P105 Basic Physics of Sound
Indiana University, Spring 2009
Exam #1
February 16, 2009

Instructions:
1. Please do not start the exam until instructed!

2. Print your Name and ID# and sign your NAME at the top of this page.

3. Calculators are allowed. No books or notes are allowed. Please leave your course materials at the rear of the room.

4. The exam consists of 5 Questions (8 points each for 40 points) and 4 Problems (15 points each for 60 points), for a total of 100 points. Please budget your time with these values in mind.

5. The last page contains Equations, Conversion Factors, and Constants. You may gently tear off this last page for use during the test.

6. If you have any questions or if you need extra paper, please raise your hand.

7. At the end of the exam please turn in your test paper at the front of the room.

8. Please keep your work covered and your eyes on your own paper during the exam. The penalty for cheating is an automatic zero.

9. Good luck!

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<thead>
<tr>
<th>#</th>
<th>Max</th>
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<tbody>
<tr>
<td>Q1</td>
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Total 100
I. Questions: 40 points (Where indicated show work with units to receive credit.)

Q1. Sound refers either to an auditory sensation in the ear or to the disturbance in air that causes this sensation. Its waves are _______________ vibrations of air molecules that carry _______________ from one point in space to another. Sound waves passing through an aperture will spread out due to _______________. The effect heard when two pure tones with a very small frequency difference (< 10 Hz) are sounded simultaneously is known as ________.

Q2. Describe in your own words what “resonance” is.

Q3. Steel has a density of about 7700 kg/m$^3$. What is it in units of g/cm$^3$? (Show your work to receive credit.) __________________

Q4. A sound wave passing through air produces the pressure variation $\Delta p$ with time $t$ (as measured at a particular point in space) that is illustrated below.

(a) The amplitude of the oscillation in micropascals = __________________.

(b) The period of the oscillation in milliseconds = __________________.

(c) The frequency of the oscillation in Hertz = __________________.

Q5. True or False:
(a) Sound waves can be focused by reflection from a curved surface. T or F
(b) The phenomenon of "beats" is an interference effect. T or F
(c) Increasing a string's tension will increase the wavelength of its vibrations. T or F
(d) The reflections of waves impinging upon a fixed end of a string are inverted relative to the incident waves. T or F
II. Problems: 60 points (Show your work to receive full credit. Answers must have units.)

P1. A stretched string of length 1.60 m, fixed at both ends, is vibrating in its 4th normal mode (where the fundamental is the 1st mode). The total mass of the string is 0.00120 kg, and the frequency of oscillation in this mode is 720 Hz.

(a) Sketch the shape of the string at a time when it is at its maximum distortion.

(b) What is the wavelength of this standing wave?

(c) What is the tension of the string, in Newtons?

P2. It is well known that male zebra finches sing a very highly rehearsed song to attract females. The primary frequency of this song is at about 3,000 Hz. It is not known what criteria are used by the female birds to accept a particular male, but let’s suppose that they only accept males whose songs are at a frequency of less than 3.200 kHz. For this problem use \( v = 343.1 \text{ m/s} \) for the speed of sound in air.

(a) Suppose a particular male zebra finch has perfect pitch and can sing songs with a primary frequency of 3.000 kHz exactly. If this bird is flying toward a stationary female with a velocity of 22.00 m/s while singing, will the female be attracted or not? Explain why or why not.

(b) What about for the case where the male bird in (a) is stationary, but the female bird is moving toward the male bird with a velocity of 22.00 m/s?
P3. An air-filled pipe open at both ends has a length of 0.80 m. The temperature is 20°C, so the speed of sound is 343 m/s.

(a) What is the frequency of the fundamental standing wave in this pipe?

(b) If one end of the pipe is closed, what is the new fundamental frequency?

(c) For this closed pipe, what is the frequency of the next highest resonant mode?

P4. A block of mass \( m = 3.0 \text{ kg} \) is lying on a frictionless surface, and is attached to the wall by a spring with spring constant \( k = 972 \text{ N/m} \). Initially it is stationary at a distance of 1.0 m from the wall where the spring is neither stretched nor compressed.

(a) A young child pulls the block away from the wall an additional 12 cm, and then releases it. What is the closest that the block will come to the wall?

(b) How much time will elapse between when the block is released and when the block reaches its point of closest approach to the wall?

(c) Suppose the child pulls the block instead by 24 cm before letting go. Will the time elapsed between the release of the block and when it reaches its point of closest approach to the wall be longer, shorter, or the same as in part (b)? Explain your answer.
Equations

Motion: speed \( v = \frac{\Delta x}{\Delta t} \); for motion with constant speed \( v \), the distance \( d = v \times t \)
acceleration \( a = \frac{\Delta v}{\Delta t} \); for motion with constant \( a \), \( v = a \times t \)

Newton’s 2nd Law: \( F_{\text{net}} = ma \); Weight: \( w = mg \); Force due to spring: \( F_{\text{spr}} = -kx \)

Energy: kinetic energy \( KE = \frac{1}{2}mv^2 \); potential energy \( PE_{\text{grav}} = mgh \) & \( PE_{\text{spr}} = \frac{1}{2}kx^2 \)
Work and Energy: Work = Force \( \times \) distance; \( W = Fd \); Work done = \( \Delta KE \); \( \Delta PE = -(W_{\text{done by force}}) \)
Conserv’n of energy: \( KE + PE = \text{constant} = E_{\text{total}} \), for dropped mass = \( \frac{1}{2}m(v_{\text{bot}})^2 = mgh_{\text{top}} \)

Periodic motion: frequency \( f \) (Hz); period \( T \) (s); \( f = \frac{1}{T} \); amplitude \( A \); \( PE_{\text{max}} = \frac{1}{2}kA^2 \)
Mass on spring: \( F_{\text{sp}} = -kx \), \( f = \frac{1}{2\pi}\sqrt{\frac{k}{\mu}} \); Pendulum: \( f = \frac{1}{2\pi}\sqrt{\frac{g}{l}} \)

Relations involving \( v \), the wave speed:
- wave relation: \( v = \lambda \times f \)
- sound wave in air: \( v = (331.3 + 0.6 \ t_{\circ \text{C}}) \text{ m/s} \) -> at \( 20^\circ \text{C} \) \( v = 343.3 \text{ m/s} \)
- wave on a string: \( v = \sqrt{T/\mu} \), \( T \) is string tension [N] and \( \mu \) is mass/length [kg/m]

Wave propagation: reflection (\( \theta_{\text{inc}} = \theta_{\text{refl}} \)); refraction (speed varies); diffraction (size~\( \lambda \))

Wave interference due to path length difference, \( (d_2 - d_1) \):
- constructive, \( (d_2 - d_1) = 0, \lambda, 2\lambda, 3\lambda,… \)
- destructive, \( (d_2 - d_1) = \frac{1}{2}\lambda, 3/2\lambda, 5/2\lambda,… \)

Doppler effect: receiver(R) moving & source(S) stationary: \( f_R = f_S(v+v_R)/v \)
receiver(R) stationary & source(S) moving: \( f_R = f_S v/(v-v_S) \)

Interference of waves with \( f_1 = f_2 \): \( f_{\text{perceived}} = \frac{1}{2}(f_1 + f_2) \); \( f_{\text{beats}} = f_2 - f_1 \)

Harmonic Series for Standing waves: harmonic number \( n \), fundamental is \( n = 1 \)
On a string (fixed at both ends): \( f_n = nf_1 \), \( \lambda_n = 2L/n \), for \( n = 1,2,3… \) \( f_n = v/\lambda_n = (n/(2L)) \sqrt{T/\mu} \)
Air-filled pipe, open at both ends: \( f_n = v/\lambda_n = (n/(2L))v \), for \( n = 1,2,3… \)
Air-filled pipe, closed at one end: \( f_n = v/\lambda_n = (n/(4L))v \), for \( n = 1,3,5… \)

Conversion Factors and Constants

<table>
<thead>
<tr>
<th>Conversion Factors</th>
<th>Constants</th>
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<tbody>
<tr>
<td>( 1 \text{ kg} ) = 1000 gm</td>
<td>Acceleration due to gravity ( g = 9.8 \text{ m/s}^2 )</td>
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<tr>
<td>( 1 \text{ m} = 100 \text{ cm} ) = 39.37 in</td>
<td>Density (( \rho = \text{Mass/Volume} )) ( \text{Water} = 1000 \text{ kg/m}^3 ) Steel = 7700 kg/m³</td>
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<tr>
<td>( 1 \text{ km} ) = 1000 m</td>
<td></td>
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<tr>
<td>( 1 \text{ in} ) = 2.54 cm</td>
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<tr>
<td>( 1 \text{ ft} = 12 \text{ in} ) = 0.305 m</td>
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</tr>
<tr>
<td>( 1 \text{ mile} = 5280 \text{ ft} = 1610 \text{ m} )</td>
<td></td>
</tr>
<tr>
<td>( 1 \text{ s} = 1000 \text{ ms} )</td>
<td></td>
</tr>
<tr>
<td>( 1 \text{ hour} = 3600 \text{ s} )</td>
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</tr>
<tr>
<td>( 1 \text{ N} = 1 \text{ kgx/m/s}^2 )</td>
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<tr>
<td>( 1 \text{ J} = 1 \text{ Nx/m} = 1 \text{ kgxm}^2/\text{s}^2 )</td>
<td>Abbreviations</td>
</tr>
<tr>
<td>mega</td>
<td>( M = 10^6 )</td>
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<tr>
<td>kilo</td>
<td>( k = 10^3 )</td>
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<tr>
<td>milli</td>
<td>( m = 10^{-3} )</td>
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<tr>
<td>micro</td>
<td>( \mu = 10^{-6} )</td>
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