STANDING WAVES

PURPOSE: To show that standing waves can be set up in a string and in an air column, to determine the velocity of a standing wave, and to understand the differences between transverse and longitudinal waves.

APPARATUS: Function generator, speaker, tube with rod, buzzer board with string, meter stick, weight holder, weights.

INTRODUCTION: A traveling wave is a disturbance in some quantity, such as air pressure in the case of a sound wave, that moves through the medium with a wave velocity c. A sinusoidal traveling wave appears as a series of maxima (or minima) separated by a distance λ (the wavelength). An observer will see these maxima pass by every T seconds (the period). The wave velocity c is λ/T. Because f (the frequency) is defined as $1/T$, we can also write $c = f\lambda$. Light and sound are examples of traveling waves, albeit very different kinds of waves.

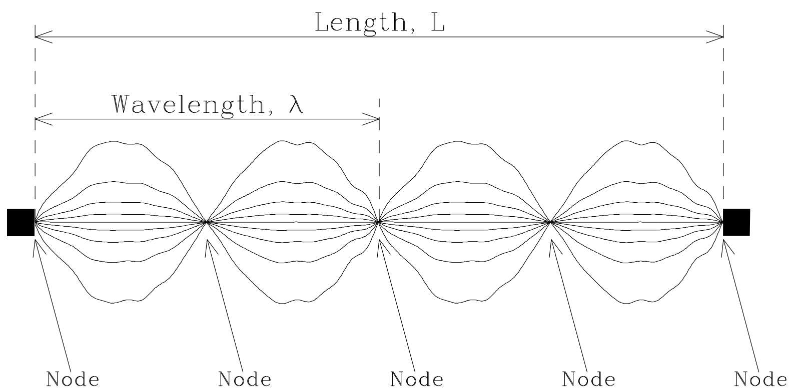

FIGURE 1. Standing waves on a vibrating string

A standing wave is produced by superposing two similar (same frequency and wavelength) traveling waves, moving in opposite directions. The figure shows a vibrating string. At the fixed ends the traveling waves are reflected. If the wavelength is just right we see nodes where there is no motion or variation at all. The "just right" condition is that the wavelength is a half-multiple of the string's length: $n/2 = L/\lambda$, $n = 1, 2, \ldots$. A vibrating string is an example of a *transverse* wave: its oscillation is perpendicular to the direction of its velocity. On the other hand, a sound wave is a *longitudinal* wave: its oscillation is in the same direction as its velocity. These waves have similar properties, but they are quite different as you will see.

PART A: STANDING WAVES ON A STRING

EXPERIMENT: On the standing wave board shown schematically in Figure 2, a buzzer vibrates a string with a frequency of 120 Hz. Because the motion is perpendicular to the direction of propagation, these are *transverse* waves. Both

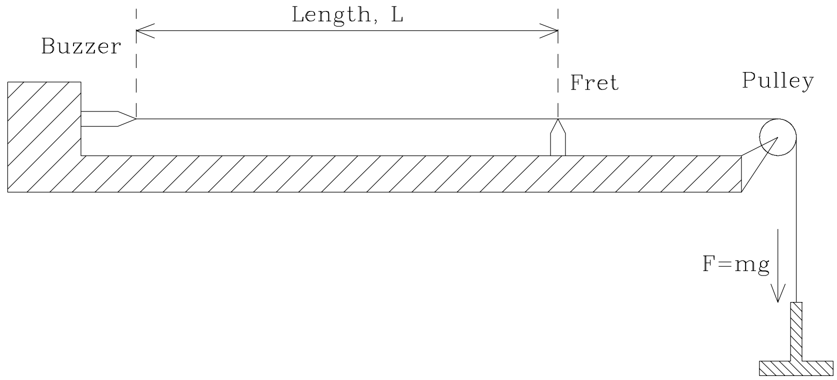

FIGURE 2. Side view (schematic) of standing wave board – waves are viewed from above.

ends of the string are fixed; thus, a standing wave will be set up with each end being a **node**, a location of minimum displacement.

This requires that L, the length of the string, must be equal to any whole number of half-wavelengths:

$$L = n\lambda/2, n = 1, 2, \ldots \tag{1}$$

Although the buzzer end of our string is vibrating, its amplitude is so small that the end is a good approximation of a node. Standing waves will appear between the buzzer end and the movable fret

The wave velocity depends on the tension and material (density and diameter) of the string. Their relation is given by

$$c = \sqrt{F/\rho} \tag{2}$$

where F is the tension produced by the suspended mass ($F = mg$), and ρ is the *linear density* of the string (mass per unit <u>length</u>, not <u>volume</u>). For a particular string (fixed ρ), changes in F by varying m enables us to verify the square root dependence of wave velocity. For a given string with linear density ρ and tension F, the velocity c is fixed. The frequency f is given by the buzzer (120 Hz). If both ends of the string are fixed, a standing wave will be produced when, and only when, the conditions given by Eqn. (1) above are met.

PROCEDURE:

1. Turn on the buzzer. Produce a large transverse standing wave by varying L (i.e., move the fret along the string) . Using a meter stick, determine the distance between nodes by measuring the length between the most widely separated nodes and then dividing by the number of segments in that length. Find as many patterns as possible for a given tension. [Don't let the weight swing!]

2. Change the tension and repeat step 1. Use at least three different tensions. The hanger alone may give a nice standing wave pattern.

3. For each value of tension determine $\lambda/2$ and thus your experimental value of c (for that particular value of tension). The most accurate results are obtained by using the longest length of string. Compare the experimental and theoretical values of c for each tension value, using Eqn. (2) to calculate the theoretical value. [For the tension do not forget the weight of the hanger.] The linear density of the string is nominally 2×10^{-4} kg/m.

PART B: STANDING WAVES IN AN AIR COLUMN

EXPERIMENT: The waves in the setup for this part of the lab are made by a small loudspeaker inside a clear plastic tube and attached to a sine wave (function) generator. The speaker sets the air molecules into *longitudinal* vibration (molecular vibration in the direction of wave propagation). The oscilloscope shows two signals (traces). One trace is the sinusoidal signal applied to the speaker. The other is the output of the microphone and shows the amplitude of the standing sound wave at the microphone.

PROCEDURE:

1. Set the generator at a frequency near 1000 Hz. The sine-wave generator should not be set at the maximum-amplitude or the loudspeaker will be damaged.

2. The signal from the function generator should be applied to oscilloscope input B and should trigger the scope, since its amplitude is constant as you slide the plunger. Input A comes from the microphone. Check that the microphone switch is on. Also check that the A and B inputs are set for AC or DC, but not Gnd. Check that the Mode is Dual, and the Trigger is B. Adjust the trace sweep speed and the A and B amplifier gains as needed for a clear, stable pattern.

3. Move the plunger to vary the length of the air column. When the plunger length is just right, an anti-node develops at the microphone, and a strong standing wave is set up in the tube. You can recognize the anti-node by the sharp maximum in the amplitude as the plunger is moved. Determine all positions of the plunger for maximum sound intensity. The distance between two adjacent positions of maximum intensity is equal to $\lambda/2$.

4. Repeat for two other widely different frequencies. From f and λ determine the speed of sound c for each pattern. Calculate the average speed $\overline{c}$ for each of the three frequencies. Compare your average experimental value with the theoretical value

$$c = (331.4 + 0.6T)\,\mathrm{m/s}, \tag{3}$$

where T is the temperature in degrees centigrade. (Room temperature is about 22° C.)