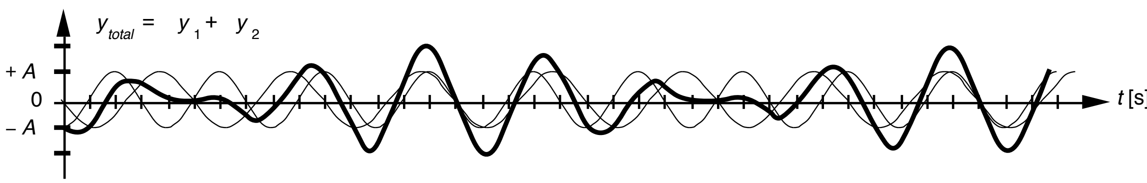
Lecture 23 Sound
Beats
Sound
Solids and Fluids

To round out our discussion of interference and waves, we should talk about beats. When you combine two waves (sound is a good example), if the frequencies of the two waves are close enough, you get beats.



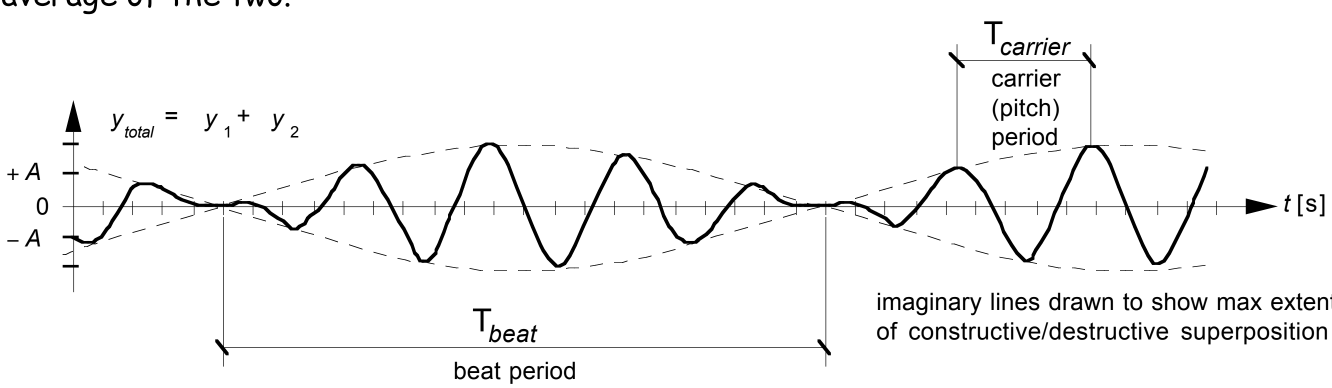
This combining of frequencies can also produce a phenomenon called beats. If the two frequencies are close enough, we hear constructive and destructive interference over time. There's an applet that demonstrates this(http://library.thinkquest.org/19537/java/Beats.html). To find the frequency of the beats we take the difference of the frequencies.

$f_{beat} = f_1 - f_2$

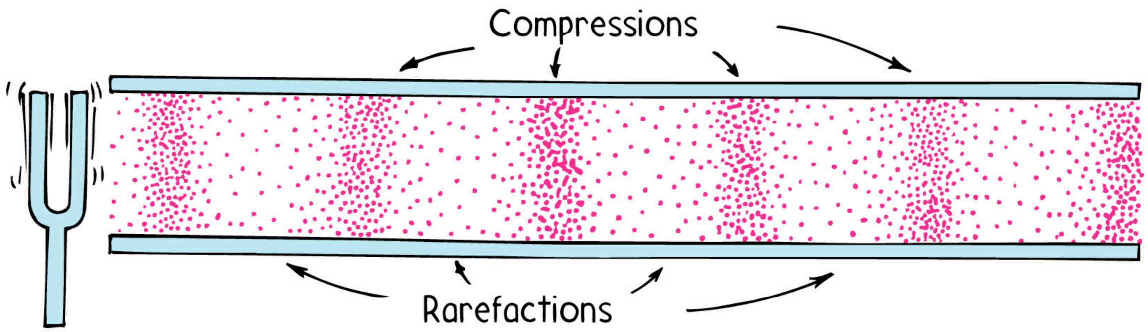
The beat frequency is the loud-soft-loud pattern we hear.
The other frequency we hear is the carrier frequency. It's the actual sound that gets loud, soft, and loud. The way we get this is to take the average of the two frequencies.

$f_{carrier} = \left(\frac{f_1 + f_2}{2}\right)$

If you think about combining two frequencies a higher one and a lower one, which will you hear – not the higher one, not the lower one. You hear the average of the two.



So, speaking of sound we should talk a little about the physical details of sound.



Sound is a longitudinal wave. If you shake air molecules, with a tuning fork for instance, you can create regions of compression (high density/pressure) and rarefactions (low density/pressure). For a picture of this in three dimensions: http://www.kettering.edu/~drussell/Demos/rad2/mdq.html. One important way to characterize sound is by the intensity of the sound. However, in order to talk about intensity, we should first review the concept of power. Power has to do with energy – with respect to sound waves it is the energy emitted by the source per unit of time.

$$Power = \frac{Energy}{time} \Rightarrow \frac{Joules}{\sec ond} \Rightarrow Watts$$

Recall the a Joule per second is called a Watt. So, now that we've reviewed what power is, we can define intensity. Intensity is the power per unit of area. If you recall the animation we looked at of the sound waves traveling out from the source – what happens to the energy is that it is distributed over larger and larger circles in space. Though the energy stays the same, it is being spread over larger and larger areas, so the intensity goes down.

$$Intensity = \frac{Power}{Area} \Rightarrow \frac{Watts}{m^2}$$

We've introduced the idea of waves spreading in two dimensions, this gives us a circular area. But if the waves spread in three dimensions – what is our geometry then? It has to be spherical. So to find the intensity of a real sound wave, we have to calculate a spherical wavefront. Recall the Area of a sphere: $A_{SPHERE} = 4\pi r^2$.

Often we speak of sound in terms of decibels. Decibels measure intensity, but on a log scale:

$$\beta = 10\log\left(\frac{I}{I_o}\right) \quad I_o = 10^{-12}\frac{W}{m^2}$$

I_o is a reference level we define because it is the threshold of hearing. In other words, for a sound to be heard it has to have enough energy. Otherwise, your eardrum will not be stimulated enough to transmit the signal to your brain. If we plug this value into our equation we get:

$$\beta = 10\log\left(\frac{I}{I_o}\right) = 10\log(1) = 0\ dB$$

So a sound of 0 dB is just at the threshold of hearing (i.e. you can't hear it). We also have a pain threshold defined. When the intensity reaches 1 W/m^2, this is the point when a sound becomes painful to the ears. If we plug this value into our equation we get:

$$\beta = 10\log\left(\frac{I}{I_o}\right) = 10\log\left(\frac{1\,W/m^2}{10^{-12}\,W/m^2}\right) = 120\ dB$$

Another element key to the perception of sound is frequency. The frequency range of a typical human is 20 to 20,000 Hz. Above this range, sounds are called ultrasound. Below this range sounds are called infrasound. By the way since we know that $v = \lambda f$, an important bit of information is that the speed of sound in air is approximately 330 m/s.

Now moving on to new material.
Solids and Fluids (ch. 9) is where we'll start. First, we'll start with pressure and pascal's principle. First, we should define a fluid. A fluid is simply a substance that flows (i.e. a gas or liquid). One main difference between gasses and fluids though is that gasses are compressible while liquids are incompressible. That is a gas can be easily squeezed or expanded due to the empty space between its molecules. When we talk about fluids, one of the bulk properties we can talk about is pressure. Basically, pressure is the way we express force on a fluid:

$$p = \frac{F}{A} = \frac{N}{m^2} = (Pa)scal$$

Pressure is a scalar, not a vector. If we solve for force, we get the relation:
$F = pA$
where the force is perpendicular to the area.

If we had a pressure-o-meter, we could make some observations about pressure in a fluid:

- There is pressure everywhere in a fluid, not just at the bottom or walls of a container.
- The pressure at one point in the fluid is the same no matter how you orient your pressure-o-meter. The fluid pushes up, down, and sideways with equal strength.
- In a liquid, the pressure increases with depth below the surface. In a gas, the pressure is the same at all points (at least in laboratory-size containers).

Another very important quantity to understand with respect to fluids is density. Often we use density instead of mass in describing fluids.

$$\rho = \frac{m}{V} = \frac{kg}{m^3}$$

Density is mass per unit volume. Water has a density of $1*10^3$ kg/m^3. Mercury has a density of $13.6*10^3$ kg/m^3. This means the density of Mercury is 13.6× greater than that of Water. These are both good numbers to know off-hand by the way.

There are two main sources of pressure of a fluid (mainly a gas) in a container:

- A gravitational contribution that comes from gravity pulling down on all the particles in a fluid. There is a slightly higher density at the bottom of a container than at the top. Subsequently a slightly higher pressure.
- A thermal contribution due to the collisions of the particles (between particles, and between the particles and walls of the container).

Now we're ready to talk about atmospheric pressure. The atmospheric pressure is due to the fact that you have a huge amount of gas (i.e. the atmosphere) hovering over the earth. Gravity pulls down on all this gas, which then exerts a force on everything that sits at the surface of the earth. Depending on how much atmosphere is over you, you will experience more or less pressure at the surface. For instance, the atmospheric pressure in Denver is less than in Miami. Atmospheric pressure decreases with height. There is an average standard we use for atmospheric pressure at sea level.

The standard atmosphere is:
$1atm = 101{,}300Pa$, this is a typical unit used, though you'll have to convert to Pascals if you plan on doing calculations.

Now we can talk about pressure in a liquid. We can set up our problem such that we are looking at a resting liquid and we want to find the pressure at a depth *d* from the top of the liquid. If we draw a picture of this, there's a cylinder of liquid over over the point we've defined at depth *d*. There are three forces that act on this cylinder: the weight of the cylinder *mg*, a downward force p_oA due to the pressure p_o at the surface of the liquid, and finally the upward force due to the liquid beneath the cylinder *pA*. Since the liquid is resting, the forces must be balanced:

$$pA = p_oA + mg$$

$$m = \rho V = \rho Ad$$

$$pA = p_oA + \rho Adg$$

$$p = p_o + \rho dg$$

What we've found is called the hydrostatic pressure (at some depth d in a liquid), because our assumption is that the fluid is at rest. Notice that $p = p_o$ when d = 0. At the surface of the liquid the pressure should be the pressure at the surface. For a liquid open to the air, p_o = 101,300 Pa.

Now for a quick example:
A submarine cruises at a depth of 300m. What is the pressure at this depth? Give the answer both in pascals and and atmospheres.

The density of seawater is ρ = 1030 kg/m^3. The pressure at depth d = 300m is then found to be:

$$p = p_o + \rho g d = 1.013 \times 10^5 Pa + (1030 kg/m^3)(9.8 m/s^2)(300 m)$$

$$= 3.13 \times 10^6 Pa$$

Converting to atmospheres:

$$3.13 \times 10^6 Pa \left(\frac{1\ atm}{1.013 \times 10^5 Pa} \right) = 30.9\ atm$$