Speed of Sound—Resonance Tube

OBJECTIVES

- ❑ Determine the effective length of a closed tube at which resonance occurs for several tuning forks.
- ❑ Determine the wavelength of the standing wave from the effective length of the resonance tube for each tuning fork.
- ❑ Determine the speed of sound from the measured wavelengths and known tuning fork frequencies and compare with the accepted value.

EQUIPMENT LIST

- Resonance tubes (with length scale marked on the tube)
- Tuning forks (range 500 to 1040 Hz) and rubber hammer
- Thermometer (one for the class)

THEORY

Traveling waves of **speed** V, **frequency** f, and **wavelength** λ are described by

$$V = f\lambda \qquad \text{(Eq. 1)}$$

We can determine the speed of a traveling wave for known frequency and wavelength from Equation 1. It is difficult to measure the properties of a traveling wave directly. When two waves of exactly the same speed, frequency, and wavelength travel in opposite directions in the same region, they produce **standing waves.** These standing waves can be measured easily.

This laboratory uses a device called a resonance tube to produce standing waves from the sound waves emitted from a tuning fork. The can shown in Figure 22-1 contains water, and the level of the water in the tube can be varied as the can is moved up and down. The water acts as the closed end of the tube, and changing the water level changes the effective length of the resonance tube.

A tuning fork, clamped just above the open end of the tube, is struck with a rubber hammer. Sound waves travel down the tube and are reflected when they strike the water. Standing waves are produced by these traveling waves going in both directions inside the tube. The waves reflected from the

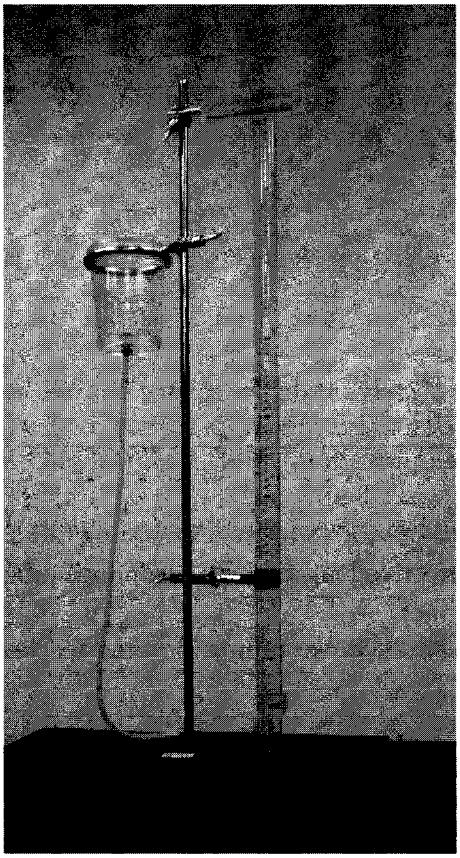

Figure 22-1 Resonance tube apparatus.

closed end of the tube undergo a phase change of 180°, and are completely out of phase with the incide waves. Therefore, the combined amplitude of the incident and reflected waves must be zero at the clos end of the tube. A point in space with wave amplitude zero at all times is called a node N. From simi considerations of the relative phase between the incident and reflected waves, at the open end of the tu the wave amplitude must be a maximum at all times. Such a point is called an antinode A. The speed sound is fixed, and, for a given tuning fork, the frequency is fixed. Therefore, the resonance conditions c be satisfied for only certain specific lengths of the tube.

Figure 22-2 illustrates the necessary relationship between the length of the tube and the wavelength the wave for the first four resonances of the tube. Sound waves are a type of wave known as longitudin The amplitude of a sound wave is determined by pressure variations in the air along the direction of wa motion. The sound waves in the figure are pictured as if they were transverse waves for ease representation. The resonances are pictured from left to right as they are encountered when the le of the water in the tube is lowered, increasing the effective length of the tube. The distances L_1, L_2, L_3, a L_4 refer to the distance from the top of the tube to the water level for the first four resonances. The locatic of the nodes N and antinodes A are shown for each of these resonances. In the first resonance there i single node and antinode. Each successive resonance adds an additional node and antinode. The distar between a node and the next antinode is one-fourth wavelength ($1/4\,\lambda$). The distance between nodes one-half wavelength ($1/2\,\lambda$).

The location of several of the resonances for each tuning fork will be determined experimental If the situation were ideal, the following relationships would be implied by Figure 22-2 for the first fc resonances shown.

$$L_1 = 1/4\,\lambda \qquad L_2 = 3/4\,\lambda \qquad L_3 = 5/4\,\lambda \qquad L_4 = 7/4\,\lambda \qquad \text{(Eq.}$$

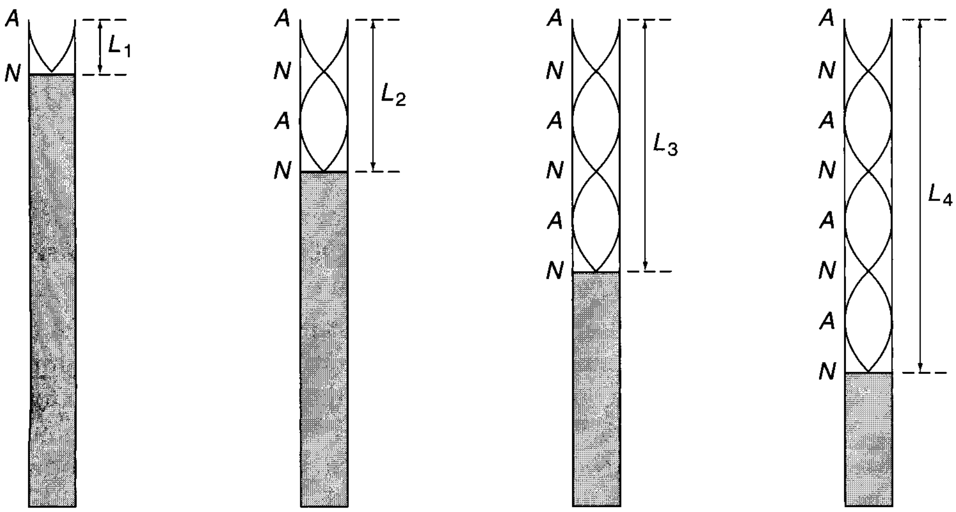

Figure 22-2 Nodes and antinodes of first four resonances of a tube closed at one end.

Examine Figure 22-2 carefully to be sure that you understand how the relationships given in Equations 2 are implied by the figure.

The relationships given in Equations 2 are not valid for a real resonance tube because the point at which the upper antinode actually occurs is just outside the end of the tube. The exact location depends upon the diameter of the tube. Equations 2 are not directly useful to determine the wavelength λ of the wave.

The end effect is the same for each of the resonances and will cancel if differences between the locations of the individual resonances are considered. Considering the differences between adjacent resonances gives the following

$$L_2 - L_1 = L_3 - L_2 = L_4 - L_3 = \lambda/2 \qquad \text{(Eq. 3)}$$

Equations 3 determine the wavelength, and the frequency of the tuning fork is known. Equation 1 then allows determination of the speed of sound.

If Equations 3 are used and the results are then averaged, it would amount to taking the sum of twice the three differences and then dividing by three. In that process, all but the first and last resonance positions cancel from the calculation. In effect, one might as well have not measured the middle two resonances. There is nothing incorrect about such a procedure, but it loses some of the information contained in the data. This shows that there is often more than one way to analyze data, but often one technique gives more information than the others.

All the data contribute to the result if each wavelength is computed, not from the adjacent differences, but from the differences between each resonance and the first resonance. The resulting equations for the wavelength are given below. A subscript has been placed on the wavelength, but it is still understood that each of the wavelengths, λ_1, λ_2, and λ_3, refer to the same wavelength calculated from three different sets of resonances. The equations are

$$\lambda_1 = 2(L_2 - L_1) \qquad \lambda_2 = (L_3 - L_1) \qquad \lambda_3 = 2/3(L_4 - L_1) \qquad \text{(Eq. 4)}$$

The speed of sound in air has a slight linear dependence on the air temperature for a limited range of temperature. The speed of sound V_T at a temperature of T° C will be determined from

$$V_T = (331.5 + 0.607\,T)\ \text{m/s} \qquad \text{(Eq. 5)}$$

where T is the temperature in °C.

EXPERIMENTAL PROCEDURE

Note carefully that tuning forks should be struck only with the rubber hammer. Take care to ensure that neither the hammer nor a vibrating tuning fork comes into contact with the tube.

1. Measure the room temperature of the air and record it in Data Table 1.
2. Adjust the water level until the can is essentially empty when the tube is almost full. The water level in the tube should come to at least within 0.050 m of the open end of the tube. It may be necessary to remove some water from the can when the water level is near the bottom of the tube.
3. Clamp a tuning fork above the top of the tube, and one partner should strike it repeatedly with the rubber hammer. Keep the fork vibrating continuously with a large amplitude. With the tuning fork vibrating, another partner should slowly lower the water level from the top while listening for a resonance. The sound will be very loud when a resonance is achieved. Try to measure the position of each resonance to the nearest millimeter. Raise and lower the water level several times to produce three trials for the measured position of the first resonance and record the values in Data Table 2. Record the frequency of the tuning fork in Data Table 2.
4. Repeat the procedure in Step 3 to locate as many other resonances as possible. Depending upon the frequency of the tuning fork, either three or four resonances should be attainable. Record in Data Table 2 the location of resonances that are attained.
5. Use a second tuning fork of different frequency and repeat Steps 1 through 4. Record in Data Table 3 the frequency of the tuning fork and the position of as many resonances as are attained.

CALCULATIONS

1. Use Equation 5 to calculate the accepted value of the speed of sound from the measured room temperature. Record it in Data Table 1.
2. Calculate the mean and standard error of the three trials for the location of each of the resonances. Record each of the means and standard errors in Calculations Tables 2 and 3.
3. Use Equations 4 to calculate the wavelengths that are appropriate. If four resonances were found, then all three values of λ can be determined. If only the first three resonances were measured, then only two values of λ can be determined. If this is the case, just leave the Calculations Table blank at the appropriate position. Use the mean values of the lengths to calculate the wavelengths.
4. Calculate the mean and standard error for the number of independent wavelengths measured for each tuning fork. Record those values in the Calculations Tables as $\bar{\lambda}$ and α_λ.
5. From the values of $\bar{\lambda}$ and the known values of the tuning fork frequencies, calculate the experimental value for V, the speed of sound.
6. Calculate the percentage error of the experimental values of V compared to the accepted value of the speed of sound in Data Table 1.

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PRE-LABORATORY ASSIGNMENT

1. What is the equation that relates the speed V, the frequency f, and the wavelength λ of a wave?

2. How are standing waves produced?

3. What name is given to a point in space where the wave amplitude is zero at all times?

4. What name is given to a point in space where the wave amplitude is a maximum at all times?

5. What are the conditions that must be satisfied to produce a standing wave in a tube open at one end and closed at the other end?

6. For an ideal resonance tube an antinode occurs at the open end of the tube. What property of real resonance tubes slightly alters the position of this antinode?

7. A student using a tuning fork of frequency 512 Hz observes that the speed of sound is 340 m/s. What is the wavelength of this sound wave? Show your work.

8. A student using a resonance tube determines that three resonances occur at distances of $L_1 = 0.172$ m, $L_2 = 0.529$ m, and $L_3 = 0.884$ m below the open end of the tube. The frequency of the tuning fork used is 480 Hz. What is the average speed of sound from these data? Show your work.

Name　　　　Section　　　　Date

Lab Partners

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LABORATORY REPORT

Data Table 1

Room Temperature = °C	Speed of sound = m/s

Data Table 2

Frequency Fork One = Hz			
L_1 (m)	L_2 (m)	L_3 (m)	L_4 (m)

Data Table 3

Frequency Fork Two = Hz			
L_1 (m)	L_2 (m)	L_3 (m)	L_4 (m)

Calculations Table 2

$\bar{L}_1 =$ m	$\bar{L}_2 =$ m	$\bar{L}_3 =$ m	$\bar{L}_4 =$ m
$\alpha_{L1} =$ m	$\alpha_{L2} =$ m	$\alpha_{L3} =$ m	$\alpha_{L4} =$ m
$\lambda_1 = 2(L_2 - L_1) =$ m	$\lambda_2 = (L_3 - L_1) =$ m	$\lambda_3 = 2/3(L_4 - L_1) =$ m	
$\bar{\lambda} =$ m	$\alpha_\lambda =$ m	$V = f\bar{\lambda} =$ m/s	% Err =

Calculations Table 3

$\bar{L}_1 =$ m	$\bar{L}_2 =$ m	$\bar{L}_3 =$ m	$\bar{L}_4 =$ m
$\alpha_{L1} =$ m	$\alpha_{L2} =$ m	$\alpha_{L3} =$ m	$\alpha_{L4} =$ m
$\lambda_1 = 2(L_2 - L_1) =$ m	$\lambda_2 = (L_3 - L_1) =$ m	$\lambda_3 = 2/3(L_4 - L_1) =$ m	
$\bar{\lambda} =$ m	$\alpha_\lambda =$ m	$V = f\bar{\lambda} =$ m/s	% Err =

SAMPLE CALCULATIONS

1. Speed Sound $= 331.5 + 0.607\ T =$
2. $\lambda_1 = 2(L_2 - L_1) =$
3. $\lambda_2 = (L_3 - L_1) =$
4. $\lambda_3 = 2/3(L_4 - L_1) =$
5. $V = f\bar{\lambda} =$
6. % Error $= |E - K|/K\ (100\%) =$

QUESTIONS

1. What is the accuracy of each of your measurements of the speed of sound? State clearly the evidence for your answer.

2. What is the precision of each of your measurements of the speed of sound? State clearly the evidence for your answer.

3. Equations 2 provide a means to determine the end correction for the tube. Using the value of $\bar{\lambda}$ for the first tuning fork, calculate values for L_1 and L_2 from those equations. They should be larger than the measured values of L_1 and L_2 by an amount equal to the end correction. Repeat the calculation for the second tuning fork. Compare these values for the end correction and comment on the consistency of the results.

4. Suppose that the temperature had been 10 °C higher than the value measured for the room temperature. How much would that have changed the measured value of $L_2 - L_1$ for each tuning fork? Would $L_2 - L_1$ be larger or smaller at this higher temperature?

5. Draw a figure showing the fifth resonance in a tube closed at one end. Show also how the length of the tube L_5 is related to the wavelength λ.