Sound Waves

Sound is a form of energy resulting from oscillations in pressure (or density) of the medium in which the sound is travelling.

Sound is a longitudinal wave, since the particles vibrate parallel to the motion of the wave, creating areas of alternating high and low pressure. The areas of high pressure are called compressions and the low pressure areas are rarefactions.

http://www.physicsclassroom.com/class/sound/u11l1c.cfm

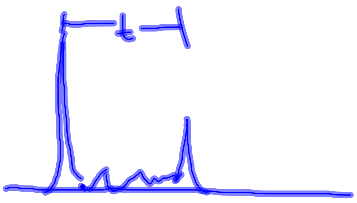
We are able to hear SOME sound, depending on its frequency and volume. (The volume is proportional to the amplitude of the wave.)

Frequencies that are in the range of human hearing (20 Hz to 20 000 Hz) are said to be audible. Frequencies above this range are called ultrasonic and frequencies below are said to be infrasonic.

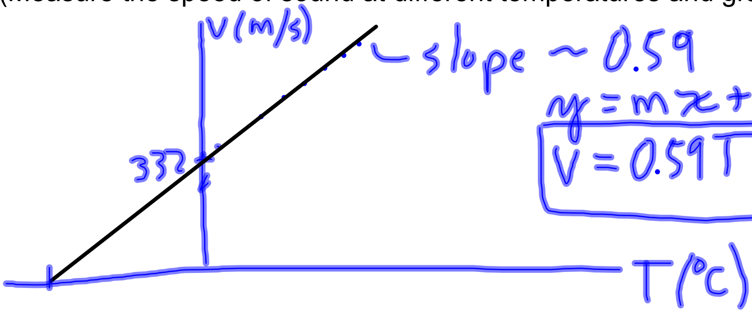
The Speed of Sound

Since sound waves propagate based on the density of the particles in their medium, it would make sense that the speed of the wave depends on the characteristics of the medium. For that reason, the speed of sound changes based on the medium through which it is travelling.

Eg. material	speed (m/s)
-air (0 °C)	332
-water	1500
-steel	5000



There is also a temperature dependance in most media. This dependency can be determined experimentally.
(Measure the speed of sound at different temperatures and graph it.)



slope ~ 0.59

$y = mx + b$

$\boxed{v = 0.59T + 332}$

Examples:

Determine the wavelength in air at 20°C of a 440 Hz sound.

$T = 20°C$

$f = 440\ Hz$

$\lambda = ?$

$v = ?$

$v = 332 + 0.59T$

$= 332 + 0.59(20)$

$= 332 + 11.8$

$= 343.8\ \frac{m}{s}$

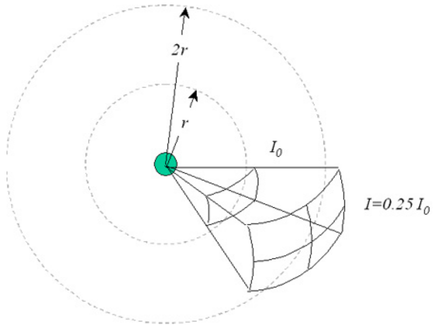
$v = f\lambda$

$\lambda = \frac{v}{f} = \frac{343.8}{440}$

$= 0.78\ m$

Sound Intensity

When sound is emitted, its energy spreads out in all directions. As it gets further form the source, the energy becomes more spread out. This is why the sound is not as loud. Sound intensity a measure of the amount of sound energy per second per square meter at a given point.



sound intensity --> $J/s/m^2$
$= W/m^2$

Sound intensity is different from loudness (or volume) because loudness is subjective. A sound can be very intense, but impossible to hear.

Sound Intensity Scale

Sound intensities vary quite a bit. For example, the sound intensity of a person whispering 2 m away is about 10^{-10} W/m^2. A slightly louder sound, say a normal conversation between 2 people, is 10 000 times more intense (10^{-6} W/m^2). A loud rock concert can reach up to 1 W/m^2 (10 billion times more intense than the whisper.)

When numbers rise so rapidly, a linear scale does not work very well. We use a logarithmic scale. In this case, we use the concept that a change in 1 bel or 1 B represents a change in intensity of 10 times. Note that 1 B = 10 dB. We often call this the decibel system.

For example, an increase in 50 dB (or 5 B) represents a sound that is 10^5 times more intense. (100 000x).

Try these: 1) A sound has an intensity of 60 dB. What is its intensity in dB if it is 1000 times less intense?

2) How many times more intense is a 75 dB sound than a 15 dB sound?

3) What dB increase represents a sound that is 5000 times more intense.

$1000 \rightarrow 3\text{ B}$
$\sim 30\text{ dB}$
$10000 \rightarrow 4\text{ B}$
$\sim 40\text{ dB}$

$10^{\Delta B} = \text{Intensity change}$

$10^{\Delta B} = 5000$

$\log 10^{\Delta B} = \log 5000$

$\Delta B \log 10 = \log 5000$

$\Delta B (1) = 3.7$

$\Delta B = 3.7$ or $\boxed{37\text{ dB}}$

$\log x^y = y \log x$

4) How much less intense is a 43 dB sound than a 88 dB sound?

4.3 B 8.8 B

$\Delta B = 8.8 - 4.3$
$= 4.5\text{ B}$

$\text{Intensity} = 10^{4.5}$
$= 32\,000\text{x}$

dB Supplementary Questions

1. Determine the change in dB if a sound is 340 000 times less intense.
2. How much more intense is a 67 dB sound than a 0 dB sound? $10^{6.7}$
3. You are at a rock concert, and find yourself too close to the speaker. The sound intensity where you are is 120 dB. You move 10 times further away from the speaker. What is the new dB level where you are now standing? (This is a tricky question. Refer to the diagram on page 4 for a hint.)

$S.I._0 = 120\,dB$

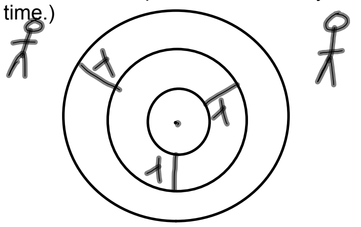
$r \times 10 \rightarrow \therefore I$ goes down by $100X$

$100\times$ less $= 10^2$ less $\therefore dS.I. \downarrow$ by $2B$ or $20\,dB$

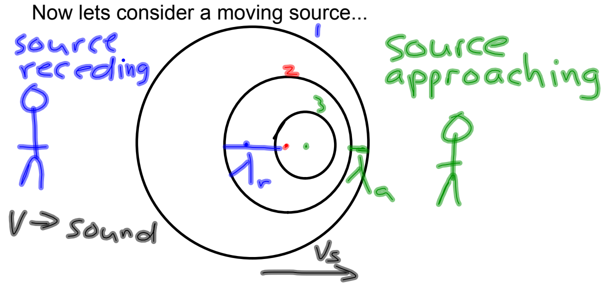
$\therefore$ New $S.I._1 = 100\,dB$

The Doppler Effect

When a stationary object emits sound, the wave spreads out evenly in all directions.
(The circles in the diagram below represent a wave front: the location of a common point in a wave, say its crest, at a given time.)



Now lets consider a moving source...

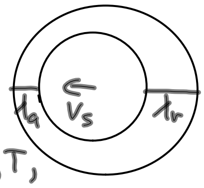


Notice that the wavelengths appear to be smaller in the direction that the source is moving and larger in the direction that the source is moving away from.

Approaching... $\underline{\lambda}$ is getting smaller, so f is getting <u>larger</u>

Receding... $\underline{\lambda}$ is getting larger, so f is getting <u>smaller</u>

Doppler Effect Equation



Let's say the 2 wave fronts are emitted 1 period, T, apart

$t = T$

In that time, the object moves...

$d = V_s T$

Normally, the wave fronts are λ apart.
But the object moves before the next wave is emitted

$\therefore \lambda_a = \lambda_o - d$ and $\lambda_r = \lambda_o + V_s T$

$= \lambda_o - V_s T$

but $\lambda = \dfrac{V}{f}$

$\therefore \lambda_a = \dfrac{V}{f_a}$ and $\lambda_o = \dfrac{V}{f_o}$

$\dfrac{V}{f_a} = \dfrac{V}{f_o} - V_s T$ but $T = \dfrac{1}{f_o}$

$\dfrac{V}{f_a} = \dfrac{V}{f_o} - \dfrac{V_s}{f_o}$

$\dfrac{V}{f_a} = \dfrac{V - V_s}{f_o} \rightarrow \dfrac{f_a}{V} = \dfrac{f_o}{V - V_s}$

$f_{a,r} = f_o \left(\dfrac{V}{V \mp V_s} \right)$

Example

A siren has a frequency of 1200 Hz. What frequency is heard by child on the side of the road if the siren is approaching at $90 \frac{km}{h}$? (Assume an air temperature of 20°C.)

$f = f_o \left(\dfrac{V}{V \pm V_s} \right)$

$f_o = 1200$ Hz

$f_a =$

$V_s = 90 \frac{km}{h} = 25 \frac{m}{s}$

$V = 332 + 0.59T$
$= 332 + 11.8$
$= 343.8 \frac{m}{s}$

$f = 1200 \left(\dfrac{343.8}{343.8 - 25} \right)$

$= 1200 \left(\dfrac{343.8}{318.8} \right)$

$= 1294$ Hz

After you have done the hit-list questions in the textbook, try this one...

As an ambulance drives by you, its frequency appeared to change by 10%.
a) Did the frequency go up or down?
b) Determine the speed of the ambulance.

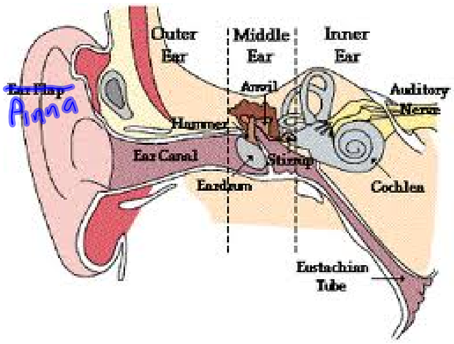
$T = 20°C$

Human Hearing

Outer Ear: Sound Collection

Sound waves are funneled into the ear by the pinna, where it is amplified. It then travels down the ear canal before striking the eardrum, which is a thin tissue than is stretched tight over the end of the ear canal.

Middle Ear: Transfer Station



The vibration of the eardrum is transferred to 3 tiny bones (the hammer, anvil, and stirrup) where it is amplified slightly. This vibration causes the cochlea to vibrate.

Inner Ear: Sorting Station

The cochlea is a fluid-filled sac containing thousands of tiny hair-like structures called cilia . When the cochlea vibrates, the motion of the fluid causes the cilia to vibrate. However, each cilia has its own resonance frequency. If the frequency of vibration of the cochlea (which is the same as the incoming sound) is the same as the resonance frequency of a particular cilia, then that cilia will vibrate. Each cilia is attached to a nerve ending. When a cilia vibrates, it sends a signal through this nerve to the auditory nerve where it is received by the brain and interpreted.