Transverse and Longitudinal Standing Waves
Physics 110 Laboratory

When a physical system is driven by an oscillation, the resulting motion of the system will have a response that depends on the driving frequency. In particular, if we oscillate a medium that can carry a wave, a disturbance of energy that travels in the medium, the resulting amplitude of the wave will depend on the frequency of this wave. The maximum response, corresponding to the largest amplitudes, in a system correspond to where it **resonates**.

Waves act like particles in some ways, such as reflecting off surfaces, carrying energy, losing energy, etc., but they also exhibit a phenomenon very different from particles: they interfere. Two waves that travel in opposite directions pass through each other so that at every point in space the net disturbance is an effective sum of their individual disturbances. If the driving force in a medium is equal to a resonant frequency, we will get a **standing wave**.

In this laboratory we will study two examples of standing waves, waves that have a stationary pattern of nodes (places of zero wave disturbance) and antinodes (places of maximal disturbance). The two examples are standing transverse waves on a string and standing longitudinal waves formed in a column of air driven by a small speaker.

For a wave of a definite frequency, a simple expression relates the propagation speed of the wave to the frequency and the wavelength:

\[
v_{\text{wave}} = f \lambda.\tag{1}\]

where \(v_{\text{wave}}\) is the wave propagation speed, \(\lambda\) is the wavelength. If a standing wave exists in a length of \(L\), then the number of waves that fit into the length determine the wavelength:

\[
\lambda = L/\text{number of complete sine waves}\]

Note that the number of complete sine waves may be fractional.

**Longitudinal waves in a variable length air column**

1. Before turning on the function generator connected to your speaker, turn the amplitude knob all the way down (counter-clockwise), and then switch it on. Keep the input amplitude setting low (less then half a full turn) throughout the lab so as to not burn out the speaker. Set the function generator’s frequency to 1000 Hz. Position the moveable piston head near the speaker, but **do not touch the speaker with the piston head. The speakers are fragile**.

2. Gradually pull the piston out of the tube until you hear a clear resonance. Record the position of the piston by reading it on the scale. A resonance occurs when the piston head coincides with a node, and thus the distance between successive resonances equals \(\lambda/2\).

3. Continue drawing the piston head out of the tube and record the lengths of the air column at subsequent resonances.

4. From your data obtain a best estimate of \(\lambda\). Calculate the speed of sound (with uncertainty) for a wave of frequency equal to 1000 Hz.
5. Repeat the above steps for $f = 2000$ Hz.

<table>
<thead>
<tr>
<th>Resonance #</th>
<th>Length of column (m)</th>
<th>$\lambda/2$ (m)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>Average</td>
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<tr>
<td>St. Dev.</td>
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</tbody>
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6. Do your two results for the speed of sound in air agree within experimental uncertainty? Explain.
7. Do your results agree within experimental uncertainties with the value for the speed of sound at the temperature of the air in the room from a reference (such as the web)?

8. Switch the frequency mode on the function generator down to the 1-10 Hz range by pushing the range button down twice. Turn the amplitude all the way down, and connect the function generator to the mechanical oscillator.

9. Set up the string with a 250 g mass hung over the pulley and measure and record below the length L (with uncertainty) of string between the two fixed nodes (the pulley and the mechanical oscillator). Also, mark the string at the oscillator and the top of the pulley.

10. Turn the amplitude knob up about a quarter of a turn until you see the oscillator moving.

11. Tune the frequency knob until you see a 1 loop resonance standing wave, with one antinode at the center.

12. Repeat for resonances with 2 through 7 loops.

13. From your sketch and measurement of the length of the string, determine the corresponding wavelength for each resonant frequency and record the results in the table.

14. Make a chart showing frequency (vertical axis) versus 1/λ (horizontal axis) and fit the data to determine the velocity of the wave. Use the regression tool in Excel to determine the uncertainty in the velocity and record your result on the chart with the appropriate significant figures and units. Print a copy of the chart and attach it to the lab write-up.

15. The wave velocity can also be found from the equation

$$v_{\text{wave}} = \sqrt{\frac{T}{\mu}}$$

where T is the tension in the string and μ is the linear mass density of the string (the mass divided by length). Remove the string and measure the total mass of the string $m_{\text{tot}}$, the total length of the unstretched string $L$, and the distance between the marks when the string is unstretched $L_{\text{marks}}$. Record your measurements with estimates of the uncertainties in the space below.
16. Calculate the linear mass density $\mu$ for the stretched string from your earlier measurement of the stretched length $L$ and your measurements above for $m_{\text{tot}}$, $L_{\text{tot}}$, and $L_{\text{marks}}$. Show your calculations and record your final result for $\mu$ with the appropriate number of significant figures and uncertainty in the space below.

17. Calculate the velocity of the wave using equation (2) and record the result with the appropriate number of significant figures and uncertainty in the space below. Do the two values for the velocity of the wave agree within experimental uncertainties? Explain.