**29**

# Standing Waves
# Sound Barrier

## Purpose

To determine the speed of sound using the principle of resonance.

## Required Equipment and Supplies

resonance tube approximately 50 cm long or a golf club tube cut in half
tall glass cylinder or one-liter graduated cylinder
meterstick
set of tuning forks of 256 hertz or more
rubber band

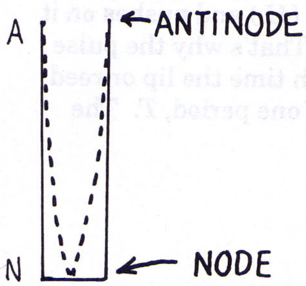
## Discussion

You are likely familiar with many examples of resonance. You may have heard a vase across the room rattle when a particular note on a piano was played. The frequency of that note was the same as the natural vibrating frequency of the vase. Gases resonate as well in organ pipes, flutes, and soda-pop bottles. Your textbook provides other examples of resonance.

A vibrating tuning fork held over an open tube may vibrate the enclosed air column at its resonant frequency. The length of the air column can be shortened by adding water to the tube. The volume of the sound becomes loudest when the proper length is selected for resonance.

For a tube open at one end and closed at the other, resonance occurs when the air column is one-fourth the wavelength of the sound wave. To better understand why this is so, let's have a closer look at what's going on.

### Displacement vs. Pressure




Drawing sketches of standing waves helps us to visualize how resonance occurs. Most of the time we refer to the motion or *displacement* of the molecules. For a tube open at one end and closed at the other, the air molecules at the open end of the tube are able to jiggle back and forth, whereas the air molecules next to the closed end can't. Thus, the open end of the air column is a displacement *antinode* and the closed end a displacement *node*.

Helpful as these displacement diagrams are to visualize the motion of molecules, they do not help us understand why certain notes resonate while others do not. To understand better how acoustical resonance comes about, imagine a pressure pulse traveling down a tube with an open end generated by vibrating lips or reeds at the closed end of the tube.

First, a high-pressure pulse generated by the player as shown in Figure 29.1 forces the reed to close as the pulse continues down the tube (a). The high-pressure pulse reaches the open end (b) (a total distance, $L$, so far) and is reflected just as a pulse traveling down a slinky does when it reaches its end. The reflected pulse, however, changes phase 180° (c) and becomes a low-pressure pulse—too low to push the reed open when it arrives at the end of the tube (d) (total distance traveled is now $2L$). At the closed end, the pulse reflects in phase (e), and continues toward the open end as a low-pressure pulse (f) (total distance traveled now $3L$). A phase change upon reflecting from the open end converts it to a high-pressure pulse (g).

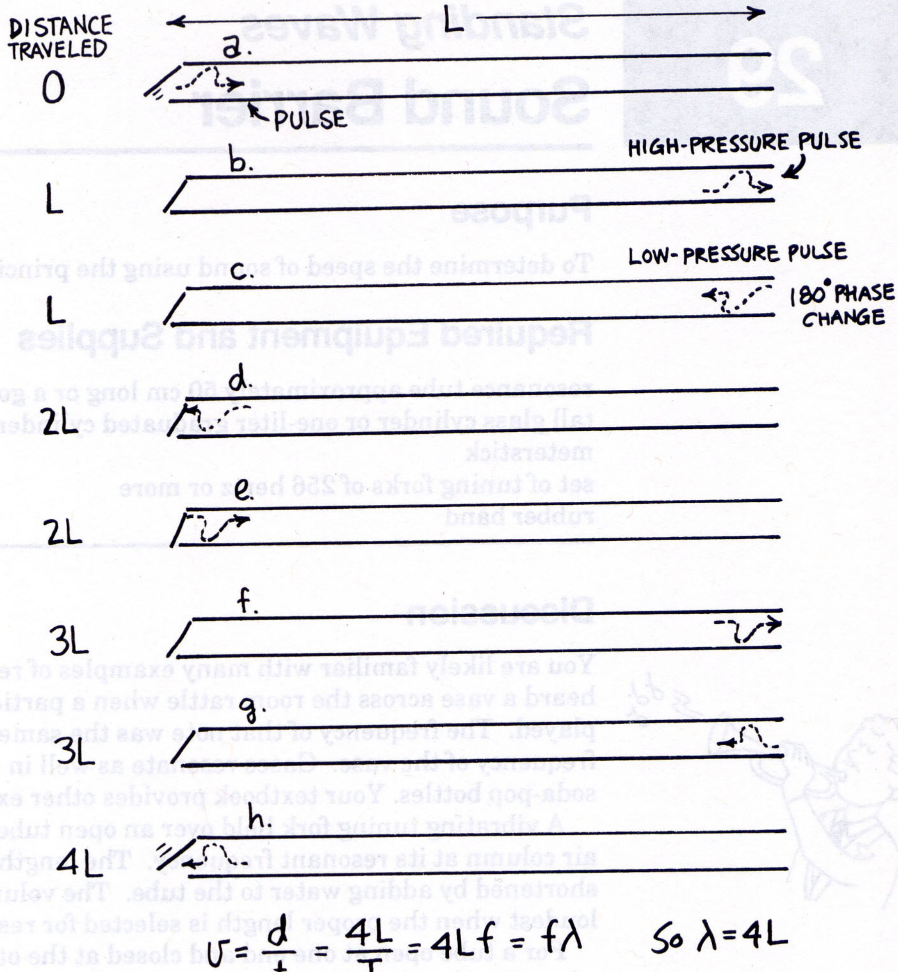



*Figure 29.1*

This high-pressure pulse travels back to the reed ($4L$) and pushes on it with sufficient pressure to swing it open again (h). That's why the pulse makes two round trips for a total distance of $4L$ each time the lip or reed vibrates at frequency once during a time interval of one period, $T$. The speed (velocity = distance/time) of the wave is

$$v = \frac{4L}{T} = 4Lf$$

The length of the tube, therefore, is $\lambda/4$.

When you tighten your lips and blow on a trumpet or other wind instrument, your lips are capable of vibrating at all sorts of frequencies. The air column, however, selects certain frequencies and resonates. The vibration of your lips (or reed in the case of clarinets, etc.) is regulated by the "acoustic feedback" of the air column itself. That is, the air column helps your lips vibrate at a particular frequency...your lips provide energy to vibrate the air column...which in turn helps your lips vibrate...voila—*resonance*!

Displacement is not to be confused with pressure. A displacement *antinode* is at a pressure *node* and vice versa. The molecules near the closed end of the tube are compressed by molecular bombardment, whereas the molecules near the open end remain at the same pressure.

In this experiment you will use the principle of resonance to determine the wavelength of a sound wave of known frequency. You can then compute the speed of sound by multiplying the frequency by the wavelength.

## Procedure

**Step 1.** Using dashed lines as shown in Figure 29.2, sketch the *displacement* standing waves of the first four harmonics in the tube below. Indicate the nodes and antinodes with the letters "N" and "A."

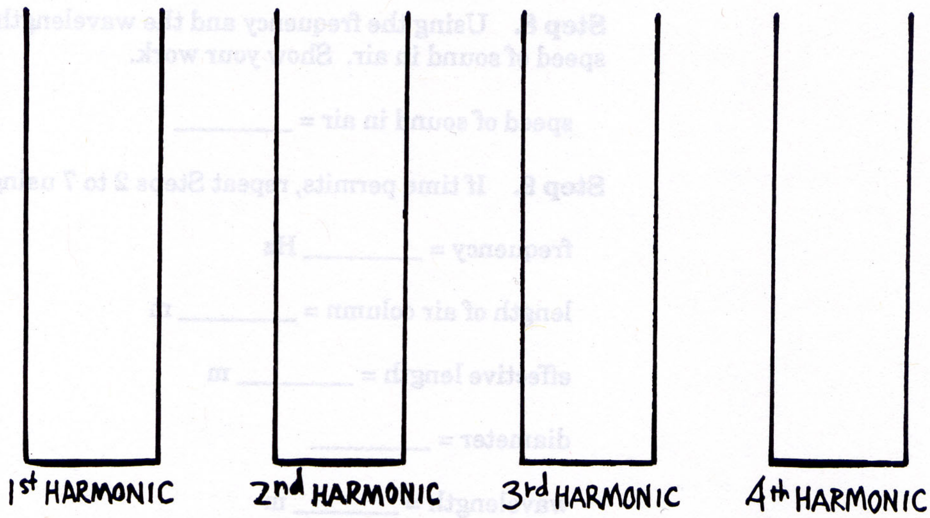
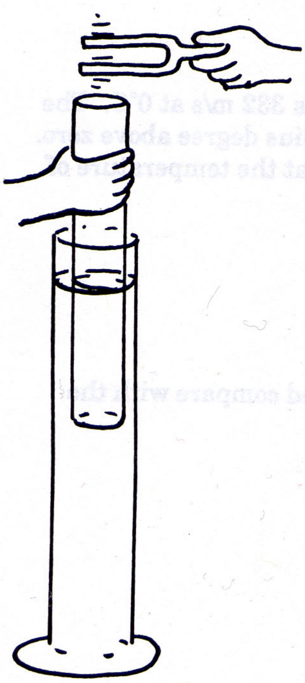



*Figure 29.2*



**Step 2.** Fill the cylinder with water to about two-thirds of its capacity. Place the resonance tube in the cylinder. You can vary the length of the air column in the tube by moving the tube up or down.

**Step 3.** Select a tuning fork and record its frequency.

frequency = ________ Hz

Strike the tuning fork on the heel of your shoe (*not* on the cylinder). Hold the tuning fork horizontally, with its tines one above the other, 1 cm above the open end of the tube. Move both the fork and the tube up and down to find the air column length that gives the very loudest sound. (There are several loud spots). Mark the water level in the tube by stretching a rubber band around the cylinder at the level for the loudest sound.

**Step 4.** Measure the distance from the top of the resonance tube to the water level marked by the rubber band.

length of the air column = ________ m

**Step 5.** Measure the diameter of the resonance tube.

diameter of the resonance tube = ________ m

**Step 6.** Add 0.4 times the diameter of the tube to the measured length of the air column. This *effective length* accounts for the small amount of air just above the tube that also vibrates.

effective length = ________ m

**Step 7.** The effective length is one-fourth of the wavelength of the sound vibrating in the air column. Compute the wavelength of that sound.

wavelength = ________ m

**Step 8.** Using the frequency and the wavelength of the sound, compute the speed of sound in air. Show your work.

speed of sound in air = ________

**Step 9.** If time permits, repeat Steps 2 to 7 using a different tuning fork.

frequency = ________ Hz

length of air column = ________ m

effective length = ________ m

diameter = ________

wavelength = ________ m

speed of sound = ________ m

## Analysis

1. The accepted value for the speed of sound in air is 332 m/s at 0°C. The speed of sound in air increases 0.6 m/s for each Celsius degree above zero. Compute the accepted value for the speed of sound at the temperature of your room.

2. How does your computation for the speed of sound compare with the accepted value? Compute the percentage error.