Quiz on Chapters 13-15
Chapter 16

Waves and Sound
continued

Final Exam, Thursday May 3, 8:00 – 10:00PM
ANH 1281 (Anthony Hall). Seat assignments TBD

RCPD students: Thursday May 3, 5:00 – 9:00PM,
BPS 3239. Email will be sent.

Alternate Final Exam, Tuesday May 1, 10:00 – 12:00
PM, BPS 3239; BY APPOINTMENT ONLY, and
deadline has past. Email will be sent.
16.8 **Decibels**

The **decibel** (dB) is a measurement unit used when comparing two sound intensities.

Human hearing mechanism responds to sound **intensity level**, logarithmically.

\[
\beta = (10 \text{ dB}) \log\left(\frac{I}{I_o}\right)
\]

**dB (decibel)**

\[
I_o = 1.00 \times 10^{-12} \text{ W/m}^2
\]

Note that \(\log(1) = 0\)

<table>
<thead>
<tr>
<th>Intensity Level (\beta) (dB)</th>
<th>Intensity (I) (W/m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold of hearing</td>
<td>(1.0 \times 10^{-12})</td>
</tr>
<tr>
<td>Rustling leaves</td>
<td>(1.0 \times 10^{-11})</td>
</tr>
<tr>
<td>Whisper</td>
<td>(1.0 \times 10^{-10})</td>
</tr>
<tr>
<td>Normal conversation (1 meter)</td>
<td>(3.2 \times 10^{-6})</td>
</tr>
<tr>
<td>Inside car in city traffic</td>
<td>(1.0 \times 10^{-4})</td>
</tr>
<tr>
<td>Car without muffler</td>
<td>(1.0 \times 10^{-2})</td>
</tr>
<tr>
<td>Live rock concert</td>
<td>1.0</td>
</tr>
<tr>
<td>Threshold of pain</td>
<td>10</td>
</tr>
</tbody>
</table>
16.8 Decibels

Example 9 Comparing Sound Intensities

Audio system 1 produces a sound intensity level of 90.0 dB, and system 2 produces an intensity level of 93.0 dB. Determine the ratio of intensities.

\[ \beta = (10 \text{ dB}) \log \left( \frac{I}{I_o} \right) \]

\[ 90 \text{ dB} = (10 \text{ dB}) \log \left( \frac{I}{I_o} \right) \]
\[ \log \left( \frac{I}{I_o} \right) = 9; \]
\[ I = I_o \times 10^9 = (1 \times 10^{-12} \text{ W/m}^2) \times 10^9 \]
\[ = 1 \times 10^{-3} \text{ W/m}^2 \]

\[ 93 \text{ dB} = (10 \text{ dB}) \log \left( \frac{I}{I_o} \right) \]
\[ \log \left( \frac{I}{I_o} \right) = 9.3; \]
\[ I = I_o \times 10^{0.3} = (1 \times 10^{-12} \text{ W/m}^2) \times 10^{0.3} \]
\[ = 1 \times 10^{-3.3} \text{ W/m}^2 = 1 \times 10^{-3} (10^{0.3}) \text{ W/m}^2 \]
\[ = 1 \times 10^{-3} (2) \text{ W/m}^2 = 2 \times 10^{-3} \text{ W/m}^2 \]

93 dB = 90 dB + 3 dB

Adding 3 dB results in a factor of 2 increase in the intensity.

\[ 3 \text{ dB} = (10 \text{ dB}) \log \left( \frac{I_2}{I_1} \right) \]
\[ 0.3 = \log \left( \frac{I_2}{I_1} \right); \]
\[ I_2 = 10^{0.3} I_1 = 2I_1 \]
The **Doppler effect** is the change in frequency or pitch of the sound detected by an observer because the sound source and the observer have different velocities with respect to the medium of sound propagation.

**SOURCE (s) MOVING AT** $v_s$ **TOWARD OBSERVER (o)**

$$f_o = f_s \left( \frac{1}{1 - v_s/v} \right)$$

**SOURCE (s) MOVING AT** $v_s$ **AWAY FROM OBSERVER (o)**

$$f_o = f_s \left( \frac{1}{1 + v_s/v} \right)$$
Chapter 17

The Principle of Linear Superposition and Interference Phenomena
17.1 *The Principle of Linear Superposition*

When the pulses merge, the Slinky assumes a shape that is the sum of the shapes of the individual pulses.

(a) Overlap begins

(b) Total overlap; the Slinky has twice the height of either pulse

(c) The receding pulses
17.1 The Principle of Linear Superposition

When the pulses merge, the Slinky assumes a shape that is the sum of the shapes of the individual pulses.
17.1 *The Principle of Linear Superposition*

THE PRINCIPLE OF LINEAR SUPERPOSITION

When two or more waves are present simultaneously at the same place, the resultant disturbance is the sum of the disturbances from the individual waves.
17.2 Constructive and Destructive Interference of Sound Waves

When two waves always meet condensation-to-condensation and rarefaction-to-rarefaction, they are said to be exactly in phase and to exhibit constructive interference.
17.2 Constructive and Destructive Interference of Sound Waves

When two waves always meet condensation-to-rarefaction, they are said to be *exactly out of phase* and to exhibit *destructive interference*.
17.2 Constructive and Destructive Interference of Sound Waves
17.2 Constructive and Destructive Interference of Sound Waves

If the wave patterns do not shift relative to one another as time passes, the sources are said to be **coherent**.

For two wave sources vibrating in phase, a difference in path lengths that is zero or an integer number (1, 2, 3, . . ) of wavelengths leads to constructive interference; a difference in path lengths that is a half-integer number (½, 1 ½, 2 ½, . . ) of wavelengths leads to destructive interference.
Example 1 What Does a Listener Hear?

Two in-phase loudspeakers, A and B, are separated by 3.20 m. A listener is stationed at C, which is 2.40 m in front of speaker B.

Both speakers are playing identical 214-Hz tones, and the speed of sound is 343 m/s.

Does the listener hear a loud sound, or no sound?

Calculate the path length difference.

$$\sqrt{(3.20 \text{ m})^2 + (2.40 \text{ m})^2} - 2.40 \text{ m} = 1.60 \text{ m}$$

Calculate the wavelength.

$$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{214 \text{ Hz}} = 1.60 \text{ m}$$

Because the path length difference is equal to an integer (1) number of wavelengths, there is constructive interference, which means there is a loud sound.
Conceptual Example 2  Out-Of-Phase Speakers

To make a speaker operate, two wires must be connected between the speaker and the amplifier. To ensure that the diaphragms of the two speakers vibrate in phase, it is necessary to make these connections in exactly the same way. If the wires for one speaker are not connected just as they are for the other, the diaphragms will vibrate out of phase. Suppose in the figures (next slide), the connections are made so that the speaker diaphragms vibrate out of phase, everything else remaining the same. In each case, what kind of interference would result in the overlap point?
17.2 **Constructive and Destructive Interference of Sound Waves**

![Diagram of Constructive and Destructive Interference]

**Constructive interference**

- Two waves of same frequency and amplitude interfere to produce a wave of larger amplitude.
- Graphically, it's represented by the superposition of two waves of the same amplitude and phase, resulting in a wave of twice the amplitude.

**Destructive interference**

- Two waves of same frequency and amplitude interfere to produce a wave of smaller amplitude.
- Graphically, it's represented by the superposition of two waves of the same amplitude and phase, resulting in a wave of zero amplitude at certain points.
17.3 Diffraction

The bending of a wave around an obstacle or the edges of an opening is called *diffraction*.

(a) With diffraction

(b) Without diffraction
17.3 Diffraction

single slit – first minimum

\[ \sin \theta = \frac{\lambda}{D} \]
Circular opening – first minimum

\[ \sin \theta = 1.22 \frac{\lambda}{D} \]
Two overlapping waves with *slightly different frequencies* gives rise to the phenomena of beats.
17.4 Beats

The **beat frequency** is the **difference** between the two sound frequencies.
17.5 Transverse Standing Waves

Transverse standing wave patterns.

(a) Image of a transverse standing wave pattern.

(b) Image showing nodes and antinodes.

(c) Image illustrating a different pattern with nodes marked.

Frequency $= f_1$

- 1st harmonic (fundamental)
- 2nd harmonic (1st overtone)
- 3rd harmonic (2nd overtone)
In reflecting from the wall, a forward-traveling half-cycle becomes a backward-traveling half-cycle that is inverted.

Unless the timing is right, the newly formed and reflected cycles tend to offset one another.

Repeated reinforcement between newly created and reflected cycles causes a large amplitude standing wave to develop.
17.5 Transverse Standing Waves

String fixed at both ends

\[ f_n = n \left( \frac{v}{2L} \right) \quad n = 1, 2, 3, 4, \ldots \]
17.6 Longitudinal Standing Waves

**Tube open at both ends**

\[ f_n = n \left( \frac{v}{2L} \right) \]

\[ n = 1, 2, 3, 4, \ldots \]
**Example 6** Playing a Flute

When all the holes are closed on one type of flute, the lowest note it can sound is middle C (261.6 Hz). If the speed of sound is 343 m/s, and the flute is assumed to be a cylinder open at both ends, determine the distance $L$.

$$f_n = n \left( \frac{v}{2L} \right) \quad n = 1, 2, 3, 4, \ldots$$

$$L = \frac{nv}{2f_n} = \frac{1(343 \text{ m/s})}{2(261.6 \text{ Hz})} = 0.656 \text{ m}$$
17.6 *Longitudinal Standing Waves*

*Tube open at one end*

\[ f_n = n \left( \frac{v}{4L} \right) \]

\( n = 1, 3, 5, \ldots \)
17.7 Complex Sound Waves

Complex pressure pattern

Air pressure vs. Time

Spectrum analyzer

Amplitude vs. Harmonic number

1 2 3

Amplitude vs. Harmonic number

1 2 3