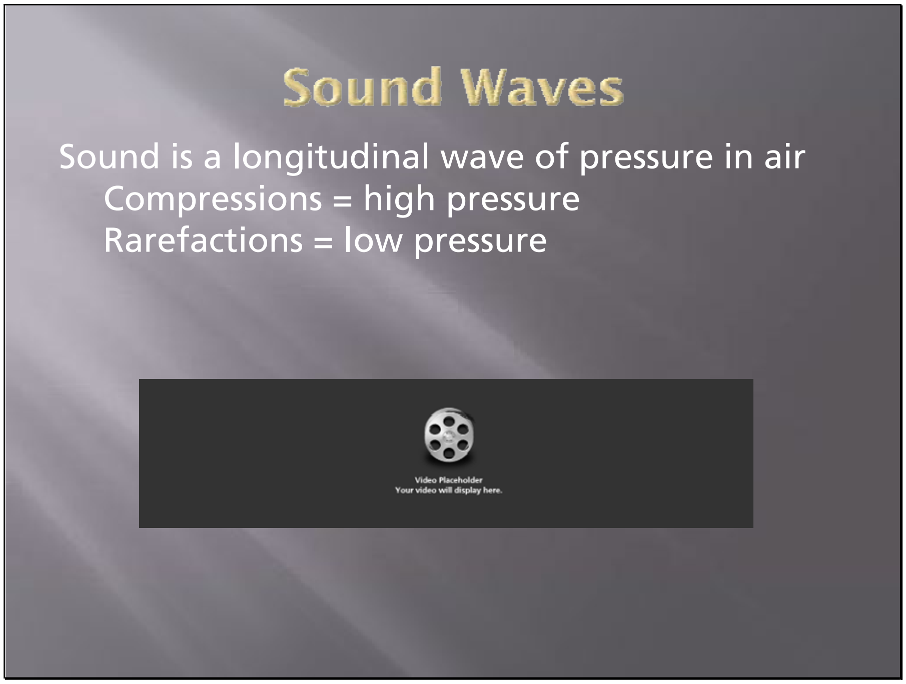
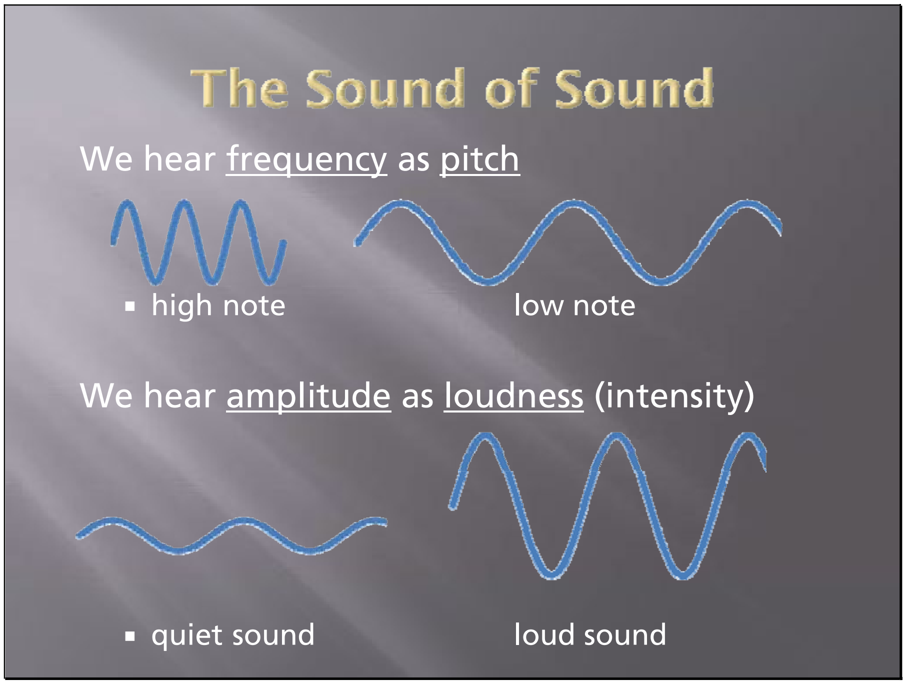
Module 6: Waves

Topic 3 Content: Sound Waves Presentation Notes



Sound is a longitudinal wave that can travel through air as well as solids and liquids. Vibrating objects vibrate the air around them, and these areas of high and low pressure move through the air as a longitudinal wave to reach our ears.

Areas of high pressure are called compressions and areas of low pressure are called rarefactions.

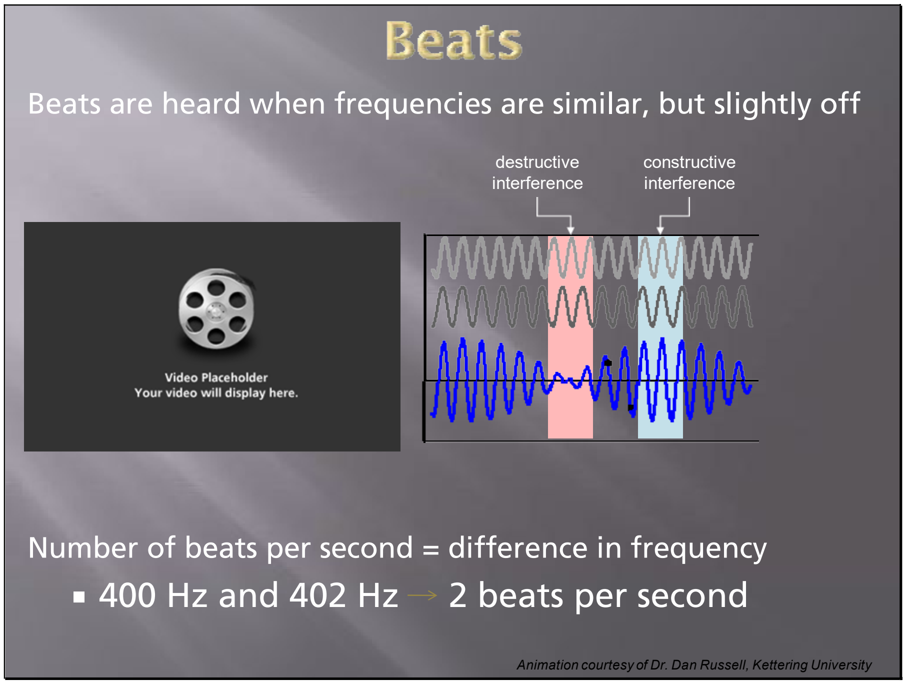


Our ears react to these changes in pressure and send signals to our brains.
Now you will hear a sound with a relatively high pitch.
Next you will hear a sound with a lower pitch.

The frequency of the wave determines the pitch we hear. Higher frequency vibrations are perceived as higher pitch notes and lower frequency vibrations are perceived as lower notes.

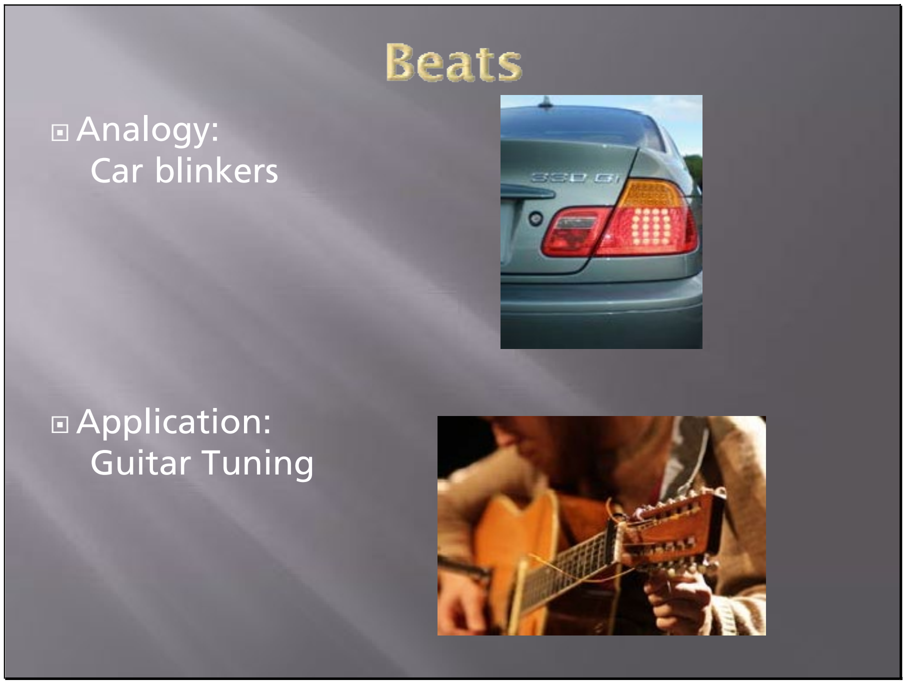
Now you will hear a sound with a small amplitude.
Next you will hear a sound with a larger amplitude.

The amplitude of the wave generally determines the loudness of the note. Pressure waves with a small amplitude will be perceived as quiet sounds and pressure waves with larger amplitudes will be perceived as loud sounds, as the larger amplitude waves carry more energy to our ears.



When two notes that have close frequencies are played together, beats are heard.
First, let's listen to the two notes individually.
Now listen to the two notes played together.

If we hear two notes at the same time that are similar, but whose frequencies don't quite match, we experience what are called beats. If you look at the diagram, you can see that when the two waves of similar frequency are added, the resulting wave has an amplitude that changes with a periodic frequency. Beats occur as the waves alternate between being in phase, resulting in constructive interference and being out of phase, resulting in destructive interference. What you hear is a note that is the average of the two source frequencies, but which oscillates from loud to quiet to loud again. The number of beats you hear is precisely the difference between the two frequencies.



You’ve probably experienced something similar to beats in the past. If you’ve ever been sitting in a left turn lane behind a line of cars with your blinker on, sometimes you will notice that your blinker is blinking at the same time as the blinker in front of you. Then it will drift out of phase, then drift back into phase. This is very similar to how the two waves interact, first cancelling when out of phase, then adding when in phase.

Musicians will often use beats when tuning their instruments. A skilled guitar player can play the same note on two strings at the same time.
If he hears beats, he adjusts the tension in one of the strings until the beats stop. If no beats occur, the two strings are in tune.

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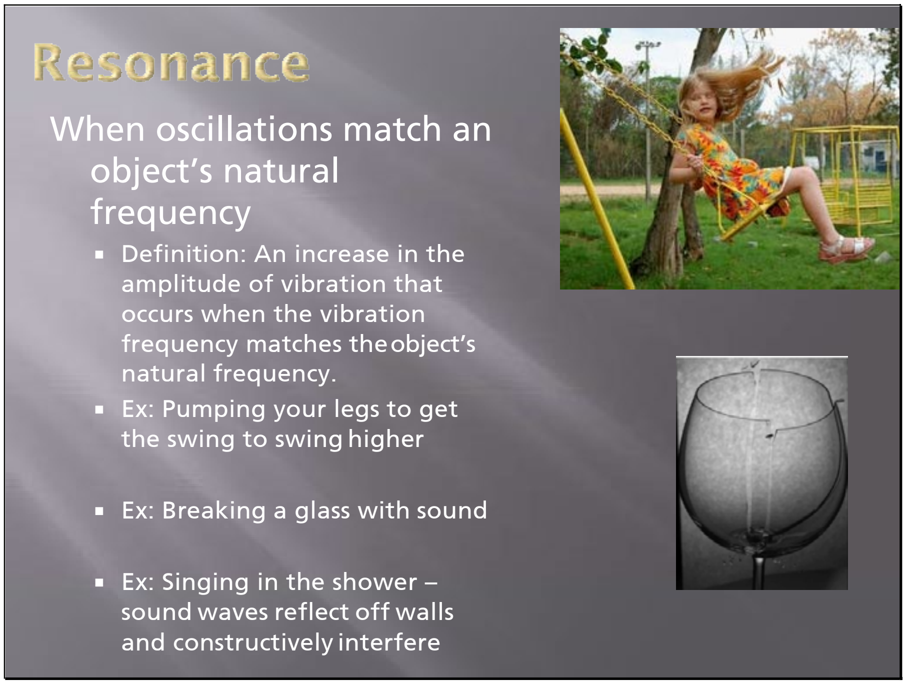
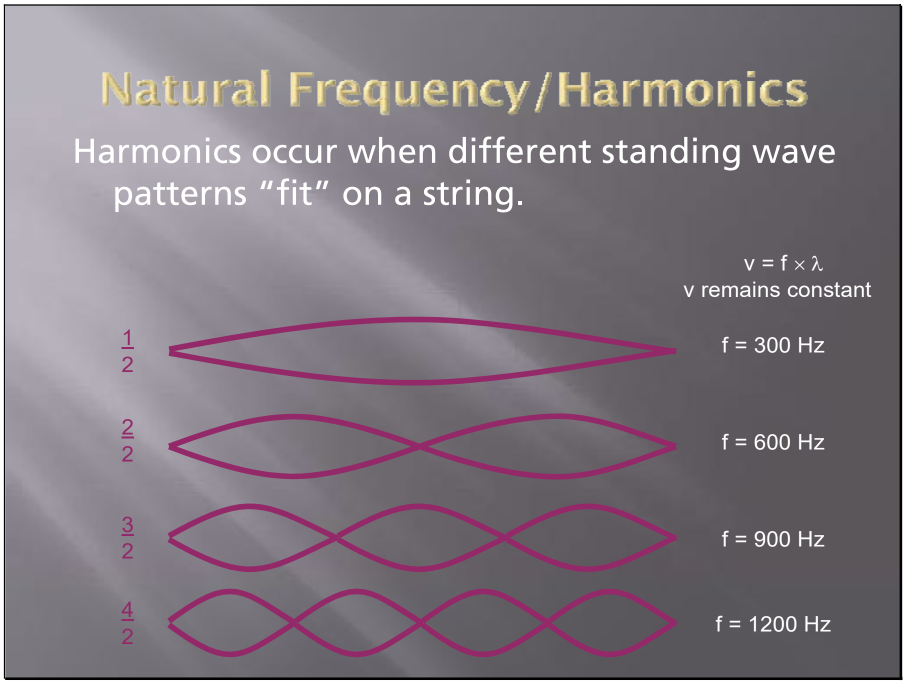


Another interesting phenomenon often associated with sound is the concept of resonance. Resonance occurs when an object is oscillated at a frequency that matches the object's natural frequency. Every object, due to its shape, materials and construction has a certain natural frequency at which it will vibrate. Some objects will demonstrate their natural frequency when you strike them. If you volunteer to empty the silverware from the clean dishwasher, you may notice that every fork sounds the same when you drop it in the silverware drawer. Knives have their own sound, as do soup spoons, teaspoons and dessert forks. As long as the silverware comes in a matching set, you should be able to recognize the specific tone made by a particular type of utensil, and if you practice, you can even recognize them blindfolded, which makes for a nice way to impress your family members. The reason for this is that each type of utensil contains a different amount of material and is shaped in a different way from the others. These properties give it a certain ring when dropped into the drawer. Another example of resonance is when you sit on a swing and pump your legs to get the swing to go higher. There is one optimal frequency at which you can pump your legs that will result in you going higher. If you try to swing too fast or too slow, the swing will hardly get anywhere. This is because the swing has a natural rate at which it will swing back and forth, which is primarily due to the length of the chains. This determines the swing's natural frequency. If you match this frequency with the swinging of your legs, each time you pump your legs, you will be giving the swing another little push at just the right time. These pushes produce an increasing amplitude.

A singer can shatter a glass using only her voice. Typically, she will first strike the glass to hear the note it produces.

By singing this precise note, each pressure wave hits the glass at precisely the right time, causing the amplitude of vibration to increase to the point where the glass shatters.

Some people like to sing in the shower. The flat, bare walls of the shower allow strong reflections of sound waves. When these waves are of just the right frequency, they can bounce back and forth, constructively interfering with each reflection, resulting in a rather loud sound from a relatively quiet original note.



This is an example of resonance. Usually there is more than one frequency that can create resonance in an object. These different frequencies are called harmonics. Each harmonic corresponds to a different standing wave pattern, but often, there are multiple frequencies that may result in resonance.

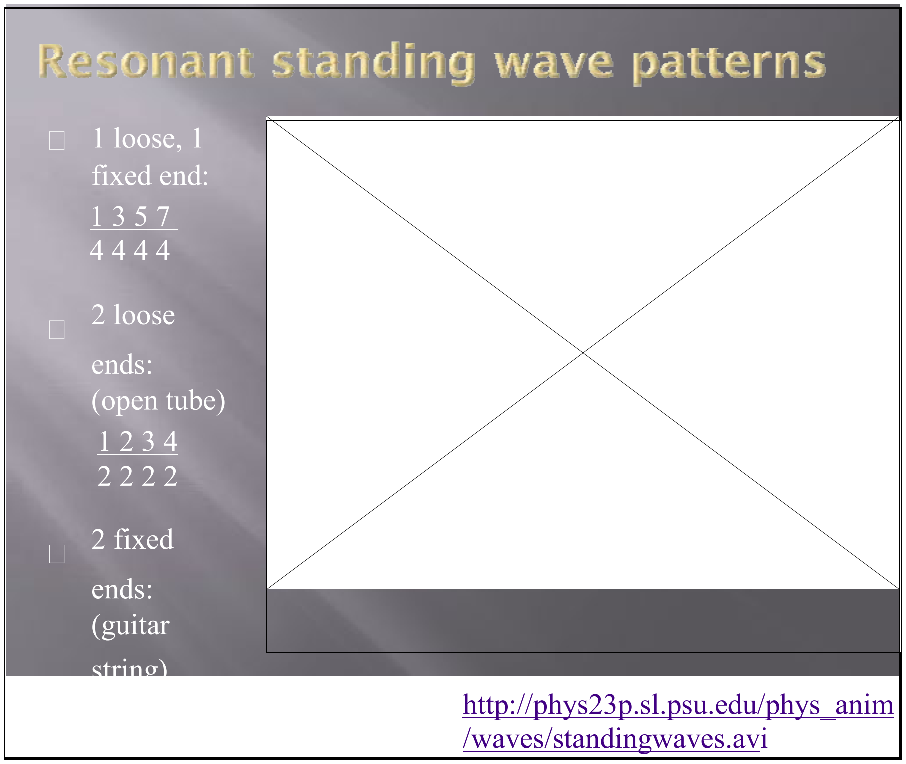
Using a guitar string as an example, we know that in order for a standing wave to form upon it, both fixed ends must correspond to nodes. The simplest standing wave that can fit upon that string, therefore, is a wave where the length of the string represents half the wavelength of the wave. In this case, the string will oscillate back and forth with a node at each end and an antinode at the middle of the string. This is called the fundamental frequency.

The next pattern has a node at each end and also one in the middle. Since the distance between nodes is half a wavelength, this represents a wave where the length of the string is two half wavelengths or one complete wave. Following this logic forward, the patterns continue with three half wavelengths, then four half wavelengths and so on.

It is the combination of these multiple harmonics in different amounts that actually make a guitar sound like a guitar and a violin sound like a violin, even when they are playing the same note. This is called timbre.

Also, since the speed of a wave depends on the characteristics of the medium, all these waves must have the same speed. If the frequency is doubled, the wavelength will be cut in half so that the product of frequency and wavelength remains constant.

The second harmonic has twice the frequency of the first harmonic. Your ear perceives this as a note that is one octave higher.



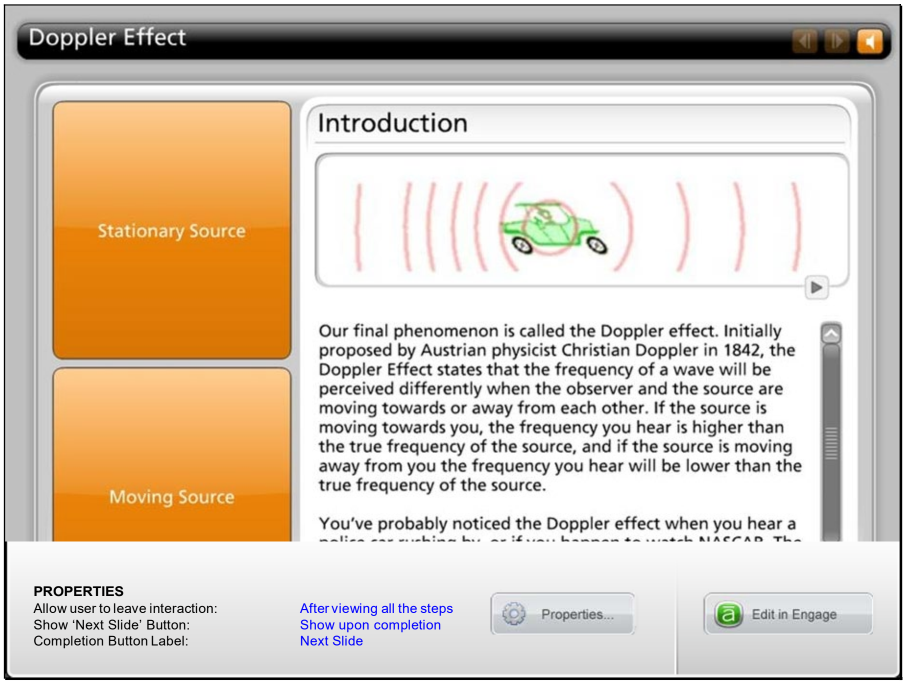
Instruments use standing waves to create different notes. Stringed instruments have strings that are fixed on both ends, so standing wave patterns must have nodes at both ends.

However, standing waves can also occur for sound waves in a tube of air. Wind instruments can have one end of the tube open or both ends open. The open end is an antinode and the closed end is a node.

This animation shows standing wave patterns that can occur on objects with different combinations of fixed and loose ends. You'll notice that at the bottom, we again have our guitar string with two fixed ends and we see multiples of half wavelengths fitting on the string.

Above that we find that two loose ends also produces waves that are multiples of half wavelengths. Watch the animation and count the nodes and antinodes to confirm this.

Finally, at the top, we see waves produced with one loose and one fixed end. These result in odd multiples of quarter wavelengths. The first wave is one quarter wavelength, the next is three quarters of a wave, the next is five quarters, and so on.

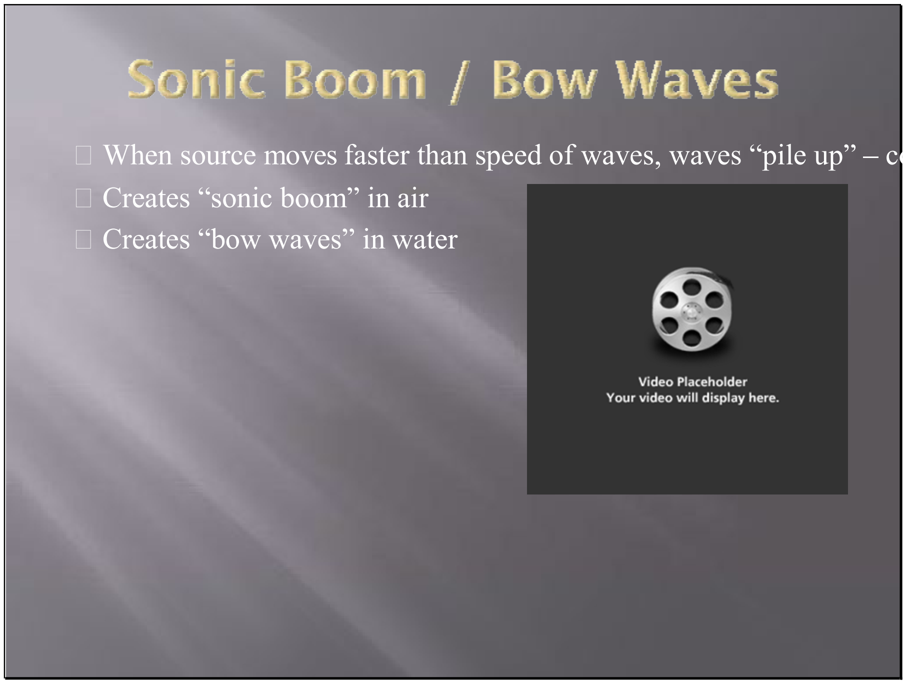


Our final phenomenon is called the Doppler effect. Initially proposed by Austrian physicist Christian Doppler in 1842, the Doppler Effect states that the frequency of a wave will be perceived differently when the observer or the source are moving towards or away from each other. If the source is moving towards you, the frequency you hear is higher than the true frequency of the source, and if the source is moving away from you the frequency you hear will be lower than the true frequency of the source.

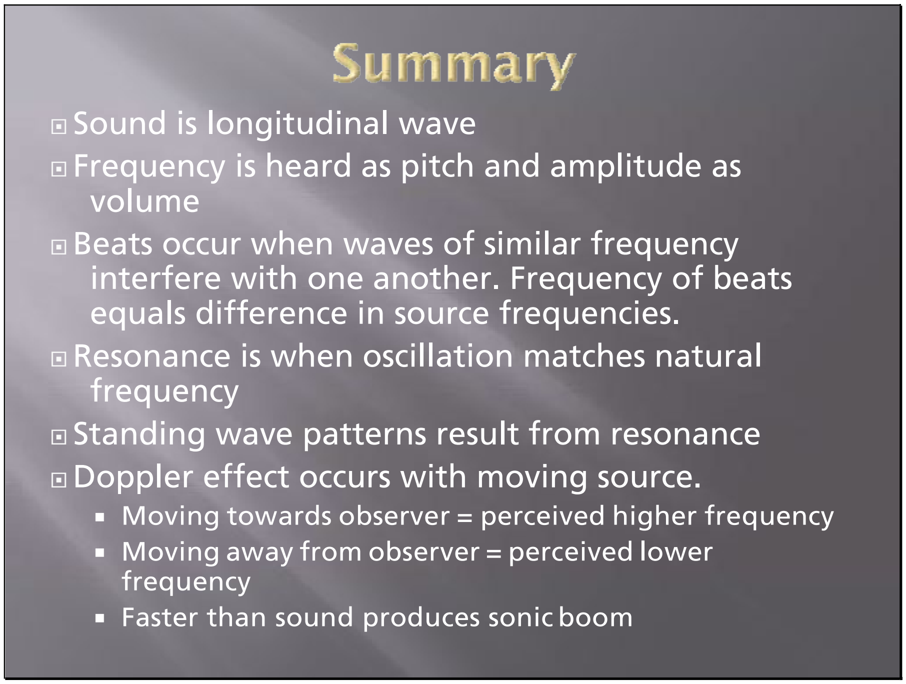
You've probably noticed the Doppler effect when you hear a police car rushing by, or if you happen to watch NASCAR. The pitch of the siren or of the speeding cars starts high as the car rushes towards you, the drops to a lower pitch as it passes and zooms away from you.

If the source is stationary, the sound that it makes radiates out equally in all directions, producing a set of concentric circles of sound.

If the source is in motion, however, the waves in front of the source are compressed and the waves in back of the source are further apart. So, if the source is coming toward you, the crests are closer together and you hear a higher frequency. If the source is moving away from you, the crests are farther apart and you hear a lower frequency.



When the source of sound moves at or greater than the speed of sound, an interesting effect occurs. If an object moves quicker than the speed of sound, the leading edge of the pattern of waves forms a cone shape behind the object. When the source moves faster than the speed of sound, the waves follow the source, forming a cone shape. When this cone of air pressure hits the observer it creates a sonic boom.



In summary, sound waves are longitudinal pressure waves, generally in air. We hear frequency as pitch and amplitude as volume. Several interesting wave phenomenon are primarily associated with sound.

Beats occur when two waves of similar frequency interfere with each other. The number of beats heard is equal to the difference in the frequency.

Resonance occurs when the oscillation of an object matches its natural frequency. The amplitude of the oscillations increases, which can lead to devastating consequences.

Resonance is also responsible for the notes produced by musical instruments. The structure of the instrument determines the number of half or quarter wavelengths that can fit in the structure and which frequencies will resonate.

The Doppler effect occurs when a source is moving relative to an observer. If the source is moving toward the observer, the perceived frequency is higher than the actual frequency of the sound. If the source is moving away from the observer, the perceived frequency is lower than the actual frequency of the sound. When the speed of the source exceeds the speed of sound, a sonic boom may occur.