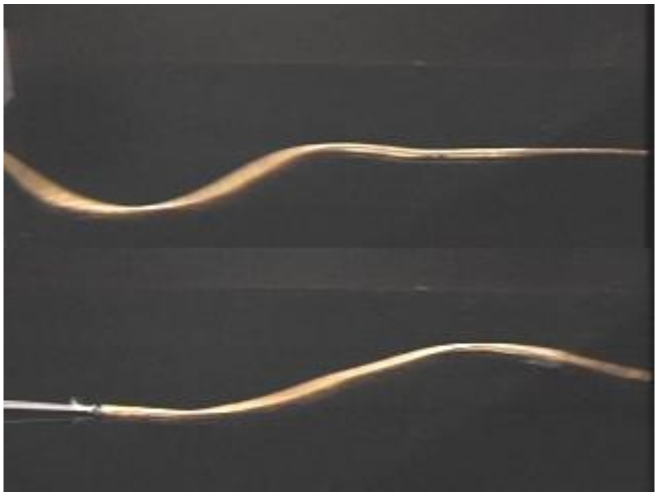
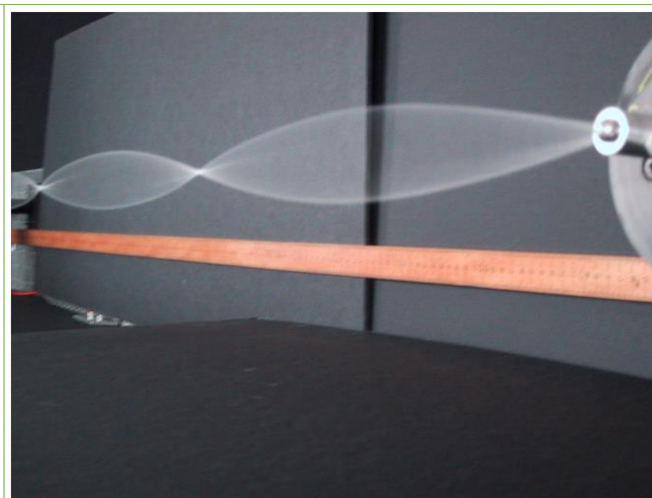
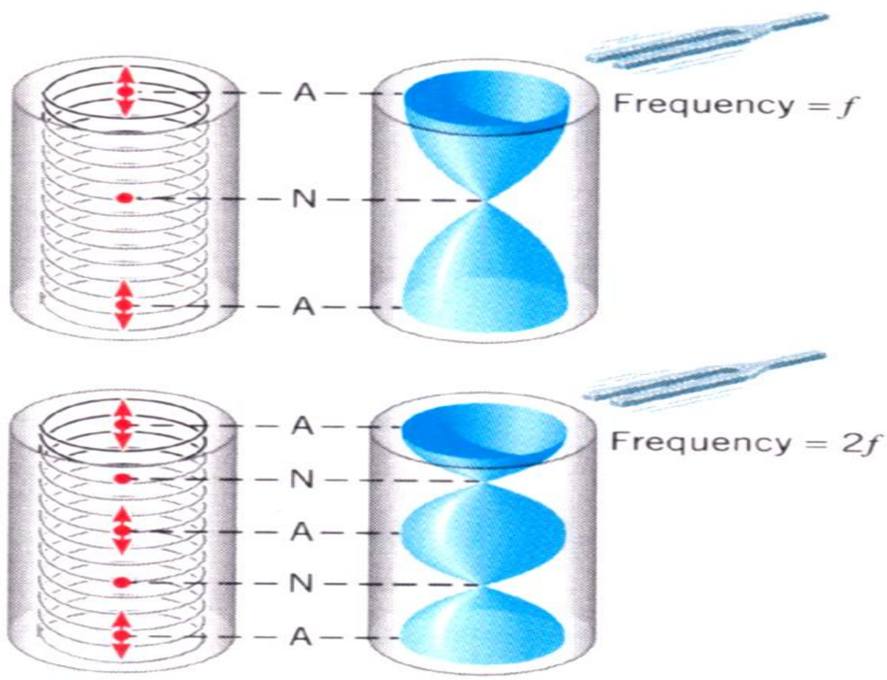
Waves







Objective: To visually observe and measure both traveling and standing waves. To change the parameters of a standing waves. To be able to understand the manifestations of the boundary conditions imposed on a standing wave.

Apparatus: Wave oscillator, string, mass hanger, pulley, masses, long bungee cord, sample bungee cord length, tube open at both ends, scale, stopwatch (or smartphone or smartwatch), meter stick

Introduction

Waves are pervasive in science, engineering and everyday life. You can't see or hear without waves, nor would modern communications be possible. Waves are everywhere, in matter, in air, water; even in the vacuum of outer space. At the smallest scales, one can no longer pinpoint the exact location of particles of matter – probability waves are used to describe their *likely* locations. Waves can be longer than the distance from the Earth to the Sun (gravitational waves) or much smaller than an atom (gamma rays). In short, you can't avoid waves since they're an integral part of your life.

In this lab we will study both traveling waves, which travel in space, and standing waves, which remain stationary in space. One simple example of the former is a wave pulse on a string (as shown above, on the left) or a devastating Tsunami; an example of the latter is shown on the above right, or the sound wave coming out of a violin or guitar.

Theory

Here is a brief summary of the equations you may already have covered in lecture:

$v = f\lambda$ The velocity of a wave is the product of its frequency and wavelength.

$v = \sqrt{\frac{T}{\mu}}$ The velocity of a wave on a string is the square root of (Tension/Linear Mass Density)

$\mu = M/L$ Linear Mass Density is (String Mass/Length of String)

For a standing wave fixed at both ends, the requirement (also called a *boundary condition)* is that an integral number of half-wavelengths must fit the length along which the string is stretched:

$$n\frac{\lambda}{2} = L \quad ; n = 1,2,3\ldots$$

The *fundamental*, or longest possible wavelength that fits the boundary conditions results from fitting half a wave into a column of length L, is:

$$\lambda_1 = 2L$$

This leads to restrictions on the frequencies allowed for a fixed wave velocity (tension):

$$f_n = \frac{nv}{2L}; \; n = 1, 2, 3 \ldots$$

For an open column of air, in which both ends are antinodes (regions where the waves are oscillating greatly), the (see illustration on first page, N=node, A=antinode):

$$\frac{\lambda_1}{2} = L \quad or \quad \frac{v}{2f_1} = L \quad \dashrightarrow \quad f_1 = \frac{v}{2L}$$; where v=speed of sound in air

The allowed frequencies are the same as with the wave on a string:

$$f_n = \frac{nv}{2L};\ n = 1, 2, 3 \ldots$$

Procedure

As usual, write your lab report in Google Docs and share it with lab partner(s), TA and LA.

Traveling Waves (25 pts)

1. There is one long bungee cord strung out between two corners or walls in your lab room – make sure it is weighted down at one end and fastened securely at the other end. The tension in the string is just the weight of the large mass hanger and masses weighting it down.

2. Practice plucking the cord on one end, so that you generate a pulse that travels to the other end and then back again. This will happen several times, until the amplitude (height of wave) will die down.

3. Calculate and predict the speed of the wave pulse, using your knowledge of parameters that affect wave speed. There is sample bungee cord length near the front of the room in case you need to make measurements without taking down the long bungee cord. Show your calculation in your lab report. (10 pts)

4. Design **and perform** an experiment to measure this speed. Note that if you will measure the time it takes for a pulse to get from one end of the string to another, you will make it easier (and reduce random uncertainty) by timing many pulses and dividing by the number of pulses – this is akin to measuring the thickness of a book page by measuring the thickness of the book and dividing by the number of pages. Detail your experiment in your lab report. (10 pts)

5. Discuss how your measured and predicted value compare; Write everything in your lab report. (5 pts)

Standing Waves – String (25 pts)

1. On your lab table is a thin, relatively short bungee string, stretched between the Wave Oscillator and a pulley, over which is a mass providing tension. Although the end touching the wave oscillator oscillates (technically not a node), the amplitude is small enough for us to approximate that it is a node – it is basically fixed at both ends.

2. You will be using software called Function Generator (Desktop or Dock --> Lab Apps --> Function Generator). You can control the frequency with this, and the amplitude by adjusting the speaker Volume control (the speaker provides the signal). To adjust the frequency: you can either press the +/- buttons on the software, move the slider to the desired frequency, or enter the frequency with the keyboard directly.

3. After making all the necessary measurements, predict the frequencies at which you will see a standing wave (as in the top right illustration). Do not unravel the knots on either end of the thin, white bungee string. Show all work in your lab report. (10 pts)

4. Perform the actual experiment – vary the frequency of the wave oscillator until you obtain standing waves, and make note of these frequencies. Record everything in the lab report. (10 pts)

5. Discuss how your measured and predicted values compare; Write everything in your lab report. (5 pts)

Standing Waves – Tube (25 pts)

1. So far you have been using strings as the medium of wave oscillation. Now we will use air, which carries sound waves. You are given a plastic tube open at both ends. **If your tube is less than 0.6m in length, look for an unused tube in another lab table and use that instead.** You also have a speaker from which you can hear sound waves at different frequencies. Keep one end of the tube near the speaker. The sound waves coming out of the speaker set up standing waves in the tube. As the frequency of the sound is changed, the amplitude changes. At certain frequencies, you can hear a very loud sound. This is the phenomenon of resonance, in which a standing wave is formed inside the tube.

2a. Perform the necessary measurement and predict the frequencies at which a resonance (standing wave will be formed. Then, do the experiment (using the same software in the previous part) and note these frequencies. Show all work in your lab report. (15 pts)

Your experimental results may not agree with your predictions as well as they did with in the String part you did earlier. The reason for this is that the anti-node of the open tube closest to your ear may not actually be at the tube opening. The Physics of this is rather complicated but can be roughly explained by the idea that the point at which the open-end reflection occurs (due to the pull-back suction of the rarefied air just behind the wave pulse encountering the tube end) actually occurs outside the tube due to non-uniformities in the region between the inside of the tube (where the waves are flat; also called "plane waves") and the outside of the tube (where the waves radiate outwards; also called "spherical waves"). This "end correction" to the column length is of great importance in the construction of woodwind instruments, for ignoring this correction could lead to the production of, for example, a flute that does not play properly spaced notes and would sound unacceptably bad. The "acoustic length" then differs from the "tube length" by a factor of 0.6 times the tube diameter:

$$L' = L_0 + 0.6d$$

2b. Does the use of the end correction length improve the agreement of your results to your predictions? Give your supporting calculations, together with your answer, in your lab report. (10 pts)

QUESTIONS (25 pts)

After recording your observations and calculations in the lab report, answer these questions:

1. For the speed of the wave pulse, how close (within what %) were your experimental to your predicted results? Did you take into account that the cord's linear density changes when there is tension in it? How would that affect the predicted speed of the speed of the wave pulse – would that make it slower or faster? (2 + 4 + 4 =10 pts)

2a. With the small bungee cords driven by the wave oscillator, suppose you get a standing wave at a particular frequency and mass hanger mass – what quantities in your calculation for standing wave frequencies would change by the addition of a small amount of weight to the mass hanger? If your standing wave goes away from this added mass, how would you restore it? (2 + 3 = 5 pts)

2b. The point where the small bungee cord is moved up and down by the wave oscillator is approximately a node, even though there is slight vibration at that point. If you *softly* pinch one of the other nodes (except the node at the pulley) with your thumb and forefinger, explain why the wave still exists past that point. (5 pts)

3. If many frequencies are possible at the resonances with the sound tube, why is there the need for valves and stops in wind instruments? (5 pts)