Waves
Standing Waves and Sound

Lana Sheridan

De Anza College

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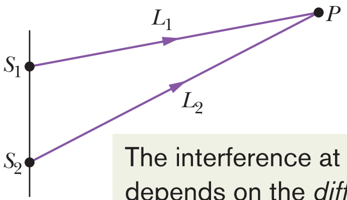
Last time

- speed of sound
- interference and sound

Overview

- interference example
- standing waves and sound

Interference of Sound Waves



The interference at *P* depends on the *difference* in the path lengths to reach *P*.

This is because the path difference will correspond to a phase offset of the arriving waves at P:

$$\begin{aligned}
\Delta P &= \Delta P_1 + \Delta P_2 \\
&= \Delta P_{\max}(\sin(kL_1 - \omega t) + \sin(kL_2 - \omega t)) \\
&= \underbrace{\left[2\Delta P_{\max} \cos\left(\frac{k(L_2 - L_1)}{2}\right)\right]}_{\text{new amplitude}} \sin\left(\frac{k(L_2 + L_1)}{2} - \omega t\right)
\end{aligned}$$

Interference of Sound Waves

The new amplitude could be written as:

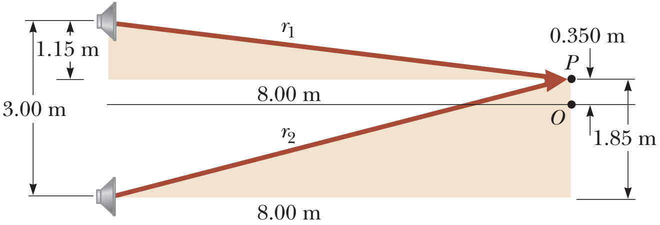
$$2\Delta P_{\max} \cos\left(\frac{\pi(L_2 - L_1)}{\lambda}\right)$$

When $|L_2 - L_1| = n\lambda$ and $n = 0, 1, 2, \ldots$ the sound from the two speakers is loudest (a maximum).

When $|L_2 - L_1| = \frac{(2n+1)\lambda}{2}$ and $n = 0, 1, 2, \ldots$ the sound from the two speakers is cancelled out (a minimum).

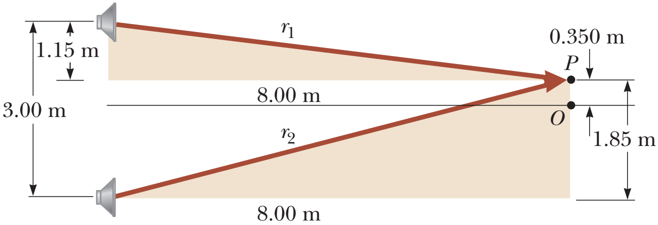
Example 18.1

Two identical loudspeakers placed 3.00 m apart are driven by the same oscillator. A listener is originally at point O, located 8.00 m from the center of the line connecting the two speakers. The listener then moves to point P, which is a perpendicular distance 0.350 m from O, and she experiences the first minimum in sound intensity. What is the frequency of the oscillator?



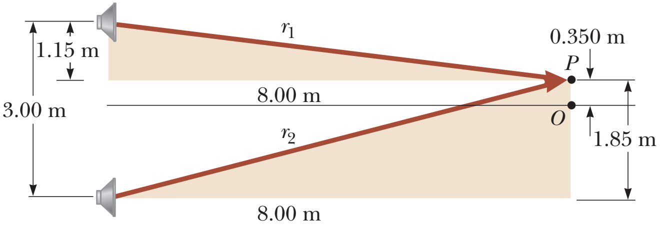
[0]Serway & Jewett, page 537

Example 18.1



P is first minimum.

Example 18.1



P is first minimum.

That means $r_2 - r_1 = \frac{\lambda}{2}$. If we find λ, we can find f, since we know the speed of sound.

$$\lambda = 2(\sqrt{1.85^2 + 8^2} - \sqrt{1.15^2 + 8^2}) = 0.26 \text{ m}$$

$$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.26 \text{ m}} = \underline{1.3 \text{ kHz}}$$

Standing Sound Waves in air columns

Standing sound waves can be set up in hollow tubes.

This is the idea behind how pipe organs, clarinets, didgeridoos, *etc.* work.

Displacement fluctuation:

$$s(x,t) = [2s_{\max}\cos(kx)]\;\cos(\omega t)$$

Question

Quick Quiz 17.1[1] If you blow across the top of an empty soft-drink bottle, a pulse of sound travels down through the air in the bottle. At the moment the pulse reaches the bottom of the bottle, what is the correct description of the displacement of elements of air from their equilibrium positions and the pressure of the air at this point?

(A) The displacement and pressure are both at a maximum.
(B) The displacement and pressure are both at a minimum.
(C) The displacement is zero, and the pressure is a maximum.
(D) The displacement is zero, and the pressure is a minimum.

[1] Serway & Jewett, page 510.

Question

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[1] Serway & Jewett, page 510.

Standing Sound Waves in air columns

Displacement fluctuation:

$$s(x,t) = [2s_{\text{max}} \cos(kx)] \; \cos(\omega t)$$

For a tube with a closed end, the closed end forms a **displacement node**.

This is logical because the air cannot move past the sealed end.

(But that does also mean that the closed end is a pressure antinode. Here we will speak about sound waves in terms of displacement.)

Standing Sound Waves in air columns

The open end or ends of a tube are approximately[2] **displacement antinode**.

This can be thought of as being because the pressure outside the tube is atmospheric pressure, P_0, so the open end is a pressure node, therefore a displacement antinode.

The waves are partially reflected from the open end because the air outside the tube can expand in 3-dimensions, rather than just one, so it behaves very differently than the air in the tube.

It is effectively a change of medium.

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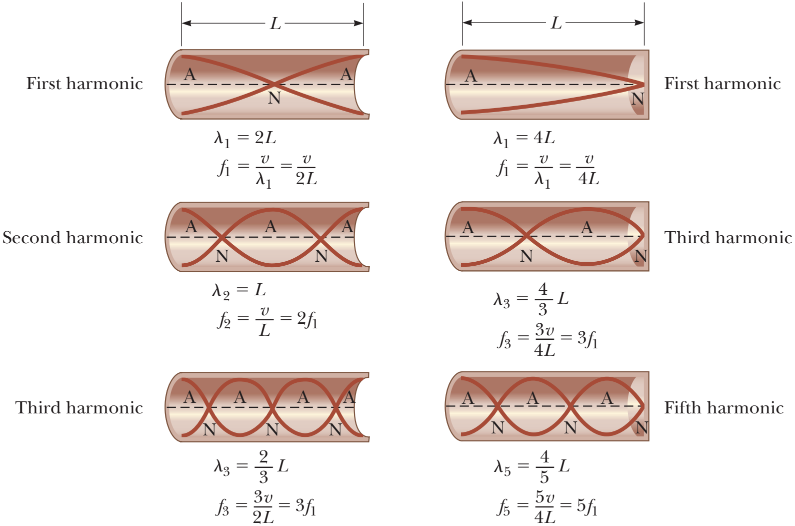
[2] This is not exactly true. Actually the antinode is located just beyond the end of the tube. For this course, we will say the the open end is an antinode.

Standing Sound Waves in air columns - Displ. wave

Two open ends | One closed end



[1]Figure from Serway & Jewett, page 547.

Standing Sound Waves in air columns

For double open ended tubes:

The wavelengths of the normal modes are given by the constraint $|\cos(0)| = |\cos(kL)| = 1$:

$$\lambda_n = \frac{2L}{n}$$

where n is a positive natural number (1, 2, 3...).

The **natural frequencies**:

$$f_n = \frac{nv}{2L} = n\,f_1$$

where n is a positive natural number.

The **fundamental frequency**, also called the **first harmonic** is the lowest frequency sound produced in the column. It is

$$f_1 = \frac{v}{2L}$$

Standing Sound Waves in air columns

For tubes with one closed end: **fundamental frequency** $f_1 = \frac{v}{4L}$

The wavelengths of the normal modes are given by the constraint $\cos(0) = 1$, $|\cos(kL)| = 0$:

$$\lambda_{2n-1} = \frac{4L}{(2n-1)}$$

where n is a positive natural number (1, 2, 3...).

The **natural frequencies**:

$$f_{2n-1} = \frac{(2n-1)v}{4L} = (2n-1)f_1$$

where n is a positive natural number (1, 2, 3...).

(For this case the # of nodes = # of antinodes = n.)

Summary

- interference of sound example
- standing waves and sound