Physics in Everyday Life

Physics of Sound and Hearing

What is Sound?
• Sound is a compression wave
• The air is temporarily compressed to a slightly higher pressure than normal
• The wave front passes through the medium

In Two Dimensions
• The wave spreads out from a point source in a circular pattern

• This is similar to the effect of disturbing the surface of water
• The ripples (wavefronts) move outwards

• We can see this in animated form
  http://resource.isvr.soton.ac.uk/spcg/tutorial/tutorial/Tutorial_files/Web-basics-pointsources.htm

Sound Waves are Longitudinal
• There are two types of waves
• Transverse
• Longitudinal
• Sound waves, and all compression waves are Longitudinal

http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html
Intensity

- We measure the “strength” of the sound with the quantity called Intensity, which has units of Power per unit area

- The intensity decreases as you get further from the source, because the same power is spread over a larger area

Decibel Scale

- The decibel scale is a way of quantifying the Sound Intensity Level
- It is a non-linear scale (based on logarithms), but it simulates how the brain perceives the relative “loudness” of noises

<table>
<thead>
<tr>
<th>Perceived Loudness</th>
<th>Intensity (watts/m²)</th>
<th>Intensity Level in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold of hearing</td>
<td>10⁻¹²</td>
<td>0</td>
</tr>
<tr>
<td>Rattle of leaves</td>
<td>10⁻¹¹</td>
<td>10</td>
</tr>
<tr>
<td>Whisper</td>
<td>10⁻¹₀</td>
<td>20</td>
</tr>
<tr>
<td>Watch ticking at 1 metre</td>
<td>10⁻⁹</td>
<td>30</td>
</tr>
<tr>
<td>Radio (low)</td>
<td>10⁻⁶</td>
<td>40</td>
</tr>
<tr>
<td>Quiet conversation</td>
<td>10⁻⁷</td>
<td>50</td>
</tr>
<tr>
<td>Quiet motor at 1 metre</td>
<td>10⁻⁶</td>
<td>60</td>
</tr>
<tr>
<td>Busy street traffic</td>
<td>10⁻⁶</td>
<td>70</td>
</tr>
<tr>
<td>Door slamming</td>
<td>10⁻⁵</td>
<td>80</td>
</tr>
<tr>
<td>Heavy truck, 15 metres away</td>
<td>10⁻³</td>
<td>90</td>
</tr>
<tr>
<td>Lawnmower</td>
<td>10⁻²</td>
<td>100</td>
</tr>
<tr>
<td>Pneumatic drill/Jackhammer</td>
<td>10⁻¹</td>
<td>110</td>
</tr>
<tr>
<td>Close to a jet engine</td>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>Rock Concert/Physical damage possible</td>
<td>10</td>
<td>130</td>
</tr>
</tbody>
</table>

Why Use the Decibel Scale?

- It is convenient, since it follows the way the human ear perceives loudness
- A 1 dB change in the intensity level between two sounds corresponds approximately to the smallest change in loudness that the average listener with normal hearing can detect

Alexander Graham Bell, devised the Bel scale to analyse the performance of early telephones
1 Bel = 10 decibels

Frequency

- The number of complete wave cycles per second (Hertz)

The human ear is not very sensitive below 800 Hz, or above 10,000 Hz

http://fearofphysics.com/Sound/sounds.html
Human Hearing

• The ear is a sensitive detection system for sound waves

The shape of the ear is designed to guide sound waves into the auditory canal

The sound waves are funneled down the external auditory canal, and make the tympanic membrane (the ear drum) vibrate

Ear drum vibrates at the same frequency as the wave

• When the oval window vibrates it sends pressure waves down the liquid filled cochlear

Ear drum vibrates at the same frequency as the wave

• The cochlea contains the sound sensors. It is a divided and coiled tube

Fluid makes the round window vibrate – this is needed to allow pressure waves to flow easily

The position along the membrane which is most stimulated by the compression sound wave is a measure of the frequency

Perception of Pitch

• Mostly dependent on frequency
• Also depends on timbre and intensity

Our sense of pitch is a logarithmic function of frequency

Image: Wikimedia

http://en.wikipedia.org/wiki/Pitch_(music)
Localisation of Sound

• Which direction does the sound come from?
  • Difference in intensity
  • Sound arrives at the ears at different times, because it travels different distances

Limits of Human Hearing

• Humans can hear from around 20 Hz to 20,000 Hz (20 kHz)
• The upper limit is reduced as you get older
• A teenager can hear much higher pitched sounds than an older person

Subsonics

• Sounds below 20 Hz cannot be heard by people, so they are called Subsonic or Infrasonic
• For some of these frequencies we can sense the vibration in our bodies
• This can be used theatrically to induce a sense of fear or unease in some individuals
  — 17 Hz was used in an experiment in the UK in 2003 — 22% of participants reported symptoms including anxiety, uneasiness, extreme sorrow, nervous feelings of revulsion or fear, chills down the spine, and feelings of pressure on the chest!

Rhinoceros Speech

• Many animals communicate with grunts and sounds which are in the subsonic range
• The Sumatran Rhinoceros grunts at 3 Hz

Ultrasonics

• Any sound vibration which cannot be heard by humans.
• The sound may be audible to other species.
• These waves easily propagate though human tissue
• They get strongly reflected at boundaries between different tissue types, so they can be used for imaging

Dog Whistles

• Dogs can hear much higher frequencies than humans — up to 46 kHz (compared to 20 kHz for young adult humans)
• It’s easy to make a whistle which sounds at frequencies which dogs can hear, but humans can’t.
Anti-Teenager Devices

• A company in Wales markets an “Anti-teenager device” for use in shopping malls.
• It broadcasts a high frequency note which is audible to teenagers and is annoying enough to make them leave the area!
• Older customers are oblivious to the note

http://movingsoundtech.com/

Ultrasound and Medical Imaging

• Uses sound waves at the 1 MHz range
• Sometimes called a sonogram

http://pregnancy.about.com/od/fetus/ig/3D-Ultrasound-Gallery/

Sonar

• An acronym for Sound Navigation And Ranging
• A sound pulse (“ping”) is sent out and reflected

http://www.youtube.com/watch?v=D9kv_V5lhiE

Take a Break

• The beach, Sheringham, Norfolk, England

Sound of Music

• Music is a set of complex sounds
• The Pitch in music corresponds to the frequency.
• Individual musical instruments have their own “sound” characteristics, which also depend on overtones, echo/reverberation, how long each note is sustained etc.
When using an electronic instrument to synthesize a traditional one, the ADSR “sound envelope” is used for each note played.

But this is only an approximation, the sound of a “real” instrument is much richer and more complex!

Describing a Sound Wave

- The wavelength and frequency of a wave are related to the speed of the wave by:

\[ \text{speed} = \frac{\text{wavelength} \times \text{frequency}}{\text{speed}} \]

- In acoustics, we usually specify the frequency (in Hertz) to specify the wave, assuming the speed is constant.

Creating a Sound

- We need something which vibrates — this disturbs the air with the same frequency, and creates the sound wave.
  - Vibrating guitar string
  - Loudspeaker cone

Electromagnet shakes the cone. Cone shakes the air, creating the sound wave.

Standing Waves

- A standing wave may occur if a travelling wave in a medium is reflected back on itself.

http://www.walter-fendt.de/ph14e/stwaverefl.htm

- Only waves which have a wavelength which is an integer or half integer value of the length of the medium do this.

- All other waves on the string die away

https://www.youtube.com/watch?v=g7Km7DxkI

Allowed Harmonics

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Waveform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental</td>
<td><img src="image" alt="Fundamental" /></td>
</tr>
<tr>
<td>1st Overtone</td>
<td><img src="image" alt="1st Harmonic" /></td>
</tr>
<tr>
<td>2nd Overtone</td>
<td><img src="image" alt="2nd Harmonic" /></td>
</tr>
<tr>
<td>3rd Overtone</td>
<td><img src="image" alt="3rd Harmonic" /></td>
</tr>
<tr>
<td>4th Overtone</td>
<td><img src="image" alt="4th Harmonic" /></td>
</tr>
<tr>
<td>5th Overtone</td>
<td><img src="image" alt="5th Harmonic" /></td>
</tr>
</tbody>
</table>

Didjeridoo

- A didjeridoo (many spelling variants!) is a musical instrument used by the Aboriginal peoples of Australia.

- It consists of a long open tube, which is blown into at one end, the other end resting on the ground.

- It acts like a pipe with one end closed (by the mouth and lips of the player)

http://capone.mtsu.edu/wroberts/
A spectrum analyzer is able to take a sound and break it down into the individual component frequencies. This is known as Fourier analysis.

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Standing waves can also be produced when air is blown down a tube. The tube can be open at both ends, or closed at the far end.

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These create the sound by creating standing waves in a tube. You can change the notes by opening or closing holes in the side or changing the length of the tube.

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If two waves of approximately the same frequency (within ~ 20Hz) are in the same place at the same time, they produce a phenomenon known as beating.
There are now two frequencies associated with the combined wave.
The frequency of the blue waves, which is the average of the two original frequencies.
The frequency of the red modulation wave, which is the difference between the two original frequencies.

We use the beat frequency to tune musical instruments.
We use a tuning fork of known frequency/pitch and then play the instrument at the same pitch.
When the beat disappears, both frequencies are the same.

Human Voice
- How we speak:
  - Our windpipe acts as a pipe organ
  - Our vocal cords modulate the air in the windpipe to give us different frequencies.
  - We use the shape of our mouths, tongue position, lips, and cheeks to annunciate (shape the sound wave).

Making Your Voice Sound Strange!
- If you inhale a gas such as $\text{H}_2$ (low density) or $\text{SF}_6$ (high density), the speed of sound in your windpipe changes.
  - The wavelengths produced by the voice remain the same. If the density of the gas decreases, so does the speed of sound and hence so does the frequency.
  - So you sound like Donald Duck if you inhale Helium.

Do not attempt to breath the helium in directly from a pressurized tank or cylinder.
High pressure helium bubbles in the bloodstream can be fatal.

http://www.youtube.com/watch?v=d-XbfN3aoE

The Doppler Effect
- If either the source, or the observer (or both) are moving, then the wave fronts appear to be spaced differently for observers in different frames of reference.

http://www.lon-capa.org/~mmp/applist/doppler/d.htm
• If you are watching the source coming towards you, the sound waves are compressed (shorter wavelength, higher frequency)

Observer in front of source

• If you are watching the source recede, the sound waves are elongated (longer wavelength, lower frequency)

Observer behind the source

The Doppler Effect in Sound Waves

• The change in frequency (pitch) detected by an observer because the sound source and the observer have different velocities with respect to the medium of sound propagation

Christian Doppler,
Austrian Mathematician
1803-1853

Doppler Effect Movies

• http://www.wfu.edu/Academic-departments/Physics/demolabs/demos/3/3b/3B40xx.html

Video/audio clips of the Doppler effect from three reference frames;
• A stationary observer (person 1),
• the person generating the sound (person 2) in a moving vehicle
• and a person traveling in a car in the opposite direction (person 3).