Name:___________________________________ PHY123

Standing Waves: Transverse and longitudinal

Introduction:
Waves carry energy and momentum by causing a mechanical disturbance in a medium or disturbance of a filed in the medium. The wave travels in the medium with a given speed. For example, while sound waves travel at a speed of about 330 m/s in air by causing compression and rarefaction of the air molecules, light propagates slightly less than $3x10^8$m/s in air by causing variation in the electric and magnetic fields in the space. The direction of disturbance can be along the direction of propagation of the wave. Such waves are called longitudinal waves. An example of such wave is sound where the direction of compression and rarefaction is in the same direction of the propagation of the sound wave. However, there are waves where the disturbance is perpendicular to the direction of propagation. Such waves are called transverse waves. An example of such wave is the propagation of disturbance on a water waves. If you drop a stone on a calm lake, you notice that the ripples move radially outwards as the water molecules move up and down. A similar situation occurs if you pluck a horizontal taut string. The disturbance propagates perpendicular to the oscillation of the materials on the string. Nonetheless, the rate at which the energy and momentum propagate is equal to the speed of the wave. The speed of the wave, V, is given the product of it frequency and wavelength.

$$f = \frac{V}{\lambda} \quad (1)$$

where λ is the wavelength and f is the frequency of the wave.

In a system where there are boundaries, a travelling wave reflects as it reaches the boundaries. The superposition of the forward and reflected waves can create a standing wave if the wavelength and frequency of the wave matches with the natural modes (harmonics) of the system. In such case, the system resonates to produce nodes (places of zero wave disturbance) and antinodes (places of maximal disturbance). If the wavelength and frequency of the wave, however, do not match any of the harmonics of the system, the interference of the forward and backward waves eventually cancel out.

In this laboratory, we will study two examples of standing waves. A standing wave of a **transverse** waves on a taut string and a **longitudinal** wave formed in a column of air. In both cases, we will reduce the problem as a one dimensional problem, where the wave travels from the source only to be reflected backwards.

Part I. <u>Transverse waves on a string</u>

A schematic of the apparatus that you will use is presented in figure 1. A string is attached to a mass that hangs freely over a pulley where the weight of the mass creates a tension on the string. The other end is attached to a mechanical oscillator, which vibrates at a given frequency generated a signal generator. The speed of the wave in this case depends on the linear mass density (mass of the string divided by the length of the string) and the tension on the string. This is given by

$$V = \sqrt{\frac{T}{\mu}} \quad (2)$$

where T is the tension in the string and μ is the linear mass density of the string. Looking at equations 1 and 2, it is clear that the wavelength and frequency of the natural modes on a string will depend on the tension and linear mass density of the string.

Theoretical Calculations:

- Measure the mass of the string: M_string = ____________________________.

- Measure the length of the string: L_string = ____________________________.

- Calculate the linear mass density of the string, μ = ____________________.

- Hang a mass of 0.25kg and Calculate the tension on the string, T = _________________________.

- Calculate the expected speed of the wave, V = ______________________.

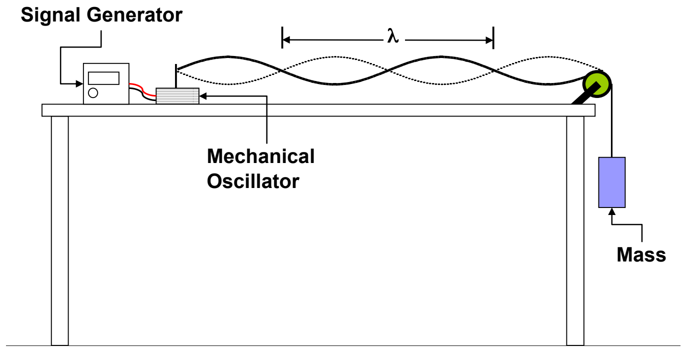

***Figure** 1. Schematic diagram of an apparatus used to study resonance on a string.*

Experimental Part I.

1. Make sure the mechanical oscillator is free to vibrate and it is **unlocked**.
2. Set up the elastic string with a 0.250 kg mass hung over the pulley.
3. Turn on the signal generator and set the frequency to 5 hz.
4. Increase the frequency of the signal generator until you achieve the first harmonics (both ends of the string will be nodes and there will be antinode at half the distance between the pulley and oscillator).
5. Estimate the wavelength of the harmonics by measuring the distance between two nodes.
6. Record the frequency and wavelength in table 1.

Table 1. Wavelength and frequency of the first few harmonics of string.

Harmonics	Frequency (hz)	Wavelength (m)
1^{st}		
2^{nd}		
3^{rd}		
4^{th}		
5^{th}		
6^{th}		
7^{th}		
8^{th}		

7. Increase the frequency to generate the subsequent 7 harmonics and record the corresponding wavelengths and frequencies on Table 1.
8. Plot the resonant frequency versus $1/\lambda$ and determine the velocity (with uncertainty) of the wave. How does your measured value compare with your expected value?

Part II. Longitudinal waves in a variable length air column

The speed of sound in air at room temperature is about 330 m/s. So for a given frequency, you can use equation 1 to find its corresponding wavelength. For example, a frequency of 1000 hz sound has a wavelength of 0.33m. In an air column where one end is a speaker that generates the sound and the other end is a solid that reflects it, the first harmonics will occur at one fourth of the wavelength, which corresponds to 0.0825 m for frequency of 1000hz. The subsequent harmonics will occur at air column length equal to the length of the first harmonic plus half of the wavelength. In general, the relationship between the harmonics, length of the column, and the wavelength can be summarizes as,

$$L = \frac{(2n-1)}{4}\lambda \quad (3)$$

Where λ is the wavelength of the wave, L is the length of the air column that corresponds to the resonance of the n^{th} harmonics.

Schematics of the setup you will use to carry out the experiment for this part is presented in Figure 2. A signal generator will force a speaker to oscillate at a set frequency. The sound generated by the speaker travels through the air column and is reflected by the piston on the plunger. When the length, L, of the air column matches an odd integral number times a fourth of the wave, the system resonates.

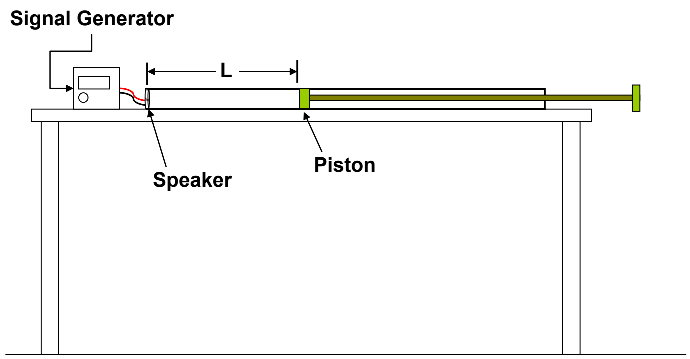

***Figure 2**. Schematics of air column driven to resonate sound wave.*

Theoretical calculation:

- Calculate the expected air column length for a sound wave whose frequencies are listed on Table 2. Record your answer on the corresponding column.

Table 2. Length of air column that resonates sound waves at different frequencies.

Frequency (hz)	Harmonics	Expected length (m)	Measured Length (m)	Measured λ (m)	Measured V (m/s)
1000	1st				
1000	2nd				
1000	3rd				
1000	4th				
1000	5th				

Experimental procedure:

1. Connect the signal generator to the speaker of the air column.
2. Set the frequency to approximately 1000 Hz. Position the moveable piston head within the resonator tube near the speaker. BE CAREFUL. THE SPEAKERS ARE FRAGILE. DO NOT TOUCH THEM WITH THE PISTON HEAD. Gradually draw the piston into the tube until you hear a clear resonance. (Keep the input amplitude to the speaker as low as you can but not zero.)
3. Record the length of the air column in the column “measured length” on Table 2.
4. Continue drawing the piston head further into the tube and record the lengths of the air column at subsequent resonances.
5. Using equation 3, calculate the measure wavelength and record it on table 2.
6. Calculate the corresponding speed of the wave, using equation 1, and record it on table 2.
7. Plot the calculated velocity versus the length of the air column.
8. How does your measured speed of sound compare to the expected value?

Report: Organize and present your results in a scientific way and write a brief discussion about your results. This is due a week from the lab is performed.