INDIANA UNIVERSITY, DEPT. OF PHYSICS
P105, Basic Physics of Sound, Spring 2006

Midterm Exam #1
Thursday, 09 Feb. 2006, 7:30 – 9:30 p.m.
Closed book. You are allowed a calculator
There is a Formula Sheet at the back of the exam
Fill in the answers on the exam sheets themselves. If you run out of room, use the back
of the sheets. In some cases I give partial credit – try not to leave blank answers

1. (4 pts) What is sound, and what is the science of sound called? How is sound
   produced?
   Sound is a longitudinal wave of alternating
   compression and rarefaction (higher pressure / lower pressure).
   Science of sound is called acoustics.
   Sound is produced where a vibrating body or
   source excited a sound wave in some medium
   touching the body.

2. (2 pts) The phenomena where a wave changes direction due to a change of velocity of
   travel in the medium is called ________refraction________.

3. (2 pts) Waves propagate at a speed of $v = 8.0 \text{ m/s}$ along a stretched string. The end of
   the string is vibrated up and down (i.e., one cycle) once every 1.5 s. What is the
   wavelength, $\lambda$, of the waves that travel along the string?

   (a) 1.5 m;
   (b) 3.0 m;
   (c) 12.0 m;
   (d) 6.0 m;
   (e) 5.33 m.

   $\begin{align*}
   T &= 1.5 \text{ s}, \quad f = \frac{1}{T} \\
   &= \frac{1}{1.5} \text{ s} \\
   f &= 0.67 \text{ Hz} \\
   \lambda &= \frac{v}{f} = \frac{8 \text{ m/s}}{0.67 \text{ Hz}} \\
   \lambda &= 12.0 \text{ m}
   \end{align*}$
4. A string is supported at two ends with a length of \( L = 15 \text{ cm} \).

(a) (2 pts) Sketch below how the fourth harmonic, \( f_4 \), wave or standing wave pattern would appear.

(b) (2 pts) What is the wavelength in meters of this oscillation?

\[
2 \lambda_4 = L, \quad \lambda_4 = \frac{L}{2} = \frac{0.15 \text{ m}}{2} = 0.075 \text{ m}
\]

(c) (2 pts) If the frequency of standing wave pattern shown is \( f_4 = 600 \text{ Hz} \), what is the fundamental frequency, \( f_1 \), of this same string?

\[
f_1 = \frac{f_4}{4} \quad \text{and} \quad f_1 = \frac{600 \text{ Hz}}{4} = 150 \text{ Hz}
\]

(d) (2 pts) What is the speed of propagation in the string?

\[
V = f_4 \lambda_4 = (600 \text{ Hz})(0.075 \text{ m}) = 45 \text{ m/s}
\]

(d) (3 pts) If the tension of the string is 20 N, what is the mass of the string?

\[
\mu = \frac{f_1^2}{2L} \quad \text{and} \quad \mu = \frac{1}{4L^2} \frac{\mu_0}{\mu}
\]

\[
\mu = \frac{1}{4L^2} \frac{20 \text{ N}}{(150 \text{ Hz})^2}
\]

\[
\mu = 0.0099 \text{ kg/m}
\]

\[
\mu = \frac{m \mu_0}{L}, \quad m = \mu_0 L
\]

\[
\mu = (0.0099 \text{ kg/m})(0.15 \text{ m}) = 0.0015 \text{ kg}
\]

\[
m = 1.5 \text{ g}
\]
5. (4 pts) Two different tones of frequency 560 Hz and 564 Hz are sounded simultaneously with the same amplitude. Describe what you would hear qualitatively and quantitatively, and sketch the resulting sound wave below.

\[ f_{\text{beat}} = \frac{|f_A - f_B|}{2} = \frac{560 \text{ Hz} - 564 \text{ Hz}}{2} = 4 \text{ Hz} \]

\[ f = \frac{560 \text{ Hz} + 564 \text{ Hz}}{2} = 562 \text{ Hz} \]

A tone of 562 Hz varying in amplitude at the frequency of \( f_{\text{beat}} = 4 \text{ Hz} \).

Note: it is not necessarily to sketch all the cycles of the high frequency signal precisely; just give a qualitative sketch.

6. The plot below shows the position versus time plot of a person walking in a straight line.

(i) (2 pts) During a part of their motion, their velocity is negative. The velocity during this time interval is:

- (a) -0.50 m/s;
- (b) -0.66 m/s;
- (c) -0.83 m/s;
- (d) -1.20 m/s;
- (e) -1.50 m/s.

\[ v = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i} = \frac{-2 \text{ m}}{3 \text{ s}} = -\frac{2}{3} \text{ m/s} = -0.66 \text{ m/s} \]

(ii) (2 pts) Over what time range is the person at rest (not moving/walking)? (fill in) \( t = 3 \text{ s} \) to \( t = 7 \text{ s} \).

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7. A partially open window presents an opening 20 cm wide.

(a) (1 pts) What kind of sounds from outside will go across the room in a well-defined beam?  
(circle one): (i) High frequencies  (ii) Low frequencies.

(b) (2 pts) Roughly what frequency marks the boundary between the two?  
($v_{\text{sound}} = 343 \text{ m/s}$)  
\[
\frac{1715}{\text{Hz.}} \quad \lambda \approx \frac{v}{f} = \frac{343 \text{ m/s}}{0.20 \text{ m}} \quad \lambda \approx 0.20 \text{ m} \\
\]

(c) (2 pts) With all other things being equal, what instrument is easier to hear around a corner, a flute or a tuba, and why?

Tuba. With typical frequencies lower than a flute, its longer wavelengths undergo more refraction around corners.

8. (3 pts) The effective area of the eardrum is estimated to be 0.55 cm$^2$. A typical sound wave exerts a perpendicular force of $5.5 \times 10^{-7}$ N on the eardrum. What is this as a pressure in Pascals [Pa]?

\[
P = \frac{F}{A} = \frac{5.5 \times 10^{-7} \text{ N}}{0.55 \times 10^{-5} \text{ m}^2} = 0.01 \text{ Pa}
\]

9. Marco Killingsworth raises a basketball with a mass of 1.0 kg a vertical height of 2.5 m to dunk over an opposing player.

(a) (2 pts) What potential energy has the ball gained? (take $g = 9.8 \text{ m/s}^2$).

N/A

(b) (2 pts) If Marco does this action over a time period of 0.5 sec, what power does he expend in Watts to just lift the ball?

N/A

(c) (2 pts) If he runs back to play defense at a velocity of 6.0 m/s and has a hefty mass of 110 kg, what is his kinetic energy?

N/A
10. (4 pts) While driving you see an ambulance racing up behind you at a velocity of 100 km/hr. You know that when it is stationary, the frequency of the siren is 1000 Hz.

What frequency of the siren do you hear, and what is this effect called? (Take $v_{\text{sound}} = 343$ m/s).

\[
\frac{100 \text{ km}}{\text{hr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ hr}}{3600 \text{s}} = 27.8 \text{ m/s}.
\]

\[
f_{\text{obs}} = f_s \left( \frac{v_s}{v_s - v_s} \right) = 1000 \text{ Hz} \left( \frac{343 \text{ m/s}}{343 \text{ m/s} - 27.8 \text{ m/s}} \right)
\]

\[
f_{\text{obs}} = 1088 \text{ Hz}
\]

Effect called Doppler Effect.

11. The graph below shows the position ($y$) versus time ($t$) plot of our familiar mass on a large spring that we encountered in lecture. The string is pulled and released to give the indicated amplitude (from equilibrium position).

(a) (2 pts) What is the period and frequency of oscillation?

\[
T = \frac{2\pi}{f} = \frac{1}{2s} = 0.5 \text{ Hz}
\]

(b) (3 pts) If the mass is $m = 2.0$ kg, what is the spring constant, $K$ in N/m?

\[
f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}, \quad f^2 = \frac{1}{4\pi^2} \frac{k}{m}, \quad k = (f^2) \left( \frac{4\pi^2}{m} \right)_m = (0.5 \text{ Hz})^2 \left( \frac{4\pi^2}{m} \right) = 19.7 \text{ N/m}.
\]

(c) (3 pts) What is the maximum potential energy, PE, stored in the spring during the motion, and at what times does it occur?

\[\text{N/A}\]

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(d) (2 pts) If I wanted to double the frequency of oscillation, by what factor would I change the spring constant by? Would the spring be stiffer or weaker?

Increase $k$ by a factor of 4

Spring would be stiffer

12. (3 pts) How long does it take a sound wave to travel a distance of $d = 1.0$ km in air

(a) at a temperature of $20^\circ$ C?

$\frac{d}{v} = \frac{t}{v} = \frac{1000 \text{ m}}{331.3 \text{ m/s}} = 2.91 \text{ s}$

(b) at a temperature of $10^\circ$ C?

$v = 331.3 \text{ m/s} + 0.6t$

$= 331.3 \text{ m/s} + (0.6)(10^\circ)\text{C}$

$= \frac{1000 \text{ m}}{397.3 \text{ m/s}}$

$t = 2.97 \text{ s}$

13. In the arrangement below, both speakers emit a sound of frequency $f = 1372$ Hz. The distance from Speaker 1 to an observer at point $P$ is $d_1 = 16.0$ m, and the distance from Speaker 2 to the observer is $d_2 = 16.5$ m.

![Diagram of two speakers with distances]

(a) (2 pts) What is the wavelength of the sound? ($v_{\text{sound}} = 343 \text{ m/s}$).

$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{1372 \text{ Hz}} = 0.25 \text{ m}$

(b) (3 pts) At point $P$ is there constructive or destructive interference? Show your reason/justification.

$|d_1 - d_2| = |16.0 \text{ m} - 16.5 \text{ m}| = 0.5 \text{ m} = (2) \lambda$

$|d_1 - d_2| = n \lambda \Rightarrow \text{ Constructive interference}$

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