#44 Doppler Effect and Shock Waves Post-class

Due: 11:00am on Friday, December 7, 2012

Note: You will receive no credit for late submissions. To learn more, read your instructor's Grading Policy

Two Loudspeakers in an Open Field

Imagine you are in an open field where two loudspeakers are set up and connected to the same amplifier so that they emit sound waves in phase at 688 Hz. Take the speed of sound in air to be 344 $\mathrm{m/s}$.

Part A

If you are 3.00 m from speaker *A* directly to your right and 3.50 m from speaker *B* directly to your left, will the sound that you hear be louder than the sound you would hear if only one speaker were in use?

Hint 1. How to approach the problem

The perceived loudness depends on the amplitude of the sound wave detected by your ear. When two sound waves arrive at the same region of space they overlap, and interference occurs. The resulting wave has an amplitude that can vary depending on how the two waves interfere. If destructive interference occurs, the total wave amplitude is zero and no sound is perceived; if constructive interference occurs, the total wave amplitude is twice the amplitude of a single wave, and sound is perceived as louder than what it would be if only one wave reached your ear.

Hint 2. Constructive and destructive interference

Constructive interference occurs when the distances traveled by two sound waves differ by a integer number of wavelengths. If the difference in paths is equal to any half-integer number of wavelengths, destructive interference occurs.

Hint 3. Find the wavelength of the sound

What is the wavelength λ of the sound emitted by the loudspeakers?

Express your answer in meters.

Hint 1. Relationship between wavelength and frequency

In a periodic wave, the product of the wavelength λ and the frequency f is the speed at which the wave pattern travels; that is,

$$v = \lambda f.$$

ANSWER:

λ = 0.500 m

ANSWER:

- yes
- no

Correct

Because the path difference is equal to the wavelength of the sound, the sound originating at the two speakers will interfere constructively at your location and you will perceive a louder sound.

Part B

What is the shortest distance d you need to walk *forward* to be at a point where you cannot hear the speakers?

Express your answers in meters to three significant figures.

Hint 1. How to approach the problem

You will not be able to hear the speakers if you are at a point of destructive interference. At a point of destructive interference, the lengths of the paths traveled by the sound waves differ by a half-integer number of wavelengths. Therefore, you can find the shortest distance you need to walk in the forward direction by determining the difference in distance from the two speakers that corresponds to the smallest possible half-integer multiple of the wavelength. Then, figure out how far forward you need to walk to obtain this path-length difference.

Hint 2. Find the path-length difference at a point of destructive interference

If d_A is the distance between you and speaker *A* and d_B is the distance between you and speaker *B*, by how much does d_A differ from d_B if you are now at the closest possible point of destructive interference?

Express your answer in meters.

Hint 1. Condition for destructive interference

Destructive interference occurs if the difference in paths traveled by sound waves is equal to any half-integer number of wavelengths. Therefore, the closest possible point of destructive interference corresponds to a path-length difference of half a wavelength.

ANSWER:

$d_A - d_B$ = 0.250 m

Hint 3. Find your distance from speaker *A*

If initially you were 3.00 m from speaker *A* and then you walked forward the shortest possible distance needed to experience destructive interference, what is your new distance d_A from that same speaker?

Express your answer in meters to four significant figures.

Hint 1. Geometrical considerations

Geometrically, your initial distance from one speaker and the distance you walked north represent the legs of a right triangle, whose hypothenuse is your new distance from that same speaker. If you apply the Pythagorean Theorem twice, you can write an expression that links d_A to d_B. This equation, combined with the relation previously found by imposing the condition of destructive interference, allows you to find d_A.

ANSWER:

d_A = 6.375 m

ANSWER:

d = 5.62 m

Correct

The beat detected on a moving platform.

A speaker fixed to a moving platform moves toward a wall, emitting a steady sound with a frequency of 220 Hz . A person on the platform right next to the speaker detects the sound waves reflected off the wall and those emitted by the speaker.

Part A

How fast should the platform move, $v_{\rm p}$, for the person to detect a beat frequency of 2.00 Hz ?

Take the speed of sound to be 344 $\mathrm{m/s}$.

Express your answer numerically in meters per second using three significant figures.

Hint 1. How to approach the problem

The key element of this problem is to recognize that the Doppler effect is involved in two different ways. When the sound emitted by the speaker reaches the wall, it has a different frequency than when it was emitted because of the Doppler effect resulting from the motion of the *source* (the speaker). Once the sound wave reaches the wall, it bounces back. Now the wall is playing the role of a source of sound (at rest) and the person on the platform that of a *listener* in motion.

Owing again to the Doppler effect, the frequency of the echo detected by the person on the platform is shifted. Therefore, the frequency of the sound emitted by the speaker is different from the frequency of the echo the person on the platform detects; the difference between the emitted frequency and the frequency of the echo is the beat frequency detected by the person on the platform.

Hint 2. Find the frequency of the wave bouncing off the wall

When the sound emitted by the speaker approaches the wall, the wall plays the role of a listener at rest. What is the frequency $f_{\rm wall}$ that a stationary listener would hear if $v_{\rm p}$ is the velocity of the speaker, f_0 is the frequency emitted by the speaker, and v is the speed of sound?

Hint 1. The Doppler effect for sound waves

The Doppler effect occurs when the source or the listener, or both, are in motion with respect to the medium in which the waves propagate. In this case, the frequency of the sound heard by a listener is shifted with respect to the frequency at which the sound is emitted by the source. This frequency shift depends on the speed of sound, as well as on the speed of the source.
If $f_{\rm S}$ is the frequency of a sound wave emitted by a source in motion at speed $v_{\rm S}$, and $f_{\rm L}$ is the frequency of the sound wave heard by a stationary listener, the Doppler effect can be expressed in the form

$$f_{\rm L} = \frac{v}{v + v_{\rm S}} f_{\rm S},$$

where v is the speed of sound. Note that conventionally the velocity $v_{\rm S}$ is positive if the source is moving away from the listener, and the speed of sound v is always considered positive.

ANSWER:

- $\frac{f_0 v}{v + v_{\rm p}}$
- $\frac{f_0 v}{v - v_{\rm p}}$ (selected)
- \frac{f_0(v+v_{\rm p})}{v}
- $\frac{f_0(v - v_{\rm p})}{v}$

Hint 3. Find the frequency of the echo that the person detects

When the sound emitted by the speaker reaches the wall, an echo is produced; the sound is reflected by the wall and bounces back toward the person on the moving platform.

Find the frequency $f_{\rm r}$ of the echo (i.e., the sound reflected by the wall) that the person detects. Let $v_{\rm p}$ be the speed of the platform, f_0 be the frequency emitted by the speaker, and v be the speed of sound.

Hint 1. The Doppler effect for sound waves

The Doppler effect occurs when the source or the listener, or both, are in motion with respect to the medium. In this case, the frequency of the sound heard by a listener is shifted with respect to the frequency at which the sound is emitted by the source. This frequency shift depends on the speed of sound, as well as the speed of the listener.
If $f_{\rm S}$ is the frequency of a sound wave emitted by a source at rest, and $f_{\rm L}$ is the frequency of the sound wave heard by a listener in motion at speed $v_{\rm L}$, the Doppler effect can be expressed in the form

$$f_{\rm L} = \frac{v+v_{\rm L}}{v} f_{\rm S},$$

where v is the speed of sound. Note that conventionally the velocity $v_{\rm L}$ is positive if the listener is moving toward the source, and the speed of sound v is always considered positive.

ANSWER:

$f_{\rm r}$ =

- (selected) $f_0\frac{v+v_{\rm p}}{v-v_{\rm p}}$
- $f_0\frac{v-v_{\rm p}}{v+v_{\rm p}}$
- $f_0\frac{v-v_{\rm p}}{v-v_{\rm p}}$
- f_0\frac{v+v_{\rm p}}{v+v_{\rm p}}

Hint 4. Find the expression for the beat frequency

If two sounds of slightly different frequencies f_1 and f_2 interfere, the resulting wave has a periodically varying amplitude. This amplitude variation causes variations of loudness that are called beats. The frequency with which the loudness variations occur is called the beat frequency $f_{\rm beat}$.

The beat frequency can be found as

$$f_{\rm beat} = f_1 - f_2.$$

In this problem, the speaker is moving toward a wall so $f_{\rm beat}$ can be represented as which of the following expressions?

ANSWER:

- f_0 - f_{\rm {r}} only
- $f_{\rm r} - f_0$ only
- either f_0 - f_{\rm {r}} or $f_{\rm r} - f_0$

Hint 5. Working the math

From Hint 4 you know that

$$f_{\rm beat} = f_{\rm r} - f_0.$$

You also know, from Hint 3, that

$$f_{\rm r} = f_0 \frac{v + v_{\rm p}}{v - v_{\rm p}}.$$

What is the value of \frac {f_{\rm r}}{f_0}= \frac {v + v_{\rm p}}{v - v_{\rm p}}?

Express your answer numerically using three significant figures.

ANSWER:

\frac {f_{\rm r}}{f_0} = 1.01

ANSWER:

v_p = 1.56 m/s

Correct

Score Summary:

Your score on this assignment is 109%.
You received 21.8 out of a possible total of 20 points.