The Production of Sound Waves

✓ All sound begins with a vibrating object

➢ Produces compression (high molecular density and high air pressure) and rarefaction (low molecular density and low air pressure)

➢ Sound waves are longitudinal waves.
Audible sound waves have frequencies between 20 and 20,000 Hz.

- **Less than 20 Hz are infrasonic**
  - Elephants use these to communicate

- **Above 20,000 Hz are ultrasonic**
  - Dogs can hear these
  - Used for ultrasounds (feature imaged has to be greater than the wavelength)
Pitch – how high or low we perceive a sound to be – determined by frequency.
Speed of Sound Waves, General

✓ The speed of sound waves in a medium depends on the compressibility and the density of the medium.
Speed of Sound

✓ Sound travels through solids and liquids and gases at different speeds. See pg. 407
Speed of Sound in Air

✓ The speed of sound also depends on the temperature of the medium

✓ This is particularly important with gases
Shock Wave

✓ The speed of the source can *exceed* the speed of the wave
✓ The envelope of these wave fronts is a cone
Shock Wave

Conical shock front

$S_0$, $S_1$, $S_2$, $S_3$, $S_4$, $S_n$

$v_S t$

$v t$

$v_S t$

$\theta$
The conical wave front produced when \( v_{\text{source}} > v_{\text{sound}} \) is known as a shock wave.

This is supersonic.

✓ jet flyby
Dimensions of sound

✔ Sounds propagate in three dimensions

➢ A small source of sound is assumed to be spherical wave fronts (areas of compression) each one wavelength apart.
3d representation
Shading represents density
wave fronts
rays
At large distances relative to the wavelength, we will assume rays of sound are parallel. (see pg. 407-8)
Doppler Effect

In general, relative motion creates a change in frequency

- Although the source frequency remains constant, the wave fronts are compressed - higher frequency - (when moving toward) and stretched - lower frequency - (when moving away) - see pg. 408

- This is how police radar systems work.
Doppler Effect, Source Moving

https://www.youtube.com/watch?v=eo_owZ2UK7E
http://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::800::600::sites/dl/free/0072482621/78778/Doppler_Nav.swf::Doppler%20Shift%20Interactive
Doppler Rocket
✓ Formative Assessment pg. 409
Sound Intensity

✓ Sound intensity is the rate at which the energy of a sound wave is transferred through a unit area of the plane wave (wave front).

✓ Power (P) is used to define the rate of energy transfer, so

\[ \text{Intensity} = \frac{P}{\text{area}} \ldots \text{which translates for a spherical wave front to be} \]

- Intensity = \( \frac{P}{4\pi r^2} \), where \( r \) is the distance from the source.
- Unit Watts/m\(^2\)
Example 1

✓ What is the intensity of the sound waves produced by a speaker at a distance of 350 cm when the power output of the speaker is 0.80 Watts?

✓ Given: \( P = 0.80 \text{W} \) \( r = 350 \text{cm} = 3.5 \text{m} \)

✓ Unknown: Intensity = ?
✓ Intensity = $P/4\pi r^2$
✓ Intensity = $0.80W/(4\pi(3.5m)^2)$
✓ $I = 5.2\times10^{-3} \text{ W/m}^2$
Example 2. The power output of an explosion is 320 W. At what distance is the intensity of the sound 1.5 x 10^{-3} W/m^2? \[ I = \frac{P}{4\pi r^2} \]

\[ r = \sqrt{\frac{P}{4\pi I}} = \sqrt{\frac{320 \text{ W}}{4\pi (1.5 \times 10^{-3} \text{ W/m}^2)}} = 130 \text{ m} \]
Example 3. How much power is radiated as sound from an alarm that has an intensity of $1.1 \times 10^{-4} \text{ W/m}^2$ at a distance of 12 m? 

$I = \frac{P}{4\pi r^2}$
You are standing 10 m away from a very loud, small speaker. The noise hurts your ears. In order to reduce the intensity to 1/2 its original value, how far away do you need to stand?

\[ I = \frac{P}{4\pi r^2} \]

- (a) 14 m
- (b) 20 m
- (c) 30 m
- (d) 40 m

r is squared in the denominator. What squared is about twice 10 squared?
You are standing 1 m away from a very large wall hanging speaker. The noise hurts your ears. In order to reduce the intensity you walk back to 2 m away. What is the ratio of the new sound intensity to the original?

 Concepts

- (a) 1
- (b) 1/2
- (c) 1/4
- (d) 1/8

\[ I = \frac{P}{4\pi r^2} \]

r is squared in the denominator
Sound Intensity and Frequency

✓ Intensity and frequency determine which sounds are audible.

 See pg. 412
 Decibel level is determined by relating the intensity of a sound wave to the intensity at the threshold of hearing.

 In general, a 10 dB increase is equivalent to doubling the volume.
Homework page 411
Resonance with a pendulum demonstration
Resonance

Every pendulum has a natural frequency that depends on its length.

- Resonance – a condition that exists when the frequency of a force applied to a system matches the natural frequency of vibration of the system.

- Earthquakes and winds can cause resonance. (see page 415)
Consider the following set of pendula all attached to the same string

If I start bob D swinging which of the others will have the largest swing amplitude?

(A)  (B)  (C)
Dramatic example of resonance

✓ In 1940, turbulent winds set up a torsional vibration in the Tacoma Narrow Bridge
✓ when it reached the natural frequency
✓ it collapsed!
Resonance in an Open Tube Lab
Standing waves on Vibrating Strings

✓ Remember...on a rope fixed at both ends, a variety of standing waves can occur (with nodes at each end).

\[ \lambda_1 = 2L \]
\[ \lambda_2 = L \]
\[ \lambda_3 = \frac{2}{3} L \]
Standing waves on Vibrating Strings

✓ $\lambda_1 = 2L$  $\lambda_2 = L$  $\lambda_3 = 2/3 \ L$

➢ Remember: $f = v/\lambda$

➢ Fundamental frequency $= f_1 = v/\lambda_1 = v/2L$

▪ Always the lowest possible frequency
Harmonics on a **Vibrating String or Open Pipe** (pg. 420)

✓ Harmonics \((f_1, f_2 \text{ etc...})\) are integral multiples of the fundamental frequency

> \(\lambda_2 = L \) so \(f_2 = 2f_1\) etc...see pg. 419-20

▪ These frequencies form what is called a harmonic series.

> Formula \(f_n = n \cdot v / 2L\) \(n = 1, 2, 3\ldots\)
Demo
Standing waves and harmonics
Lesson 13-3 Harmonics

Example 1. A violin string that is 60.0 cm long has a fundamental frequency of 480 Hz. What is the speed of the waves on this string?

\[

v = \frac{2Lf}{n} = \frac{2(0.600 \text{ m})(480 \text{ Hz})}{1} = 580 \text{ m/s}

\]
Lesson 13-3 Harmonics

Example 2. What is the fundamental frequency of a 40.0 cm guitar string when the speed of waves on the string is 135 m/s?

\[ f = \frac{\nu n}{2L} = \frac{(135 \text{ m/s})(1)}{2(0.400 \text{ m})} = 169 \text{ Hz} \]
Standing waves on a Closed Pipe (pg. 421)

✓ For a closed pipe (one end), there is a node at the closed end and an antinode at the open end.

- $\lambda_1 = 4L$
- Formula $f_n = n \cdot v / 4L$  $n = 1, 3, 5...$
  - Only odd harmonics...since the second harmonic is 3X the first...so we call it $f_3$ See page 421
Example 3. What is the fundamental frequency of a 0.40 m long organ pipe that is closed at one end, when the speed of sound in the pipe is 354 m/s?

\[ f = \frac{\nu n}{4L} = \frac{(354 \text{ m/s})(1)}{4(0.40 \text{ m})} = 220 \text{ Hz} \]
What are the first three harmonics in a 2.45m long pipe that is open at both ends? What are the first three harmonics of this pipe when one end of the pipe is closed? Use 345m/s for the speed of sound in air.
✓ L=2.45m  v=345m/s
✓ Pipe open $f_1$, $f_2$, $f_3$
✓ Pipe closed $f_1$, $f_3$, $f_5$
✓ Open: $f_n=nv/(2L)$, $n=1,2,3...$
✓ Closed: $f_n=nv/(4L)$, $n=1,3,5...$
Open

\( f_1 = \frac{(1)345}{(2)(2.45m)} = 70.4 \text{Hz} \)

\( f_2 = \frac{(2)345}{(2)(2.45m)} = 141 \text{ Hz} \)

\( f_3 = \frac{(3)345}{(2)(2.45m)} = 211 \text{ Hz} \)
Closed

\[
\begin{align*}
\checkmark f_1 &= \frac{345}{4(2.45 \text{m})} = 35.2 \text{Hz} \\
\checkmark f_3 &= \frac{345}{4(2.45 \text{m})} = 106 \text{ Hz} \\
\checkmark f_5 &= \frac{345}{4(2.45 \text{m})} = 176 \text{ Hz}
\end{align*}
\]
Practice page 423
Harmonics and Timbre

✓ A tuning fork only vibrates at its fundamental frequency...
✓ Other instruments, however, consist of many harmonics, each at different intensities - Called “Timbre”. See pg. 424
With a violin, for example, the intensity of each harmonic
Instruments

✓ From the fundamental frequency, the chromatic (half-step) consists of 12 notes, and the 13\textsuperscript{th} is the frequency of the second harmonic. This constitutes a complete octave.

✓ Beats (alternation between LOUD - \underline{complete constructive interference} - and SOFT - \underline{complete destructive interference}) are heard when two notes are slightly different frequencies.

➤ \textit{This is used to tune an instrument}
The number of beats per second corresponds to the difference between frequencies in Hertz.

- If one frequency is 257 Hz and the other is 265 Hz, you would hear 8 beats per second.
- You cannot tell whether it is 8 beats higher or lower, except by first determining relative pitch.
Timbre and beats
Graphing Beats
✓ Formative Assessment pg. 427
Review