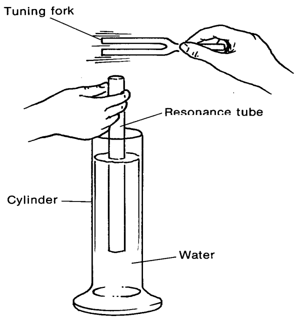
Speed of Sound: Resonance

NAME______________PARTNERS____________________ PHYSICS (AP)

OBJECTIVES:



A traveling wave is characterized by a speed **v**, a frequency **f**, and a wavelength **λ**. The relationship between the three is given by **v = λf.** (1)

When two waves of the same speed and frequency travel in opposite direction in some region of space, they can produce standing waves. When standing waves are produced in a tube the amplitude of vibration becomes very large, and the system is said to be in resonance. A tube partially filled with water acts as a resonance tube for producing standing waves. In this lab a tuning fork will be used to produce sound waves in a resonance tube to accomplish the following objectives:

1. Determination of several effective lengths of the closed tube at which resonance occurs for each tuning fork.
2. Determination of the wavelength of the wave for each tuning fork from the effective length of the resonance tube.
3. Determination of the speed of sound from the measured wavelengths and known tuning fork frequencies.
4. Comparison of the measured speed of sound with the accepted value.

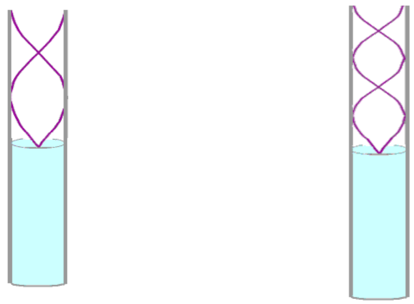
THEORY:

In practice, it is difficult to directly measure the properties of a wave. Instead, experimentally it is easier to arrange for the traveling weaves to interfere in such a way as to produce standing waves. Standing waves are produced by the interference of two waves of exactly the same speed, frequency, and wavelength traveling in opposite directions.

The tuning fork will be held directly above the resonance tube and sound waves will be produced by the striking of the fork with a rubber mallet. Sound waves travel down the tube, and they are reflected when they strike the water. Because of these reflected waves, there are waves traveling in both directions inside the tube and standing waves are produced.

The standing waves that are produced are said to be in resonance with the tube, and this can occur when there is a node at the closed end of the tube and an anti-node at the open end. The speed of sound is fixed, and for a given tuning fork, the frequency of the sound is fixed. Therefore, the resonance conditions can only occur for certain specific lengths of tube which has the proper relationship to the wavelength of the wave.

2nd resonance **3rd resonance**



The necessary relationship that exists between the length of the tube and the wavelength of the wave is illustrated in the diagram above for the first four resonances that occur for the tube.
The resonances pictured from left to right as they are encountered when the water level of the tube is lowered , this increasing the effective length of the tube closed at one end. The distances $\mathbf{L_1}$, $\mathbf{L_2}$,$\mathbf{L_3}$,and $\mathbf{L_4}$ refer to the distance from the top of the tube to the water level. In every case, the distance between nodes is one-half of a wavelength (1/2 λ).

If the situation were ideal, the following relationships would exist for the first four resonances:

$$L_1 = 1/4\ \lambda \qquad L_2 = 3/4\ \lambda \qquad L_3 = 5/4\ \lambda \qquad L_4 = 7/4\ \lambda \tag{2}$$

In fact, the relationships given are not valid for a real resonance tube because there is a small correction facto that must be made depending on the diameter of the tube. The end effect is the same for all tubes of the same diameter therefore, it will have no effect if differences between locations of the individual resonances are considered.

$$L_2 - L_1 = L_3 - L_2 = L_4 - L_3 = ½\ \lambda \tag{3}$$

Each wavelength will be computed from the difference between each resonance and the first resonance.

The equations are:

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

The speed of sound in air depends slightly on the temperature of the air. For a limited range of temperatures, the dependence is approximately linear. Let V_T stand for the speed of sound in air at a temperature T °C, given by

$$V_T = (331.5 + 0.607\ T)\ m/s \tag{5}$$

where T is the temperature in C. this equation will be sued to determine the accepted value for the speed of sound in air.

PROCEDURES:

1. Measure and record the temperature of the room. T = ___°C
2. Place the plastic tube in the graduated cylinder (or pool!) so that the water serves to close one end of the tube. Strike a tuning fork (use 400 Hz or higher) and hold it above the tube while slowly lifting the tube upward (thereby increasing the length of the resonant tube). Eventually you will hear (and feel) the tube resonating. Carefully measure and record the length (L) of the tube above the water to the nearest millimeter.

3. Raise and lower the water level several times to produce three trials for the measured position of the first resonance. Record the values of the three trials 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 on the frequency of the tuning fork used, either three or four resonances should be attainable. Record in Data Table 2 the location of the number of resonances that are attainable.

5. Repeat for a 2nd tuning fork (remember to use 400 Hz or higher) recording your results in Data Table 3.

CALCULATIONS

1. Using equation (5), calculate the accepted value for the speed of sound in the room today and

record in Data Table 1.

2. Calculate the mean and standard deviation of the mean of the three trials for the location of each of the resonances. Record each of the means and standard deviations in the appropriate place in the calculations tables 2 and 3.
3. Using equations (4) calculate the wavelengths that are appropriate. Be sure to use the mean values of the lengths to calculate the wavelengths.
4. Calculate the average of the wavelengths measured for each tuning fork and record.
5. From the values of the average wavelength and the known values of the tuning fork frequencies calculate the speed of sound v.
6. Calculate the percent error for each experimental value of v comparing it with accepted value of the speed from Table 1.

DATA & RESULTS:

Data Table 1

Room Temperature = °C
<u>Show work for speed of sound calculation</u> **Accepted speed of sound = m/s**

Data Table 2

Tuning Fork Frequency = Hz				
Trial	**L_1 (m)**	**L_2 (m)**	**L_3 (m)**	**L_4 (m)**
1				
2				
3				

Calculations Table 2

$\overline{L_1}$ = **m**	$\overline{L_2}$ = **m**	$\overline{L_3}$ = **m**	$\overline{L_4}$ = **m**
σ_{mL1} = **m**	σ_{mL2} = **m**	σ_{mL3} = **m**	σ_{mL4} = **m**
$\lambda_1 = 2(L_2 - L_1) =$ **m**	$\lambda_2 = (L_3 - L_1) =$ **m**	$\lambda_3 = \frac{2}{3}(L_4 - L_1) =$ **m**	
$\overline{\lambda}$ = **m**	$v = \overline{\lambda} f$ = **m/s**	**% error =**	

Sample Calculations

Data Table 3

Tuning Fork Frequency = Hz					
Trial	L_1 (m)	L_2 (m)	L_3 (m)	L_4 (m)	
1					
2					
3					

Calculations Table 3

$\overline{L_1}$ = **m**	$\overline{L_2}$ = **m**	$\overline{L_3}$ = **m**	$\overline{L_4}$ = **m**
σ_{mL1} = **m**	σ_{mL2} = **m**	σ_{mL3} = **m**	σ_{mL4} = **m**
$\lambda_1 = 2(L_2 - L_1) =$ **m**	$\lambda_2 = (L_3 - L_1) =$ **m**	$\lambda_3 = \frac{2}{3}(L_4 - L_1) =$ **m**	
$\bar{\lambda}$ = **m**	$v = \lambda f$ = **m/s**	**% error =**	

Questions:

1. What is your *accuracy* for the speed of sound in the room today for each tuning fork? State clearly the evidence for your answer citing % errors.

2. What is the precision of each of your measurements of the speed of sound? State clearly the evidence for your answer. Recall, *precision* is how consistent your speed calculations are to each other.

3. Equations (2) provided 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 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 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. Refer to the diagrams in the theory showing the 2nd and 3rd resonances to construct the 5th diagram.