Lab #12 Waves

Purpose: a) To explore the formation of standing waves in a vibrating string, and to use experimentally gathered data to determine the string's mass per unit length.

b) To explore the phenomenon of resonance, and to use experimentally measured data to determine the speed of sound in air.

Equipment:

Vibrating string apparatus
Hanger and weights
Graph Paper
Strobe light for demonstrations
Resonance column apparatus
Tuning forks
Barometer & Thermometer

Discussion: (General)

Waves may be divided into one of two categories: transverse waves or longitudinal waves. Transverse waves are those in which the particles in the wave medium move PERPENDICULAR to the direction of propagation of the wave itself. An example is seen after a stone is tossed into a quiet pond. The wave travels outward in an expanding circular shape, and its motion is visibly horizontal. But we can see from the motion of a waterbug or leaf on the surface that the motion of the water particles themselves as the wave passes by is vertical.

Longitude waves are those in which the particles in the wave medium move in the SAME DIRECTION as the direction of propagation of the wave itself. An example may be seen in the toy spring known as "slinky". Suppose it is stretched along the floor between two people. If one person suddenly compressed his/her end, sending a wave down the slinky toward the other person, we would notice that as the wave passes a particular coil, that coil moves in the same direction as that of the passing wave. We might also observe that the coils are closer together in the vicinity of the passing wave. These areas are called compressions, whereas the areas along the slinky in which the coils are stretched farther apart than normal are called rarefactions.

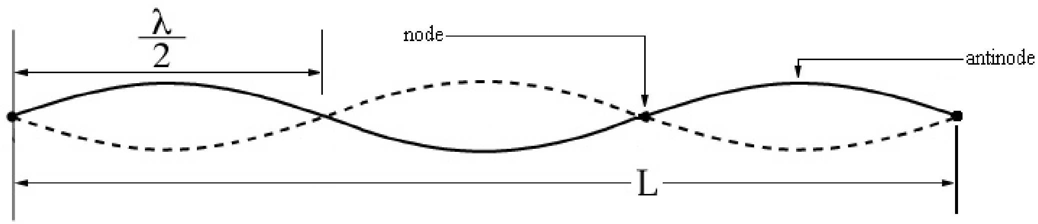
In today's lab, we will observe both kinds of waves. With the vibrating string, we will see up-and-down motion by the string as the wave passes from one side to the other. With the resonance column, we will be dealing with sound waves, which are longitudinal waves. One last general point of wave motion (and this applies to ALL waves): the velocity of a wave equals the product of its frequency and its wavelengths, or $v = \lambda \cdot f$. For example, since the speed of sound in air is roughly 340 m/s, then sound at a freq. of 1000 hz (cycles per sec) has a λ of 0.34 m, and sound at a freq. of 500 hz has a λ of 0.68 m.

Discussion Part I:
The velocity of wave traveling down a string depends on two factors: the tension in the string and the mass per unit length of the string (called linear mass density). The relation is

$$V = \sqrt{T/\mu} \qquad (1)$$

where μ is the mass per unit length of the string and T is the tension. If you pull harder on a string, increasing the tension, then the velocity of the wave increases. For a given tension, a heavier cord will produce a lower velocity.

If a wave travels down a cord toward a fixed end, it will be reflected back toward the direction the direction from which it came. If both ends of the cord are fixed, then the wave reflects back and forth, and at any instant, the actual shape of the cord is the sum of the right-traveling wave and the left-traveling wave. A stable situation called a standing wave results if the wavelengths, λ, is just right so that the wave's amplitude (vertical displacement from the reference level) is zero at either end, where it MUST be zero because its position is fixed. In other words, an integer number of half-wavelengths must fit on the cord. This situation is illustrated in the figure below, which is drawn to show a standing wave pattern with three half-wavelengths on the cord of length L.



In general, then, the resonance condition (for standing waves to exist) is:

$$L = (n \cdot \lambda) / 2 \qquad (2)$$

where L is the length of the string, n is the number of half wavelengths on the string, and λ is the wavelengths. To achieve the condition of resonance, the wavelength, λ, must be adjusted by varying the tension, T, in the string.

To see the dependence of λ on tension, note that since v = λ • f and since v also = $\sqrt{T}$ / $\sqrt{\mu}$, then:

$$\sqrt{T} = \sqrt{\mu} \cdot (\lambda f) = \sqrt{\mu} \cdot V \qquad (3)$$

Notice that $\sqrt{T}$ is directly proportional to the velocity of the wave and the constant of proportionally is $\sqrt{\mu}$. This is the same as saying that a graph of square root of tension versus velocity will be straight line, the slope of which is $\sqrt{\mu}$.

Procedure Part I:

1. Turn on power switch to activate vibration apparatus, which will vibrate string at a fixed freq. of 120 hz.

2. Gradually vary the mass on the hanger until a clearly visible and stable standing wave pattern is established. You should choose mass combinations that produce the largest amplitude at the antinodes. Mass increments of 1, 2, and 5-grams are available.

3. Measure the wavelengths as accurately as possible. For example, your meter stick might be long enough to measure five $(\lambda/2)$'s; then you would multiply that length by 2/5.

4. Repeat steps 2 & 3 for several standing wave patterns, say for n = 3, 4, 5 …11.

5. Calculate tensions and velocities and complete the data table below.

6. Plot $\sqrt{T}$ vertically versus velocity horizontally; extract the slope and determine μ for the string in your experiment.

7. (UNIV. PHYS. I): To show the conditions for resonance, plot n versus the reciprocal of λ. The slope should be 2L. (This can be verified by solving equation (2) above for n.) Measure the <u>actual</u> length of your string and determine percent error.

Trial Number	Measurement Meter stick (m)	#(λ/2)'s <u>Measured</u>	λ (m)	1/λ (m^{-1})	V (m/s)	m (kg)	T (N)	$T^{1/2}$ ($N^{1/2}$)	n = # (λ/2)'s <u>on string</u>

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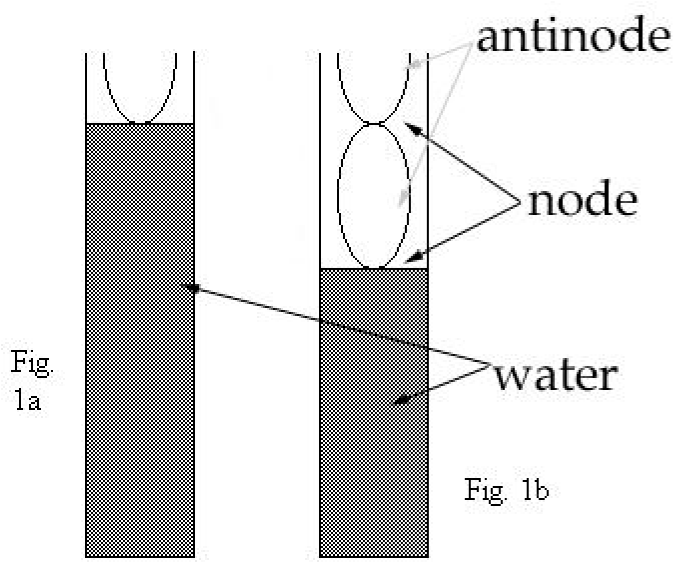
Discussion Part II:
When air is confined in a long tube, sound vibrations can only move back and forth along the direction of the tube in a movement called longitudinal oscillation. It is possible to produce a standing wave pattern in the tube whose characteristics are determined by the constants of the physical arrangements. If the tube is closed at one end, the amplitude of the wave must be zero at the point (a node). On the other hand, if the other end is open, the air motion is greatest at eh open end as air moves in and out. This maximum of air movement in the standing wave depends on the length of the tube, the frequency of oscillation, and the sound's speed in air. Determination of the speed of sound in air is our goal in this procedure. Knowing the frequency and measuring the wavelength, we can calculate the velocity using the relation $v = \lambda \cdot f$.

A tuning fork of known frequency will be used to produce vibrations in a resonating air column. If the conditions are right, a standing wave can be established in the column. This wave consists of two waves traveling in opposite directions at some unknown velocity. As the length of the air column is changed by raising or lowering the water level in the tube, certain lengths exist at which the amplitude (volume) of sound radiated into the room is noticeably greater than at other lengths. This increase in loudness occurs when the length of the air column is "in sync" with the tuning fork's frequency; this is when the tube's length equals an odd number of quarter-wavelengths of the sound wave.

Two such resonance conditions are shown in Figures 1a and 1b below, both of which satisfy the general condition for tube resonance: a node must exist at the closed end, while an antinode must exist at the open end. Resonance occurs when the air column's length is one-quarter of a wavelength long (Fig. 1a), and also when the column's length is three-quarters of a wavelength long (Fig. 1b). A third resonance point (not shown) occurs for an air column length of five quarters of a wavelength.



A correction must be applied to the measured length, L_o, for the tube because the antinode is not located exactly at the open end of the tube, but actually a little bit above. This additional distance, which should be added to the length of the tube measured, is about 0.3 times the diameter of the tube:

$$L = L_o + 0.3\ D$$

Procedure Part II:

1. Set the tuning fork into vibration and hold it over the open tube. Determine the three consecutive points of resonance by adjusting the water level with the funnel. If there is too much water in the tube, pour some into the jug provided, in determining each position of resonance, make eight careful readings: four when the water level is passing up through the point, and four when it is passing down through the point.

2. Measure the diameter of the glass tube and add the necessary correction factor to the lengths measured. Calculate the velocity of sound in air from the average of the readings taken.

3. Compare your result to that predicted by theory. The general equation for the velocity of propagation of waves in a medium of continuously distributed stiffness and inertia is given by:

$$v = \sqrt{\frac{Stiffness\ of\ the\ material}{inertia\ of\ the\ material}}$$

In the case of longitudinal (sound) waves in a gas this equation takes the form of

$$v = \sqrt{\frac{\gamma\ P_o}{\rho}},$$

where γ is a constant depending on the gas, P_o, is the static pressure of the gas, and ρ is the mass density of the gas. The density of dry air is given by the empirical expression

$$\rho = \frac{1.2929 \cdot 273.13K}{T}\ kg/m^3$$

where T is the temperature in Kelvin. The density of moist air (100% relative humidity) differs by more than 10% from this value. Is it higher or lower? (Hint: compare the mass of a water molecule to the mass of a typical molecule in air.)

The static pressure of air, in SI units, is:

$$P_o = 1.33 \times 10^3\ (H)\ N/m^2,$$

where H is barometric pressure in cm of mercury.

Record the room temperature and the barometric pressure at the beginning of the experiment and at the end. The value of γ, the ratio of the specific heat at constant pressure to the specific heat at constant volume for air, is 1.402. From these values determine the predicted speed of sound.

Part II

Data

Room temperature _________K

Diameter of glass tube _________M

Barometric pressure _________cm Hg

Frequency, f ___________Hz

Resonance point at $\frac{1}{4}\lambda$

length of air column, (m)

trial up down

1 ____________________

2 ____________________

3 ____________________

4 ____________________

average L_o______________

Resonance point at $\frac{3}{4}\lambda$

length of air column, (m)

trial up down

1 ____________________

2 ____________________

3 ____________________

4 ____________________

average L_o______________

Resonance point at $\frac{5}{4}\lambda$

length of air column, (m)

trial up down

5 ____________________

6 ____________________

7 ____________________

8 ____________________

average L_o______________

Resonance point	$\frac{1}{4}\lambda$	$\frac{3}{4}\lambda$	
L_o (m)			
L (m)			
λ (m)			

Calculations