L \text{ the opening size}$$

which is, in pictures,



The truth is that at least a little sound escapes into the region that this says should be silent–but only a little, the sound is attenuated [by roughly $(\theta/\theta_{\text{opening}})^2$].