n=9 harmonic for one-end closed air column (9λ/4 = L)

At Antinodes

P = P_{\text{atm}}
Pressure doesn’t change since particle separation stays the same

At Nodes

Pressure does change since particle separation varies over time to be either greater than or less than atmospheric pressure

When we draw standing wave diagrams like the middle diagram, we’re actually drawing the particle displacement, maximum at antinodes, zero at nodes.

www.acs.psu.edu/drussell/Demos/StandingWaves/standing.gif
Sound

Physics 116
2017
Tues. 4/25, Thurs. 4/27
Doppler Effect

• http://lectureonline.cl.msu.edu/~mmp/applist/doppler/d.htm

How can we describe what we observe using mathematics?

What must be constant in this situation, and what changes?

Can we predict how the sound will be heard by a listener if we know how the source is moving?
A train approaches a station at a constant speed, sounding its whistle continuously. Three students are discussing what an observer standing at a station would hear as the train is approaching. **With which, if any, of these students do you agree?**

Anish: "*The train is not accelerating or decelerating. I think the observer will hear a constant pitch that matches the pitch of the whistle.*"

Brooke: "*Even if it isn't accelerating, the observer will hear a higher pitch than the whistle actually emits since the train is moving toward the observer.*"

Cruz: "*I agree with Brooke that the observer will hear a higher pitch, but I think the observer will also hear the frequency increase constantly as the train gets closer and closer.*"

A. Anish  
B. Brooke  
C. Cruz  
D. None of them
A police car with a 600 Hz siren is traveling along the same street as a motorcycle. The velocities of the two vehicles and the distance between them are given in each figure.

Rank the frequency of the siren as measured by the motorcycle rider.

A. C > D > A > B
B. D > B > A > C
C. B = C > A = D
D. B > A > D > C
E. All hear the same frequency.  

*Demo time: Doppler Effect in action!*
Announcements

• Final exam in Pharmacy 111 (William Levin Hall)
  Tuesday 5/9 4 PM – 7 PM

• Pre finals help at the MSLC
  Monday 5/8 10 AM – 6 PM  ARC 326
  Tuesday 5/9 10 AM – 2PM  ARC 326
Spherical Waves

Energy propagates equally in all directions

\[ I = \frac{P}{4r^2} \quad \Rightarrow \quad \frac{I_1}{I_2} = \frac{r_2^2}{r_1^2} \]
Intensity

- Loudness of sound is related to amplitude of the sound wave – maximum displacement of the medium particles.
- All things being equal, larger amplitude means louder sound.
- Intensity (I) of sound is defined as the average power of the wave per unit area.
  \[ I = \frac{P}{4\pi r^2} \] for spherical area
- SI unit of intensity is watts/m² (W/m²).
- The wave traveling in all directions.
**Example**

If at 30 m, the intensity of a sound is 100 W/m², what will the intensity be at 300 m away?

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

\[ I \propto \frac{1}{r^2} \quad \text{OR} \quad I_1 r_1^2 = I_2 r_2^2 \]

\[ I_2 = \frac{(I_1 r_1^2)}{r_2^2} \]

\[ I_2 = \frac{(100 \times 30 \times 30)}{300^2} = 1 \text{ W/m}^2 \]
Intensity

• Louder sound has larger amplitude or larger intensity.

• Perception of loudness by the human ear varies logarithmically with intensity of sound ie, Loudness $\propto \text{Log of Intensity}$.

• The lowest intensity of sound that can be detected by the human ear is called the **threshold of hearing** and is equal to $I_0 = 10^{-12} \text{ W/m}^2$. 
Can you create an index that shows how loud each car system is using only 3 digits?
Decibels

- Sound intensity level ($\beta$) in units of decibels (dB) is defined as the log\textsubscript{10} of the ratio of a sound intensity to the threshold intensity, $I_o$ (where $I_o = 10^{-12}$ W/m\textsuperscript{2}).

$$\beta = (10 \text{dB}) \log_{10}(I/I_o).$$

- 0 dB = threshold of hearing.

- If a sound has intensity of $10^{-5}$ W/m\textsuperscript{2}, its intensity level is

$$\beta = 10 \text{dB} \log_{10}(10^{-5}/10^{-12})$$

$$= 10 \log_{10}(10^7) = 10 \times 7 = 70 \text{ dB}.$$
Logarithms

- \( \log_{10} 1 = \log_{10} 10^0 = 0 \)
- \( \log_{10} 10 = \log_{10} 10^1 = 1 \)
- \( \log_{10} 100 = \log_{10} 10^2 = 2 \)
- \( \log_{10} (a/b) = \log_{10} (a) - \log_{10} (b) \)
  - \( \log_{10} (100/10) = \log_{10} (100) - \log_{10} (10) = 1 \)
- \( \log_{10} (ab) = \log_{10} (a) + \log_{10} (b) \)
  - \( \log_{10} (100*10) = \log_{10} (100) + \log_{10} (10) = 3 \)
Example

• If at 30 m from a source of sound, the intensity of a sound is 100 W/m², what is the sound intensity level at this distance?

\[ \beta = (10\text{dB})\log_{10}(I/I_o). \]

\[ \beta = (10\text{dB})\log_{10}(10^2/10^{-12}). \]

\[ \beta = (10\text{dB})\log_{10}(10^{14}). \]

\[ \beta = 140 \text{ dB} \]
Decibels

If 1 person can shout with loudness 50 dB. How loud will it be when 100 people shout?
1) 52 dB  2) 70 dB  3) 150 dB
Decibels

If 1 person can shout with loudness 50 dB. How loud will it be when 100 people shout?

1) 52 dB  
2) 70 dB  
3) 150 dB

\[ \beta_1 = (10 \text{ dB}) \log_{10}(I_1/I_0) \]

\[ \beta_{100} = (10 \text{ dB}) \log_{10}(I_{100}/I_0) \]

\[ \beta_{100} - \beta_1 = (10 \text{ dB}) \log_{10}(I_{100}/I_1) \]

\[ \beta_{100} = 50 + (10 \text{ dB}) \log_{10}(100/1) \]

\[ \beta_{100} = 50 + 20 \]

Alternatively, you could have asked yourself, “how much more intense is the sound from 100 people compared to 1 person?”
Decibels

If 1 person can shout with loudness 50 dB. How loud will it be when 100 people shout?

1) 52 dB   2) 70 dB   3) 150 dB

$\beta_1 = (10 \text{ dB}) \log_{10}(I_1/I_0)$

$\beta_{100} = (10 \text{ dB}) \log_{10}(I_{100}/I_0)$

$\beta_{100} - \beta_1 = (10 \text{ dB}) \log_{10}(I_{100}/I_1)$

$\beta_{100} = 50 + (10 \text{ dB}) \log_{10}(100/1)$

$\beta_{100} = 50 + 20$

Alternatively, you could have asked yourself, “how much more intense is the sound from 100 people compared to 1 person?”
### Intensity of some common sounds

<table>
<thead>
<tr>
<th>Source</th>
<th>$I/I_0$</th>
<th>dB</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing Threshold</td>
<td>$10^0$</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Normal breathing</td>
<td>$10^1$</td>
<td>10</td>
<td>Barely Audible</td>
</tr>
<tr>
<td>Soft whisper</td>
<td>$10^3$</td>
<td>30</td>
<td>Very quiet</td>
</tr>
<tr>
<td>Normal conversation</td>
<td>$10^6$</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Busy traffic</td>
<td>$10^7$</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Construction noise</td>
<td>$10^{11}$</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Jet takeoff at 60 m, Rock concert</td>
<td>$10^{12}$</td>
<td>120</td>
<td>Pain threshold</td>
</tr>
<tr>
<td>Jet takeoff nearby</td>
<td>$10^{15}$</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Large rocket nearby</td>
<td>$10^{18}$</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Krakatoa Eruption (example volcanic Eruption)</td>
<td>$10^{31}$</td>
<td>310</td>
<td>Ear-shattering. Loudest sound ever recorded.</td>
</tr>
</tbody>
</table>
Intensity

• Recall Intensity = Power/Area. If you are standing 6 meters from a speaker, and you walk towards it until you are 3 meters away, by what factor has the intensity of the sound increased?

A) 2  
B) 4  
C) 8
Intensity

• Recall Intensity = Power/Area. If you are standing 6 meters from a speaker, and you walk towards it until you are 3 meters away, by what factor has the intensity of the sound increased?

A) 2
B) 4
C) 8
**Intensity**

- Recall Intensity = Power/Area. If you are standing 6 meters from a speaker, and you walk towards it until you are 3 meters away, by what factor has the intensity of the sound increased?

\[ \text{Area goes as } d^2 \text{ so if you are } \frac{1}{2} \text{ the distance the intensity will increase by a factor of 4} \]

A) 2  
B) 4  
C) 8