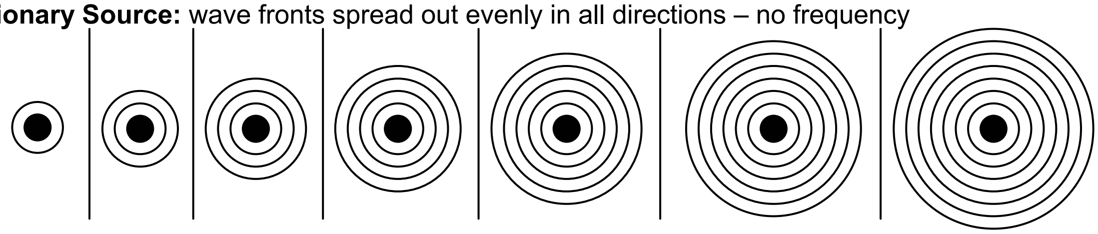
Doppler Effect:

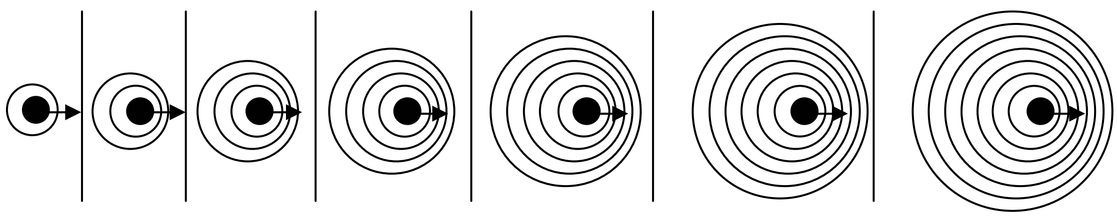
The Doppler effect is one of the most commonly experienced phenomena in science. Every time a train passes or an emergency vehicle drives by with sirens blaring, the pitch of the sound drops as soon as the vehicle drives by. Think! How would you mimic the sound of a race car speeding by? Guaranteed you would drop the pitch of your voice at the point where the car would drive by you. This is the Doppler effect.

Q: What causes the Doppler effect?
A: Sound travels at a constant speed (about 343 m/s at 20°C.). If the vehicle is moving, the separation of the sound waves gets short because the sound source is moving in the same direction of the forward moving wave front. The source however, is moving away from the rearward moving wave fronts, so the wave fronts are more spread out.

Stationary Source: wave fronts spread out evenly in all directions – no frequency



Moving Source: wave fronts ahead of the motion get compressed together – Higher frequency wave is produced.



Deriving The Formula:

Let v_s represent the speed of sound

Let v_o represent the speed of the object

Let f_1 represent the frequency of the **original** sound

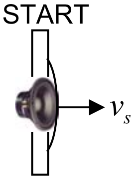
Let f_2 represent the perceived frequency of the **Doppler Shifted** sound

Formulae: $v = f\lambda$, $f = \frac{1}{T}$, and $d = vt$

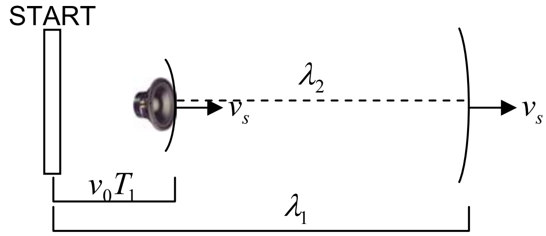
$t = 0s$: A sound wave front is generated at the sound source and moves off at the speed of sound, v_s.

The object is moving at v_o in the same direction. At $t = 0s$, no displacement yet

START



$t = T_1$: A second sound wave front will be generated after 1 period of f_1. In that time, the wave front will have traveled a displacement of λ_1 and the source will have moved a distance of $d = v_o T_1$



The wavelength of the perceived Doppler shifted sound is λ_2

$$\lambda_2 = \lambda_1 - v_o T_1$$

$$\frac{v_s}{f_2} = \frac{v_s}{f_1} - \frac{v_o}{f_1} \qquad (v = f\lambda)$$

$$\frac{v_s}{f_2} = \frac{v_s - v_o}{f_1}$$

$$\frac{f_2}{v_s} = \frac{f_1}{v_s - v_o}$$

$$\therefore f_2 = f_1\left(\frac{v_s}{v_s - v_o}\right)$$ when object is moving toward the stationary observer

$$\therefore f_2 = f_1\left(\frac{v_s}{v_s + v_o}\right)$$ when object is moving away from the stationary observer

v_s is the speed of sound in m/s, v_o is the speed of the observer in m/s, f_2 is the perceived frequency in Hz, and f_1 is the original frequency of the source in Hz

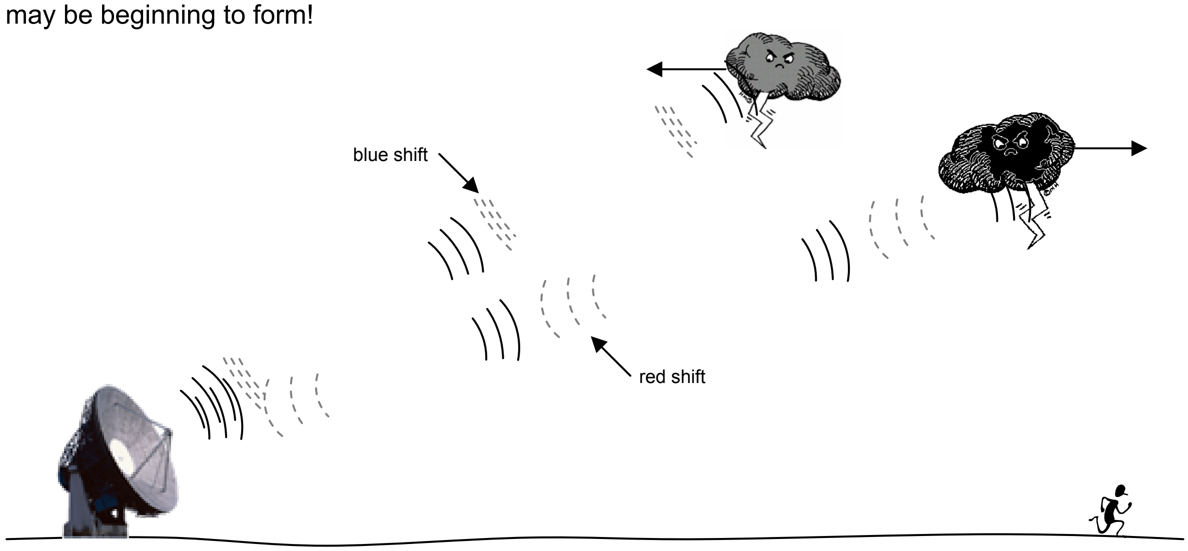
Note: There is an alternate formula for the Doppler Effect. In the above cases, the sound source is moving, but the Doppler Effect also occurs when the observer is in motion. In this case the formula for the Doppler Effect is just slightly different

$$f_2 = f_1\left(\frac{v_s \pm v_{ob}}{v_s}\right)$$

"+" for when the observer is moving toward the sound source and
"-" for when the observer is moving away from the sound source

v_s is the speed of sound in m/s, v_{ob} is the speed of the observer in m/s, f_2 is the perceived frequency in Hz, and f_1 is the original frequency of the source in Hz

Doppler Radar: Doppler radar is used extensively for weather forecasting and increasingly for traffic enforcement. Just like sound waves, radio waves that are reflected off of a moving target will experience a frequency shift. Objects moving toward the radar will experience an increase in the frequency (this is called **blue shift**), where objects moving away from the source will experience a decrease in the frequency (this is called **red shift**). The amount of shift depends on the speed of the object: the greater the speed, the greater the shift. The advantage of Doppler radar is that the radar only needs to send out one pulse in order to determine the speed and position of the object. Since the old style requires two pulses, the object's speed could changer during that time and the results would be less accurate. Doppler radar is used especially for tracking severe weather storms. The radar can track the movement of the cloud so well, that it can even detect if the cloud starts to rotate; a strong sign that a tornado may be beginning to form!



Mach Number and The Speed of Sound

Mach is simply the expression of an object's speed in reference to the speed of sound.

Mach 1= speed of sound ($v_s = 332 + 0.6T$)
Mach 2 = 2 X Speed of Sound
Mach 3= 3 X Speed of Sound etc.

So when a jet breaks the sound barrier it has reached **mach 1**