EXPERIMENT 6

THE SPEED OF SOUND USING THE RESONANCE OF LONGITUDINAL WAVES

Sound waves produced by a tuning fork are sent down a tube filled with a gas. The waves reflect back up the tube from a water surface and interfere with the waves traveling downward. By properly adjusting the water level, a resonance condition can be established. By knowing the frequency of the tuning fork and the position of the water level for two different resonant lengths, the speed at which sound waves travel through the gas is found.

THEORY

The vibration of the tines of a tuning fork creates regions of compression and rarefaction In the gas. If these disturbances are sent down a gas-filled tube and reflected back up the tube from a fixed boundary, then interference occurs between the two waves. If the distance from the open end of the tube to the closed end is appropriately chosen, then standing longitudinal waves will be set up in the tube creating a resonance condition. For sound waves, resonance is indicated by an increase in the loudness of the sound. When this condition exists, the open end of the tube corresponds to an anti-node of the vibration (maximum oscillation of the molecules) and the closed end corresponds to a node (minimum oscillation).

Because one full wavelength of a wave is the distance from a node to the second node away, with antinodes halfway between the nodes, the distance from an anti-node to a node corresponds to 1/4, 3/4, 5/4, etc. of a wavelength (refer to Figure 1).

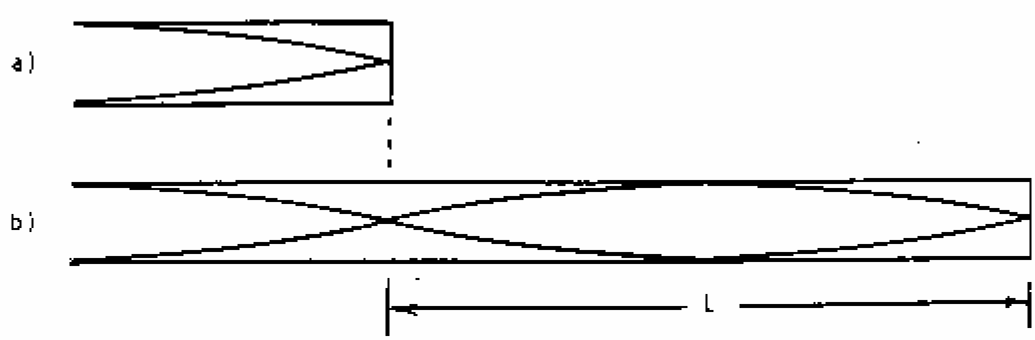

Figure 1. The particle displacement waveform for the open-closed tube in its first resonance condition, (a) and in its second resonance condition, (b). Notice that the increase in length corresponds to one-half of a wavelength.

Because the position of the anti-node at the open end of the tube cannot be precisely located, the distance from the open end to the first node is not measured. What is measured is the distance from one node, determined by the resonance condition, to the next adjacent node, also determined by the resonance condition.

When the locations of these two nodal positions are found, the distance between them corresponds to one-half of a wavelength, i.e., $L - \lambda / 2$. The speed of sound in the tube is then

$$v = f\lambda.. \tag{1}$$

or

$$v = 2fL. \tag{2}$$

The speed at which sound travels is also dependent upon the temperature of the gas. For air it is approximately

$$v = 331.4 + 0.6T. \tag{3}$$

where T is the temperature of air in degrees Celsius and the velocity is in meters per second. Similarly for carbon dioxide,

$$v = 259.0 + 0.4T. \tag{4}$$

APPARATUS

- 2 tuning forks: 426.6 Hz and 384 Hz; ±0.5%
- resonance tube apparatus
- can for water
- 0-100 ^{o}C thermometer, ±2 ^{o}C,
- rubber mallet

PROCEDURE

a) Fill the tube and the water supply container with water from the water can until the water level in the tube is within 10 cm of the top of the tube. Be sure that the container is not full, because the container will be lowered and water will flow into the container (see Figure 2).

b) Hold the thermometer in the tube and measure the temperature, T, of the air.

c) Hold the 426.6 Hz tuning fork at its yoke and either strike the tines with the rubber mallet or strike the tuning fork on something soft like your knee, the sole of your shoe, or your head. Hold the tuning fork over the open end of the tube and slowly lower the water level in the tube by lowering the water supply container until resonance is achieved. The water level in the tube now represents the position of a node. Record the water level position, L_1, and its uncertainty, δL_1. The uncertainty .here is not just the measurement uncertainty, but should also include the uncertainty associated with the difficulty in determining the water level position for the loudest sound.

d) Again strike the tuning fork and -hold it over the tube. Lower the water supply container further, and again determine the water level position for resonance. Record this level, L_2, and its uncertainty, ΔL_2. Note that the distance $L_2 - L_1 = L$ corresponds to one-half a wavelength.

e) Repeat the above procedures for the other tuning fork.

f) Leave the water level in the tube at its lowered position. Take a small piece (about I cc) of dry ice and drop it into -the tube. The carbon dioxide vapor should fill the tube. If it does not fill the tube, then drop another small piece into the tube. Wait until all the bubbling stops. Measure the temperature of the gas, T.

g) Strike the 426.6 Hz tuning fork and hold it over the tube. Gradually raise the water supply container until resonance occurs. Measure the position of the water level and its uncertainty. Continue to raise the water level in the tube until a second resonance is found and again measure the position of the water level and its uncertainty (the nodal positions should be closer together than in the case for air in the tube).

h) Repeat the above procedures for the remaining tuning fork.

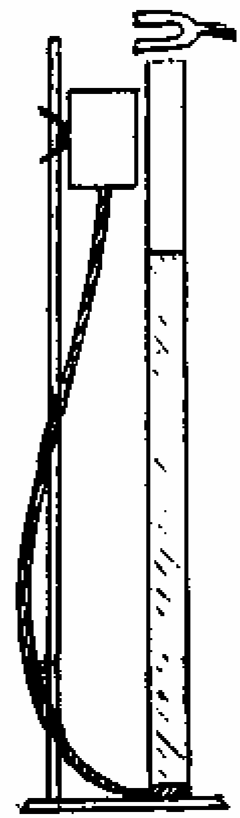

Figure 2. The resonance tube apparatus.

ANALYSIS

The uncertainty in the speed of sound using the resonance tube apparatus is

$$\delta v = v\left[\frac{\delta f}{f} + \frac{\delta L_2 + \delta L_1}{L_2 - L_1}\right], \tag{5}$$

where u is found from (2). The uncertainty using the temperature expressions (3) and (4) is

$$\delta v = k(\delta T). \tag{6}$$

where K is 0.6 for air and 0.4 for carbon dioxide.

Calculate separately for each tuning fork the speed of sound in air and carbon dioxide and the corresponding uncertainties from (2) and (5). Also calculate the expected values of the speeds of sound and uncertainties for each temperature reading from (3), (4) and (6). Report these values in a table of results.

On two separate one-dimensional graphs (one for each gas), graph the values for the speed of sound and their uncertainties for the resonance tube determinations and the temperature determinations

QUESTIONS

1. The anti-node at the open end of the tube actually occurs a small distance beyond the end of the tube. This extra distance is referred to as the end correction. Explain, on the basis of molecular oscillations why the anti-node occurs beyond the end of the tube. Hint: On the molecular level, the anti-node can be considered to be located at the average position of the oscillating molecule.

2. Draw diagrams to show that the distance from an anti-node to a node corresponds to $\lambda/4,\ 3\lambda/4,\ 5\lambda/4$, etc. for standing waves in an open closed tube.

3. Explain why the velocity of sound increases as the temperature of the gas increases.

4. Does water vapor in the air cause the speed of sound to be greater or less than the speed of sound in dry air? Explain.

5. Why is it better to raise the water supply container instead of lowering it when using carbon dioxide?

6. Why are the nodal positions closer together for carbon dioxide vapor than for air?

7. When the dry ice is placed in the tube, the gas that is in the tube is a mixture of carbon dioxide and water vapor. How does the water vapor affect the determination of the speed of sound in carbon dioxide? Explain.

8. Derive (5) from (2) and derive (6) from (3) or (4).

9. The ideal gas analysis for the root-mean-square velocity of the molecules gives the velocity as

$$v = \sqrt{\frac{\gamma RT}{M}}, \tag{7}$$

where -y is the ratio of heat capacities, R is the Universal Gas constant, 7- is the absolute temperature of the gas, and M is the molecular mass of the molecules. Use (7) to calculate the speed of sound In air for the trial when the 385 Hz tuning fork was used. Compare this value with the values obtained using the resonance tube apparatus.