### Physic 231 Lecture 35

<table>
<thead>
<tr>
<th>Main points of last lecture:</th>
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<tr>
<td>Waves</td>
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<tr>
<td>- transverse</td>
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<tr>
<td>- longitudinal</td>
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<td>traveling waves</td>
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<tr>
<td>( v_{\text{wave}} = f\lambda )</td>
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<td>Wave speed for a string</td>
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<td>( v = \sqrt{\frac{F}{\mu}} )</td>
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<td>Superposition and interference of waves; wave forms interfere.</td>
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<td>Reflection of waves.</td>
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<table>
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<tr>
<th>Main points of today’s lecture:</th>
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<td>Sound waves:</td>
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<td>Sound intensity:</td>
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<td>( \beta = 10\log_{10}\left( \frac{I}{I_0} \right) )</td>
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<tr>
<td>( I = \frac{P}{4\pi r^2} )</td>
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<tr>
<td>Dopper shift:</td>
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<tr>
<td>( f' = f \left( \frac{v + v_o}{v - v_s} \right) )</td>
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Final Exam

- A common final exam time is scheduled for all sections of Physics 231
- Time: 8:00-10:00 PM, Tues., Dec. 12
- Each section has a different exam location.
- Location for Section 1: Wells Hall B106

- An alternate exam time has been scheduled for students who have conflicts with the regular time.
  - Three students have confirmed conflicts with me and will take the exam then.
  - You must have permission from me to take the exam at the alternate time.
- Alternate time: 7:45-9:45 AM, Monday, Dec. 11
- Location: BPS 1415 (this room)
Conceptual question

- A wave pulse is moving, as illustrated, with uniform speed $v$ along a rope. Which of the graphs 1–4 below correctly shows the relation between the displacement $s$ of point $P$ and time $t$?
Sound amplitude and intensity

- The amplitude of the sound wave is proportional to the maximum velocity of the air as it moves from the high pressure to the low pressure domains.
- The energy and the power of the sound wave is proportional to the square of amplitude:
  \[ \langle E \rangle \propto \frac{1}{2} \rho v^2 \propto \text{Amplitude}^2 \propto v_{\text{max}}^2 \propto p^2 \propto x_{\text{max}}^2 \]
- More useful than the energy of a sound wave is the intensity, I, which is the power P that the sound wave transmits per unit area.
- The ear responds logarithmically to the intensity of sound waves striking the eardrum.
  - I_{\text{threshold}} = I_0 \approx 10^{-12} \text{ W/m}^2, I_{\text{pain}} \approx 1 \text{ W/m}^2
- This logarithmic behavior motivates the decibel measure of sound wave intensity.
  - \( \beta = 10 \log_{10}(I/I_0) \)
ALEXANDER GRAHAM BELL, MAKING THE FIRST CALL FROM NEW YORK TO CHICAGO GETS A WRONG NUMBER
**Example**

- The intensity level of sound A is 5.0 dB greater than that of sound B and 3.0 dB less than that of sound C. a) Determine the ratio \( \frac{I_C}{I_B} \) of the intensity of sound C to the intensity of sound B. b) Determine the ratio of the amplitudes \( \frac{p_C}{p_B} \) of the modulation in pressure caused by the sound wave.

\[ a) \quad \beta = 10 \log_{10} \left( \frac{I}{I_0} \right) \]

\[ \beta_A - \beta_B = 10 \log_{10} \left( \frac{I_A}{I_0} \right) - 10 \log_{10} \left( \frac{I_A}{I_0} \right) = 10 \log_{10} \left( \frac{I_A}{I_B} \right) = 5 \]

\[ \beta_A - \beta_C = 10 \log_{10} \left( \frac{I_A}{I_C} \right) = -3 \]

\[ \beta_C - \beta_B = 10 \log_{10} \left( \frac{I_C}{I_B} \right) = (\beta_A - \beta_B) - (\beta_A - \beta_C) = 5 - (-3) = 8 \]

\[ \Rightarrow \log_{10} \left( \frac{I_C}{I_B} \right) = 0.8 \Rightarrow \frac{I_C}{I_B} = 10^{0.8} = 6.3 \]

\[ \frac{p_C}{p_B} = \left( \frac{I_C}{I_B} \right)^{1/2} = 2.5 \]
Propagation of spherical and plane waves.

• If one vibrates as piston in a tube of cross-sectional area $A$, the sound waves travel down the tube in a straight line, like a wave on a string.

• The sound wave power $P$ crossing point $B$ and point $C$ per unit time are the same.

• Since the area $A$ of the tube is constant, the intensity $I = \frac{P}{A}$ is the same at both points.

• If one suspends non-directional sound source with power $P$ in air, the sound will radiate in all directions. All points on a sphere of radius $r$ will see the same sound intensity:

$$I = \frac{P}{4\pi r^2}$$
Example

When a helicopter is hovering 1100 m directly overhead, an observer on the ground measures a sound intensity $I$. Assume that sound is radiated uniformly as a spherical wave from the helicopter and that ground reflections are negligible. How far must the helicopter fly in a straight line parallel to the ground before the observer measures a sound intensity of $1/5$?

\[
\frac{I_f}{I_0} = 1/5
\]

\[
I_f = \frac{P}{4\pi r_f^2}, \quad I_0 = \frac{P}{4\pi r_0^2}
\]

\[
\Rightarrow r_f^2 = h^2 + d^2 = 5r_0^2 = 5h^2
\]

\[
\Rightarrow d^2 = 4h^2 \Rightarrow d = 2h = 2200m
\]
A wave is sent along a long spring by moving the left end rapidly to the right and keeping it there. The figure shows the wave pulse at $QR$—part $RS$ of the long spring is as yet undisturbed. Which of the graphs 1–5 correctly shows the relation between displacement $s$ and position $x$? (Displacements to the right are positive.)
Doppler effect for moving observer

- An observer is moving toward a stationary source
- Due to his movement, the observer detects an additional number of wave fronts
- The frequency heard is increased

- An observer is moving away from a stationary source
- The observer detects fewer wave fronts per second
- The frequency appears lower
Doppler Effect, Source in Motion – general formula

\[ f' = f \left( \frac{v + v_o}{v - v_s} \right) \]

- Both the source and the observer could be moving
- Use positive values of \( v_o \) and \( v_s \) when the motion is toward
  - Frequency appears higher
- Use negative values of \( v_o \) and \( v_s \) when the motion is away
  - Frequency appears lower

- As the source moves toward the observer (A), the wavelength appears shorter and the frequency increases
- As the source moves away from the observer (B), the wavelength appears longer and the frequency appears to be lower
Example

- A train at rest emits a sound at a frequency of 1000 Hz. An observer in a car travels away from the sound source at a speed of 30.0 m/s. What is the frequency heard by the observer? (assume \( v_s = 343 \) m/s)
  - a) 513 Hz
  - b) 713 Hz
  - c) 913 Hz
  - d) 1013 Hz
  - e) 1113 Hz

\[
\begin{align*}
\nu_s &= 0, \quad \nu_o = -30m/s \\
f' &= \left(\frac{\nu + \nu_o}{\nu}\right) f = \frac{313}{343} 1000Hz = 913Hz
\end{align*}
\]
Conceptual quiz

Three observers, A, B, and C are listening to a moving source of sound. The diagram below shows the location of the wavecrests of the moving source with respect to the three observers. Which of the following is true?

- a. The wavefronts move faster at A than at B and C.
- b. The wavefronts move faster at C than at A and B.
- c. The frequency of the sound is highest at A.
- d. The frequency of the sound is highest at B.
- e. The frequency of the sound is highest at C.
Example

- Two trucks travel at the same speed. They are far apart on adjacent lanes and approach each other essentially head-on. One driver hears the horn of the other truck at a frequency that is 1.2 times the frequency he would hear if the trucks were stationary. The speed of sound is 343 m/s. At what speed is each truck moving?

\[ \text{givens: } \frac{f'}{f} = 1.2, \quad v_s = v_o = v'' \]

\[ f' = \frac{(v+v_o)}{(v-v_s)} \quad f = \frac{(v+v'')}{(v-v'')} \]

\[ \Rightarrow \frac{f''}{f} = 1.2 = \frac{(v+v'')}{(v-v'')} \]

\[ \Rightarrow \text{ans. } v'' = 31 m/s \]