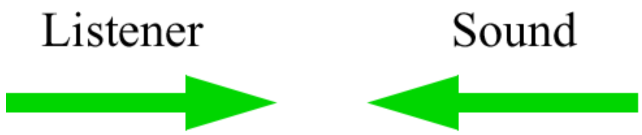
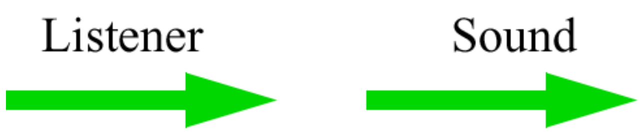
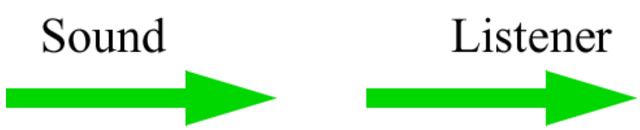


$$f' = f\left(\frac{v + v_L}{v - v_S}\right)$$

$$f' = f\left(\frac{v - v_L}{v + v_S}\right)$$



$$f' = f\left(\frac{v + v_L}{v + v_S}\right)$$



$$f' = f\left(\frac{v - v_L}{v - v_S}\right)$$

Thinking back on it, I have realized that what I wanted to say in class about the Doppler Effect and what I actually said were not the same thing. Let us push the replay button and try it again.

The Doppler Effect can be summarized by a single equation: $f' = f\,(v \pm v_L) / (v \pm v_S)$, where:

f' = shifted frequency	f = unshifted frequency
v = speed of sound	
v_L = speed of listener	v_S = speed of sound source

The tricky thing about this equation is the " ± " , because the plus or minus depends on the motion of the listener relative to the source. If the listener is moving towards the source, or the source is moving towards the listener, the pitch goes up. The opposite cases make the pitch go down. The two "±" in the equation give you four possible combinations of plus and minus, and the graphic above summarizes what the four combinations correspond to physically.

What I wanted to emphasize in class is that the concept of relative motion which you (undoubtedly) learned in the first quarter of physics doesn't apply to the Doppler Effect. In Newtonian mechanics, only the *difference* in speed between two objects matters. If there is a difference in speed of 30 m/s between you and a moving car, it does not matter whether the car is moving at 30 m/s and you are standing still, or vice versa. It doesn't matter whether you and the car are moving at 15 m/s towards each other, or at 4000 m/s and 4030 m/s, respectively, in one direction. In each case the speed difference is 30 m/s, thus your momentum and kinetic energy relative to the car are the same.

This is not true for the Doppler Effect. Look at the “green arrow” equations above. There is a difference between you approaching the sound source at 30 m/s, or it approaching you. There is yet another difference if you and the source are approaching each other at 15 m/s each. There is even a difference between you leading the sound, or the sound leading you, when you are both headed in the same direction!

The fundamental reason behind the confusion is this: sound is transmitted by air. The speed of the sound, once it sets sail, is about 340 m/s regardless of how it was emitted or who is listening to it. The relative speed between you and the sound source is important, of course, but your speed and/or the speed of the source *relative to the air* is also important. The Doppler effect between two objects moving at 0 m/s and 30 m/s is NOT the same as that for objects moving at 60 m/s and 90 m/s, even though their relative speeds are the same, because their speeds through the air are not equal.

Having said that, we have a special case. Inspection of the last two “green arrow” formulas reveals that in one scenario the Doppler effect does work something like Newtonian physics. If both the listener and the sound source are moving in the same direction at exactly the same speed ($v_L = v_S$), then the numerators and denominators cancel, i.e., the Doppler effect for one compensates for the effect from the other. (The Doppler effect isn’t abolished for $v_L = v_S$. One just has no <u>net</u> shift in the frequency because the frequency is shifted twice, equally, in opposite directions.)

In the special case where $v_L = v_S$, with both listener and source moving in the same direction, the Doppler formula somewhat follows Newtonian mechanics insofar as it does not matter what v_L and v_S are. It also does not matter whether the listener is in front or vice versa. Except. As I mentioned in class, if the listener is in front and moving faster than the speed of sound, then the sound can never reach them and there is no Doppler shift. The fourth equation is invalid here. Indeed, if *either* the listener or the source is moving supersonically (never mind both of them) then the fourth equation is invalid. (When only the source is supersonic, it passes the listener before the listener can hear it, at which point the source is in front so you have to use the third equation.)

As for the third equation, if you are trailing the sound source then you must run into its sound waves no matter its speed, and so the third equation works fine if either the listener or the source (or both of them) are moving supersonically. You may insert whatever Top Gun speeds you like into the third equation (Triple the speed of sound? Four times?), and the frequency that pops out the other side is still correct.