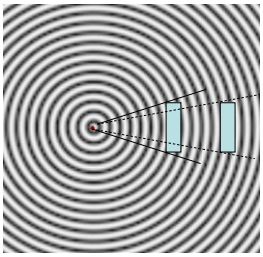
What determine how loud we hear of the sound produced by a source?

1. The power of the source
2. The distance of the source from us.

In what way does the distance of the source from us affects its "apparent" loudness?

Below is a simulation of the sound wave emitted from a point source:



In what way does the distance of the source from us affects its "apparent" loudness?

Recall that the intensity of a sound wave from a point source drops off as $1/r^2$, where r is the distance from the source.

So, the intensity change in decibel due to the distance change is:

$$\Delta\beta \text{ (in decibel)} = (10 \text{ dB})\log(r_i/r_f)^2$$
$$= (20 \text{ dB}) \log(r_i/r_f)$$

The final intensity, $\beta(r_f) = \beta(r_i) + \Delta\beta$ (all in decibels)

The Doppler Effect

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The Doppler Effect

The Doppler effect is the shift in frequency of a wave <u>as registered by an observer</u> that occurs when either the wave source, or the observer of the wave, is moving. Applications include medical tests using ultrasound, police speed traps using radar and astronomy using electromagnetic waves.

<u>Simulation</u> (stationary source)

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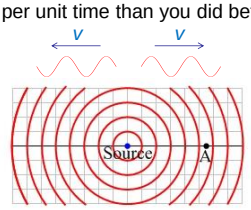
Doppler effect: a moving observer

Consider a stationary source of sound broadcasting a single-frequency sound wave. The usual relationship between frequency, speed, and wavelength is: $f = \frac{v}{\lambda}$

where v denotes the speed of sound through the medium.

Let's say you, the observer, now move toward the source with speed v_o, while the source remains stationary. You encounter more waves per unit time than you did before.



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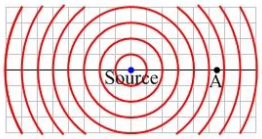
A moving observer

Let's say you, the observer, move toward a stationary source with speed v_o. You encounter more waves per unit time than you did before. For you, what change in the wave?

1. their speed
2. their wavelength



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A moving observer

Relative to you (the observer), the waves travel at a different speed: $v' = v + v_o$

If you move away from the source, the relative speed between you and the waves would be lower. In either case, this shifts the frequency of the waves you hear, to:

$$f' = \frac{v'}{\lambda} = \frac{v \pm v_o}{\lambda} = \frac{v}{\lambda} \times \frac{v \pm v_o}{v} = f\left(\frac{v \pm v_o}{v}\right)$$

Use the top sign (+) when the observer moves toward the source, and the bottom sign (-) when the observer moves away.

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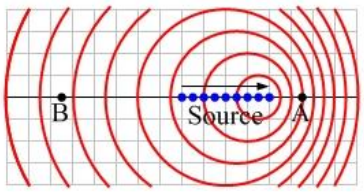
Doppler effect: a moving source

If the source moves through the medium, the situation looks a little different.

Simulation: (moving source)

Notice how the wave fronts emitted later are brought closer toward the ones emitted earlier when the source is moving toward the observer.



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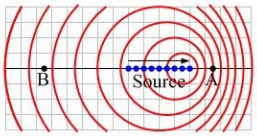
A moving source

You, a stationary observer, are near a source that is moving with speed v_s. For you, what changes in the waves in this case?

1. their speed
2. their wavelength



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A moving source

The motion of the source effectively changes the wavelength, to: $\lambda' = \frac{v}{f} \mp \frac{v_s}{f}$

Use the top sign (-) when the source moves toward the observer, and the bottom sign (+) when it moves away.

The detected frequency is:

$$f' = \frac{v}{\lambda'} = f\frac{v}{v \mp v_s}$$

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The Doppler Effect in general

In some situations, both the source and the observer move. The general Doppler equation combines the previous results.

$$f' = f\left(\frac{v \pm v_o}{v \mp v_s}\right)$$

Use the upper signs when the source and observer are approaching each other, and the lower signs when they are moving away from each another.

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A sample Doppler problem

A particular bat emits ultrasonic waves with a frequency of 56.0 kHz. The bat is traveling at 20.0 m/s toward a moth, which is hovering motionless in the air. The speed of sound is 340.0 m/s.

(a) Assume that the moth can detect the waves, what frequency would it observe of the waves?

(b) The waves reflect off the moth and are detected by the bat. What frequency are the waves detected by the bat?

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A sample Doppler problem

$$f = 56.0 \text{ kHz} \quad v_s = 20.0 \text{ m/s (towards)}$$
$$v_o = 0 \quad v = 340 \text{ m/s}$$

(a) The observed frequency is:

$$f' = f\left(\frac{v \pm v_o}{v \mp v_s}\right)$$
$$= (56.0 \text{ kHz})\left(\frac{340.0 \text{ m/s}}{340.0 \text{ m/s} - 20.0 \text{ m/s}}\right) = 59.5 \text{ kHz}$$

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A sample Doppler problem

When the waves reflect from the moth, the moth becomes the source and the bat becomes the observer. What is the frequency of the reflected sound observed by the bat?

$$f' = 59.5 \text{ kHz} \quad v_s = 0$$
$$v_o = 20.0 \text{ m/s (towards)} \quad v = 340 \text{ m/s}$$

(a) The observed frequency is:

$$f'' = f'\left(\frac{v \pm v_o}{v \mp v_s}\right)$$
$$= (59.5 \text{ kHz})\left(\frac{340.0 \text{ m/s} + 20.0 \text{ m/s}}{340.0 \text{ m/s}}\right) = 63.0 \text{ kHz}$$

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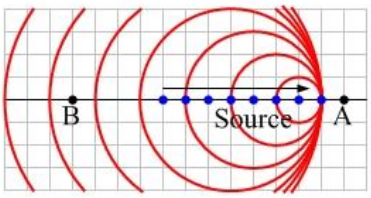
Breaking the sound barrier

If the source travels at the speed of sound, the waves pile up and move along with the source. All the peaks are at the same place, so the wavelength is zero and the frequency is infinite. This overlay of all the waves produces a shock wave known as a **sonic boom**.



Simulation

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Breaking the sound barrier

When a jet goes through the sound barrier, there are regions of very high pressure and very low pressure. In the low pressure region at the back of the jet, the air expands, cools, and water vapor condenses to form a cloud.

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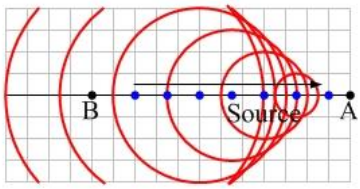
Breaking the sound barrier

When the source moves faster than the wave speed, the source outruns the wave. The waves now pile up along a particular angle, again producing a shock wave (sonic boom). The angle at which the shock wave moves away from the path of the source depends on the speed of the source relative to the speed of sound. Does the pattern look familiar?



Simulation

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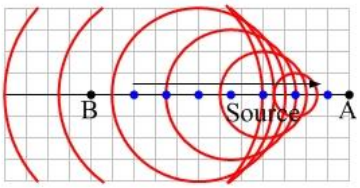
Breaking the sound barrier

Does the pattern look familiar? It looks a lot like the wake left behind by a boat moving through water. What does this tell you about how a boat's speed compares to the speed of the water waves?



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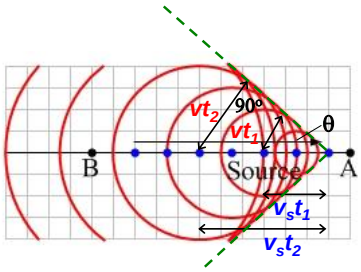
The angle made by the wave fronts of a shock wave

$\sin\theta = v/v_s$



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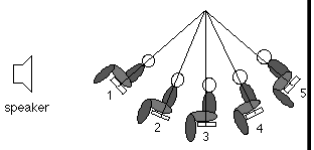
A child on a swing

A child is swinging back and forth on a playground swing. A speaker in front of the child is broadcasting a single-frequency tone. At which point in the swing does the child perceive the tone to be of lowest frequency, and of highest frequency?



1. The tone is lowest at 1, and highest at 5.
2. The tone is lowest at 5, and highest at 1.
3. The tone is lowest at 1 and 5, and highest at 3.
4. The tone is highest at 1 and 5, and lowest at 3.
5. The tone is both lowest and highest at point 3.

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Adding waves: the principle of superposition

When more than one wave is traveling in a medium the waves simply add.

The principle of superposition: the net displacement of any point in the medium is the sum of the displacements at that point due to each wave individually.

Simulation

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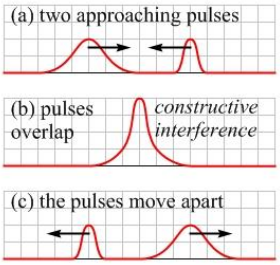
Constructive interference

When the displacements of individual waves go in the same direction at a point, the result is a larger amplitude there, because the displacements add. This is known as constructive interference. Simulation.

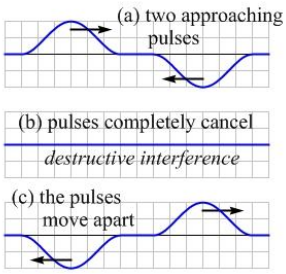
A neat feature of waves is that, after passing through one another, waves (or pulses) travel as if they had never met.



Destructive interference

When the displacements of individual waves are in opposite directions at a point, the waves cancel (at least partly). This is known as destructive interference. Simulation.

How is it possible for the two pulses to re-emerge from the flat string?



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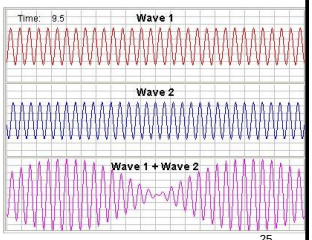
Beats

When you listen to two sound waves of similar frequency, you hear beats where the intensity of the sound rise and fall in sequence. When the waves are exactly in phase with one another, constructive interference produces a loud sound.

With the waves having slightly different frequencies, they drift out of phase over time. When complete destructive interference takes place, you hear nothing. The phase difference continues to grow and, the closer it gets to a full wavelength shift, the higher the intensity.

Simulation



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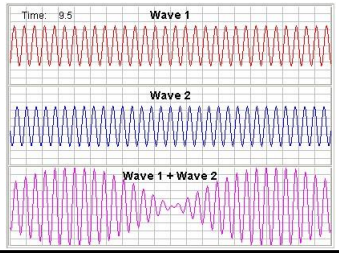
Beats

The intensity of the sound oscillates from maximum to zero and back again continually. The closer the waves are in frequency, the slower the cycle of rising and falling intensity.

The frequency of the rising and falling is known as the beat frequency, which equals the difference in frequency between the two waves.

$$f_{beat} = |f_1 - f_2|$$



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Beat frequency

You have a tuning fork with a frequency of 400 Hz. When you play it at the same time as a second tuning fork of unknown frequency, you hear beats with a frequency of 5 Hz. What is the frequency of the second tuning fork?

1. 395 Hz
2. 405 Hz
3. It could be 395 Hz or 405 Hz
4. 80 Hz
5. 2000 Hz
6. It could be 80 Hz or 2000 Hz

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