Sound

Speed, Energy, Intensity
Course Announcements

The second midterm exam will be
Thursday November 14th from 10:00 - 11:20 p.m. in ARC 103

The exam will be multiple choice.
You may bring an 8 1/2” x 11” hand-written sheet with information and formula (both sids may be used). You should also bring a calculator.
No cell phones are allowed during the exam.

The exam will cover chapters 9 - 13 in the textbook with specific sections listed in the Syllabus.
Material on the exam may come from the textbook, the workshops, the homework and the Lectures.

A practice exam has been posted on the course website.
A string has a linear mass density $\mu$ at $x < 0$ but $4\mu$ at $x > 0$. Tension $T$ is the same for all $x$. A wave of frequency $f$ and wavelength $\lambda$ is traveling from negative $x$ towards positive $x$. When the wave moves into the positive $x$ region, how will the wavelength $\lambda$ change?

a) $\lambda$
b) $4\lambda$
c) $2\lambda$
d) $\lambda/4$
e) $\lambda/2$

As a wave travels from one medium to another, its frequency does not change.

(Practice Exam)
In a typical ultrasound scan, the waves travel through body tissue with a speed of 1500 m/s. For a good detailed image, the wavelength should be no more than 1.0 mm. What frequency of sound is required for a good scan?

a) 1,500,000 rads/sec  
b) 1,500,000 Hz  
c) 15,000,000 Hz  
d) 1,500,000 sec  
e) 1,500,000 rpm
Question (Today’s Material)

The following is an example of an infrasonic wave:

a) A bird singing
b) Thunder
c) An earthquake
d) A high-pitched whistle
e) The roar of a lion
Question (Today’s Material)

The intensity level of sound is measured in

a) Watts/meter  
   b) Decibels  
   c) Beats/sec  
   d) Hertz  
   e) Dopplers
Question (Review for Exam)

When the mass in a spring-mass system is doubled but the maximum displacement is not changed, what will be the total energy? Let $E_0$ be the original total energy.

a) $E_0/2$
b) $E_0/4$
c) $2E_0$
d) $E_0$
e) $4E_0$

(Practice Exam)
Sound waves are **longitudinal** waves generated by vibrations in a medium, such as air or water.
Frequency Range of sound waves

There are three frequency ranges of sound wave.

**Audible: (to humans)**
Longitudinal waves that lie within the range of sensitivity of the human ear, approximately 20 to 20,000 Hz.

**Infrasonic: (audible to elephants and whales)**
Longitudinal waves with frequencies below the range of sensitivity of the human ear (below ~ 20 Hz).

**Ultrasonic: (audible to bats)**
Longitudinal waves with frequencies above the range of sensitivity of the human ear (above ~ 20,000 Hz).
Speed of sound

In general, the speed of sound is of the form:

\[ v = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}} \]

Recall transverse waves on a string:

\[ v = \sqrt{\frac{F_T}{\mu}} \]

In general for gas:

\[ v = \sqrt{\frac{B}{\rho}} \]

Speed of sound in a gas depends on the temperature:

\[ v = v_0 \sqrt{\frac{T}{273 \text{ K}}} \]

\[ v_0 = 331 \text{ m/s for air} \]
Question

Which of the following will increase the speed of sound in air?

a) Decreasing the air temperature
b) Increasing the frequency of the sound
c) Increasing the air temperature
d) Increasing the amplitude of the sound wave
e) Reducing the pressure of the air
A sound wave of \(343\,\text{Hz}\) is incident on the surface of water and is transmitted from air into the water. What is the wavelength of the transmitted sound in water?

\[
V_{\text{sound in water}} = 1493\,\text{m/s}
\]

\[
V_{\text{sound in air}} = 331\,\text{m/s}
\]

a) 1 m.
b) about 5 m.
c) about 0.2 m.
d) 2 m.
e) 10 m.
Energy and Intensity of Sound Waves

\[ I \equiv \frac{1}{A} \frac{\Delta E}{\Delta t} \quad (W/m^2) \]

Average Intensity \( I \) = Rate at which energy flows through the surface divided by the surface area

\[ I \equiv \frac{\text{Power}}{\text{Area}} = \frac{P}{A} \]
Spherical waves

An oscillating point source generates a spherical wave (in all directions).

Intensity of a spherical wave at distance $r$ from the source

$$I = \frac{P_{\text{ave}}}{4\pi r^2}$$

Relative intensity of two wave fronts for the same central point source.

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$
Relative Intensity and decibels

Relative intensity (intensity level):
The intensity of a sound wave, relative to the intensity at the threshold of hearing, $I_0$.

$$\beta = 10 \log \left( \frac{I}{I_0} \right)$$

$I_0 = 1.0 \times 10^{-12} \text{ W/m}^2$

Relative intensity is measured in **decibels (dB)**.

Do not confuse relative intensity with intensity!

**PAIN THRESHOLD AT 120 dB.**

<table>
<thead>
<tr>
<th><strong>Source of Sound</strong></th>
<th><strong>$\beta$ (dB)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearby jet airplane</td>
<td>150</td>
</tr>
<tr>
<td>Jackhammer, machine gun</td>
<td>130</td>
</tr>
<tr>
<td>Siren, rock concert</td>
<td>120</td>
</tr>
<tr>
<td>Subway, power mower</td>
<td>100</td>
</tr>
<tr>
<td>Busy traffic</td>
<td>80</td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td>70</td>
</tr>
<tr>
<td>Normal conversation</td>
<td>50</td>
</tr>
<tr>
<td>Mosquito buzzing</td>
<td>40</td>
</tr>
<tr>
<td>Whisper</td>
<td>30</td>
</tr>
<tr>
<td>Rustling leaves</td>
<td>10</td>
</tr>
<tr>
<td>Threshold of hearing</td>
<td>0</td>
</tr>
</tbody>
</table>
Quick Review of Logarithms

\[ x = 10^y \rightarrow y = \log_{10} x \]

\[ \log(ab) = \log a + \log b \]

\[ \log(a/b) = \log a - \log b \]

\[ \log(a^n) = n \log a \]
Question

Suppose a jet testing its engines produces a sound intensity of \( I = 0.750 \text{ W/m}^2 \) at a given location in an airplane hangar. What decibel level corresponds to this sound intensity?

a) 100 dB
b) 123 dB
c) 119 dB
d) 157 dB
e) 92 dB
A collection of four identical machines creates a decibel level of $\beta = 87.0 \text{ dB}$ in a machine shop. What sound intensity would be created by only one such machine?

a) $5.01 \times 10^{-4} \text{ W/m}^2$
b) $1.25 \times 10^{-5} \text{ W/m}^2$
c) $1.25 \times 10^{-4} \text{ W/m}^2$
d) $6.23 \times 10^{-4} \text{ W/m}^2$
e) $5.01 \times 10^{-5} \text{ W/m}^2$
The intensity level of sound at a distance of 4 m away from a source is 40 dB. What is the intensity level of sound at a distance of 1 m from the source?

a) 40 dB.
b) 160 dB.
c) 80 dB.
d) 52 dB.
e) 48 dB.

Note:
\[
\log 16 = 1.2 \\
\log(a \times b) = \log(a) + \log(b) \\
\log(a/b) = \log(a) - \log(b)
\]
A drum reaches a sound intensity level of 95 decibel if you are 4.0 meters away from it. What is the intensity level of two of the same drums together as heard by a listener at 8.0 meter?

a) 92 dB  
b) 95 dB  
c) 101 dB  
d) 98 dB  
e) 89 dB
Let the mechanical energy of a harmonic oscillator be $E_0$ and the maximum displacement be $x_0$. When the displacement is $x_0/2$, what is the kinetic energy?

a) $E_0/2$
b) $E_0/4$
c) $3E_0/4$
d) $E_0$
e) $E_0/8$

(Practice Exam)
A gasoline engine with an efficiency of 33.1% operates between a high temperature $T_1$ and a low temperature $T_2 = 350 \, \text{K}$. If this engine operates with the ideal efficiency of a heat engine, what is the high-side temperature $T_1$?

a) 1057 K  

b) 782 K  

c) 1169 K  

d) 523  

e) 434