Lab. 16, Resonance of Air Columns

1. Objective:

To determine the speed of sound in air using the resonance of an air column.

已註解 **[t1]:** OPTION: The objective of this experiment is to determine…

2. Theory:

The oscillating disturbance of a medium composed of particles is called a wave. Normally, we rarely see single waves but rather continuous wave trains. All of the particles in the medium perform the same oscillations, except that the motion of each particle is slightly delayed compared to that of the particle before it. The delay is referred to as the phase difference. Figure 1 displays a wave train traveling from left to right. The particles in the medium oscillate up and down at any given instant, as indicated by the arrows, which deforms the medium as shown by the curve. The distance between any two consecutive particles having the same phase, such as *a* and *i* or *b* and *j*, is called the wavelength.

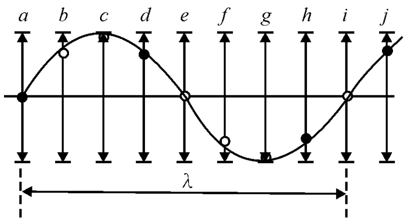


Fig. 1

Waves in which the particles oscillate perpendicular to the direction of the wave, like than in Fig. 1, are called transverse waves, whereas waves in which the particles oscillate parallel to the direction of the wave, such as sound waves, are called longitudinal waves.

The oscillations of particles in the air form condensations and rarefactions, as shown in Fig. 2. The densely dotted regions are condensations, and the sparsely dotted regions are rarefactions. All of the dots oscillate back and forth horizontally.

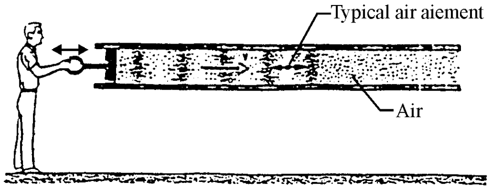


Fig. 2

The figure above does not show the displacement of each particle, but the definition of the wavelength is the same as that of a transverse wave: the distance between two consecutive particles having the same phase. The amplitude of a wave is defined as the maximum displacement of a particle from its equilibrium position. The magnitude of this amplitude is associated with energy and determines the intensity of a sound. The number of waves created each second, or the number of oscillations of the wave source each second, is called the frequency, which determines pitch. The relationship between the speed υ, frequency f, and wavelength λ of a wave is

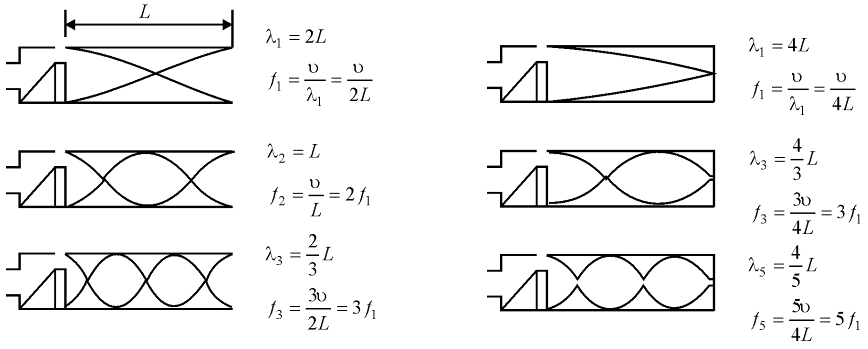
$$\upsilon = f\lambda \tag{1}$$

Therefore, we need only obtain the wavelength of a sound with a known frequency to determine the speed of sound at room temperature, υ_t. Because the density of air decreases with temperature, the speed of sound is also related to temperature according to the following relationship

$$\upsilon_t = \upsilon_0 + (0.607\ {}^{m}\!/_{s\cdot{}^\circ C})T \tag{2}$$

where υ_t is the speed of sound at $T°C$; $\upsilon_0 = 331$ m/s is the speed of sound at $0°C$, and $T(°C)$ is room temperature.

Similar to a transverse wave reflecting at the end of a string, a longitudinal wave traveling along a pipe will also reflect off the end of the pipe. The resulting interference between the incident wave and the reflected wave creates a standing wave. At the closed end, the phase difference between the incident wave and the reflected wave is $180°$. Therefore, the closed end is a node. The air particles are unrestrained at the open end, which is generally an antinode. The wavelength of sound waves at a given frequency can be measured using resonance pipes, which can be divided into open pipes (Fig. 3(a)) and closed pipes (Fig. 3(b)).



圖三(a) 圖三(b)

The end of the pipe where the sound source is placed is considered an open end. If the other end is also an open end, then the pipe is an open pipe. In open pipes, both ends are antinodes, and when the length of the pipe L is an integer multiple of the half-wavelength $\lambda/2$, resonance will occur, as shown in Fig. 3(a), or

$$\lambda_n = \frac{2L}{n} \qquad n=1, 2, 3,\ldots \tag{3}$$

If the end opposite to where the sound source is placed is closed, then the pipe is a closed pipe. In closed pipes, resonance can occur if the length of the pipe L is an odd multiple of $\lambda/4$, as shown in Fig. 3(b), or

$$\lambda_n = \frac{4L}{2n-1} \qquad n=1, 2, 3,\ldots \tag{4}$$

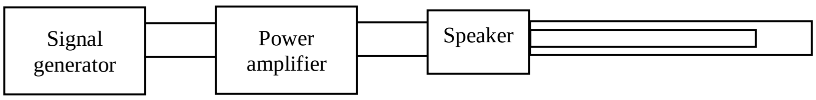


Fig. 4

3. Apparatus:

Function generator (see Appendix 8), power amplifier, speaker, resonance tube, muffler tube, cables, Styrofoam or wood chips

已註解 **[t2]:** or signal generator? (consistency)

4. Procedure:

1. Connect the apparatus as shown in Fig. 4. Spread the chips along the bottom of the resonance

tube, place the speaker at one end of the resonance tube, and close the other end to form a closed pipe.

2. Set the frequency of the signal generator to 300 Hz.
3. Tune the frequency of the signal generator until resonance occurs with distinct nodes and antinodes.
4. Measure the distances between nodes (or between antinodes) and calculate the mean to determine half-wavelength and wavelength λ.
5. Substitute the known frequency f and the corresponding wavelength λ into Eq. (1) to obtain the speed of sound υ at room temperature.
6. Change the frequency to f=500 Hz and 700 Hz, and repeat Steps 3 through 5.
7. Calculate the mean of υ, compare it with the known speed of sound υ_t at the current room temperature, and calculate the percentage error.
8. Open the closed end of the pipe to form an open pipe, and repeat Steps 3 through 7 with frequencies of f=400 Hz, 600 Hz, and 800 Hz.

已註解 **[t3]:** standard?

5. Questions:

1. Suppose that the length of the resonance tube is 1000 mm and that the speed of sound is 334 m/s. At what point will the frequency be too low for this tube to be used to determine the speed of sound?
2. If the radius of the resonance tube is doubled, how will the locations of the nodes change?
3. In Figure 3, 100 % reflection is assumed; in other words, the amplitude of the incident wave, A_i, equals the amplitude of the reflected wave, A_r. If the reflection is not 100 %, and A_r is less than A_i, how will the form of the standing wave change?