



PHY1001: Mechanics

Show steps in your homework. **Correct answers with little or no supporting work will not be given credit.** Three-star * * * labels are assigned to the most difficult ones.

Due date: 2024, May 12th, 23: 59: 00.

1 Homework Problems for Week 13: Chapter 17 Wave II

1. * Speed of sound waves

- (a) In a liquid with density 1300kg/m^3 , longitudinal waves with frequency 400 Hz are found to have wavelength 8.00 m. Calculate the bulk modulus of the liquid.

Answers: 1.33×10^{10} Pa.

- (b) A metal bar with a length of 1.50 m has density 6400kg/m^3 . Longitudinal sound waves take 3.90×10^{-4} s to travel from one end of the bar to the other. What is Young's modulus for this metal?

Answers: 9.47×10^{10} Pa.

2. * * Standing Sound Waves and Normal Modes

- (a) Standing sound waves are produced in a pipe that is 1.20 m long. For **the fundamental mode (i.e. first harmonic) and first two overtones (i.e., the second and third harmonics)**, determine the locations along the pipe (measured from the left end) of the displacement nodes and the pressure nodes if the pipe is open at both ends.

Answers: Location of the displacement nodes (N) measured from the left end: fundamental 0.60 m

1st overtone 0.30 m, 0.90 m

2nd overtone 0.20 m, 0.60 m, 1.00 m.

Answers: Location of the pressure nodes (displacement antinodes (A)) measured from the left end: fundamental 0, 1.20 m

1st overtone 0, 0.60 m, 1.20 m

2nd overtone 0, 0.40 m, 0.80 m, 1.20 m.

- (b) What if the pipe is closed at the left end and open at the right end?

Answers: Location of the displacement nodes (N) measured from the closed end: fundamental 0

1st overtone 0, 0.80 m

2nd overtone 0, 0.48 m, 0.96 m.

Answers: Location of the pressure nodes (displacement antinodes (A)) measured from the closed end: fundamental 1.20 m

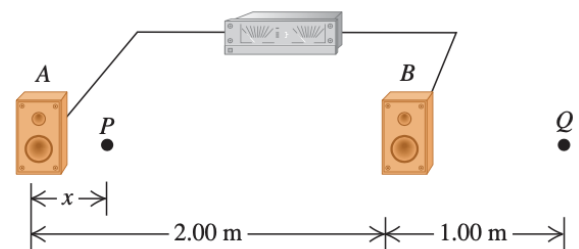
1st overtone 0.40 m, 1.20 m

2nd overtone 0.24 m, 0.72 m, 1.20 m.

- (c) **Singing in the Shower.** A pipe closed at both ends can have standing waves inside of it, but you normally don't hear them because little of the sound can get out. But you can hear them if you are inside the pipe, such as someone singing in the shower. **Show** that the wavelengths of standing waves in a pipe of length L that is closed at both ends are $\lambda_n = 2L/n$ and the frequencies are given by $f_n = nv/(2L)$, where $n = 1, 2, 3, \dots$. Modeling the shower as a pipe, **find** the frequency of the fundamental and the first two over-tones for a shower 2.50 m tall. **Are these frequencies audible?**

Answers: Derive $\lambda_n = 2L/n$ and $f_n = nv/(2L)$, then find $f_1 = 68.8$ Hz, $f_2 = 138$ Hz, and $f_3 = 206$ Hz. Yes, they are within the range of the audible sound frequency.

3. * * Two loudspeakers, A and B (Figure below), are driven by the same amplifier and emit sinusoidal waves in phase. Speaker B is 2.00 m to the right of speaker A. Consider point Q along the extension of the line connecting the speakers, 1.00 m to the right of speaker B. Both speakers emit sound waves that travel directly from the speaker to point Q. (a)



- (a) What is the lowest frequency for which constructive interference occurs at point Q?

Answers: 172 Hz.

- (b) What is the lowest frequency for which destructive interference occurs at point Q?

Answers: 86 Hz.

4. * For a person with normal hearing, the faintest sound that can be heard at a frequency of 400 Hz has a pressure amplitude of about 6.0×10^{-5} Pa. (This is a very faint sound and the displacement and pressure amplitudes are very small.) At 20°C for this sound wave (At 20°C , note that the bulk modulus for air is 1.42×10^5 Pa and $v = 344$ m/s.), calculate



(a) the intensity;

Answers: $4.4 \times 10^{-12} \text{ W/m}^2$

(b) the sound intensity level; (defined as ten times the logarithm in base 10 with $I_0 = 1 \times 10^{-12} \text{ W/m}^2$)

$$\beta = (10 \text{ dB}) \log_{10} \frac{I}{I_0}.$$

Answers: 6.4 dB

(c) the displacement amplitude.

Answers: $5.8 \times 10^{-11} \text{ m}$.

5. * A police car's siren emits a sinusoidal wave with frequency $f_s = 300 \text{ Hz}$. The speed of sound is 340 m/s and the air is still.

(a) Find the wavelength of the waves if the siren is at rest.

Answers: 1.13 m.

(b) Find the wavelengths of the waves in front of and behind the siren if it is moving at 30 m/s.

Answers: 1.03 m (in front) and 1.23 m (behind).

6. * Dune

On the planet Arrakis (also known as Dune and featured in the Dune series of novels by Frank Herbert), a male ornithoid is flying toward his friend at 25.0 m/s while singing at a frequency of 1200 Hz. If the stationary female hears a tone of 1240 Hz, what is the speed of sound in the atmosphere of Arrakis?

Answers: 780 m/s.

7. ** Moving Source vs. Moving Listener.

(a) A sound source producing 1.00-kHz waves moves toward a stationary listener at one-half the speed of sound. What frequency will the listener hear?

Answers: 2000 Hz.

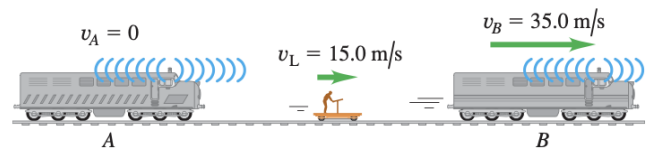
(b) Suppose instead that the source is stationary and the listener moves toward the source at one-half the speed of sound. What frequency does the listener hear? How does your answer compare to that in part (a)? Explain on physical grounds why the two answers differ.

Answers: 1500 Hz.

Comments: It is the velocity of the source and listener relative to the air that determines the effect, not the relative velocity of the source and listener relative to each other.

8. ** Two train whistles, A and B, each have a frequency of 392 Hz. A is stationary and B is moving

toward the right (away from A) at a speed of 35.0 m/s. A listener is between the two whistles and is moving toward the right with a speed of 15.0 m/s (Figure below). No wind is blowing.



(a) What is the frequency from A as heard by the listener?

Answers: 375 Hz.

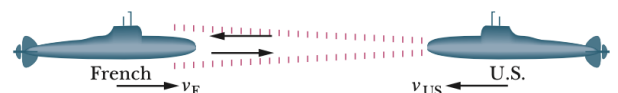
(b) What is the frequency from B as heard by the listener?

Answers: 371 Hz.

(c) What is the beat frequency detected by the listener?

Answers: 4 Hz.

9. ** (Halliday C17-P31) As shown in figure below, a French submarine and a U.S. submarine move toward each other during maneuvers in motionless water in the North Atlantic. The French sub moves at the speed $v_F = 48.00 \text{ km/h}$, and the U.S. sub at $v_{US} = 72.00 \text{ km/h}$. The French sub sends out a sonar signal (sound wave in water) at $1.560 \times 10^3 \text{ Hz}$. Sonar waves travel at 5470 km/h.



(a) What is the signal's frequency as detected by the U.S. sub?

Answers: $1.595 \times 10^3 \text{ Hz}$.

(b) What frequency is detected by the French sub in the signal reflected back to it by the U.S. sub?

Answers: $1.630 \times 10^3 \text{ Hz}$.

10. ** Supersonic Shock Waves.

On a clear day you see a jet plane flying overhead. From the apparent size of the plane, you determine that it is flying at a constant altitude h . You hear the sonic boom at time T after the plane passes directly overhead. Show that if the speed of sound v is the same at all altitudes, the speed of the plane is

$$v_s = \frac{hv}{\sqrt{h^2 - v^2 T^2}}.$$