LAB 13. STANDING WAVES

Introduction

Consider what happens when you toss a pebble into a still pond. The pebble disturbs the surface of the water, creating ripples. Picture the pattern of the ripples. Suppose a bug is floating on the water's surface some distance away from the spot where you threw in the pebble. After the stone is tossed into the pond, the bug bobs up and down as the ripples pass the bug's position. Why did the bug move up and down? How is this example different from the case of a bug that is pushed down a river by flowing water?

A wave is a propagation of energy. Electromagnetic waves (light, radio, etc.) can propagate through vacuum; other types of waves need a medium to pass through. The wave is a disturbance in that medium. The ripples on the pond are an example of water waves.

Any wave shape that repeats itself is called periodic. The distance between successive crests, successive troughs, or any other pair of identical points on the wave is called the wavelength, λ. The maximum displacement of any point from the equilibrium position is called the wave amplitude, A.

The number of complete waves that pass a single position in a unit of time, such as a second, is the wave frequency, f. The time a single wave takes to pass that position is the wave period, T. The period is related to the frequency by $T = 1/f$.

Waves may be either transverse, longitudinal, or a combination. In a transverse wave, the motion of individual points in the medium is perpendicular to the direction of propagation of the wave (i.e., up-down or left-right as the wave moves forward). In a longitudinal wave, the individual points move parallel to the direction of propagation (i.e., forward-backward as the wave moves forward). Instead of having crests and troughs, longitudinal waves have regions of compression and rarefaction. Many waves in nature, such as ocean waves, are a combination of these two limiting types.

Equipment

String waves: electronic frequency generator, vibrator, elastic cord, hanging weight for tension, table-mounted pulley

Sound waves: open-ended tube placed in a cylinder of water, meter stick; set of tuning forks, rubber mallet

Activity 1: Waves on a string

In an ideal flexible string with length density (mass per length) μ under tension F, transverse waves will propagate at speed $v = \sqrt{F/\mu}$. If a string is clamped at an end, standing waves in the string will have a node at that end.

You will use the mechanical oscillator to move one end of an elastic string up and down. The string is held under tension by a weight on a pulley as shown in Figure 1. The frequency at which the vibrator oscillates is controlled electronically by the frequency generator. The wavelength of the standing waves can be measured by using a ruler or meter stick.

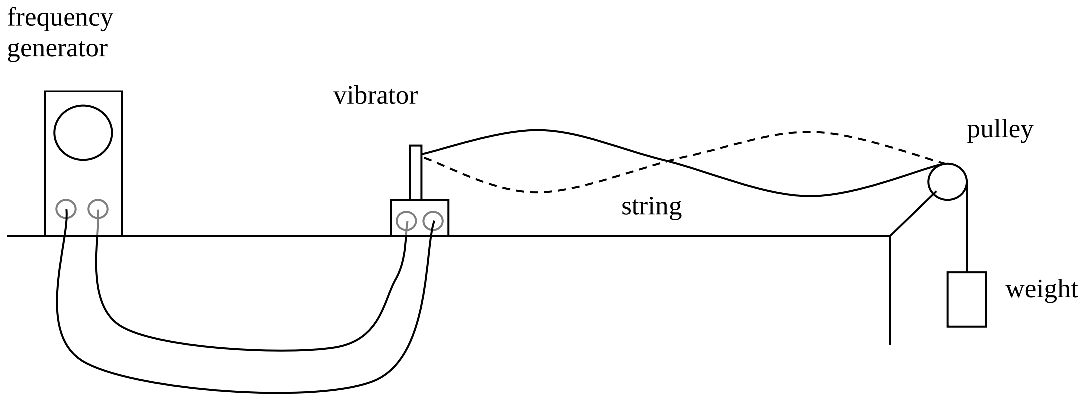


Figure 1. Diagram of a mechanical vibrator and string.

Procedure

1. The cord may have knots in it when you receive it. Untie the knots and measure the length and mass of the unstretched cord. Calculate its length density μ.

   Length _________ m Mass ________ kg Length density _________ kg/m

2. Tie a knot at one end of the cord to anchor the cord between the prongs of the reciprocating rod of the vibrator. Run the cord form the vibrator over the pulley. Tie a loop in the cord beyond the pulley to hook the hanging weight.
3. While the cord is still slack, tie two short lengths of yarn to the cord a known distance apart. Record the distance. Hook the weight on the cord, making sure that the hanging weight does not touch the ground. Now that the cord is stretched, measure the distance between the yarn markers. Determine and record the length density of the stretched cord.
4. Turn on the frequency generator. Experiment with frequencies ranging from a few hertz to a few hundred hertz. Observe how the string behaves with and without standing waves.
5. Find a frequency at which a steady standing wave develops. Record this frequency in Table 1.
6. Measure the wavelength of the standing wave with a meter stick. Note that the distance between adjacent nodes (stationary positions) equals *half* a wavelength. Also keep in mind that the vibrator is not located right at a node.
7. Change the frequency to create a different standing wave. Repeat steps 5 and 6 for the new standing wave.
8. Repeat steps 5 and 6 again with two more frequencies. Try to get a wide range of frequencies.

9. Repeat steps 3–8 with three more tensions in the cord, for a total of four different tensions each with four different resonant frequencies.

Table 1. Standing Waves in a String

Tension ____________ N Length density ____________ kg/m $\sqrt{F/\mu}$ = ____________

Frequency (Hz)	Wavelength (m)	Speed (m/s)

Tension ____________ N Length density ____________ kg/m $\sqrt{F/\mu}$ = ____________

Frequency (Hz)	Wavelength (m)	

Tension ____________ N Length density ____________ kg/m $\sqrt{F/\mu}$ = ____________

Frequency (Hz)	Wavelength (m)	Speed (m/s)

Tension ____________ N Length density ____________ kg/m $\sqrt{F/\mu}$ = ____________

Frequency (Hz)	Wavelength (m)	Speed (m/s)

Data Processing

1. Calculate the speed (speed = distance/time = wavelength/period = wavelength · frequency) of each standing wave. Record the values in Table 1.
2. The theoretical speed of a wave in a string is $v = \sqrt{F/\mu}$, where v is wave speed, F is tension, and μ is length density. Calculate the theoretical transverse wave speeds at the tensions that you studied.

Activity 2: Sound Waves

You will place a source of sound (a tuning fork) at the opening of a tube and adjust the length of the tube to bring it in resonance with the sound. This means that the sound forms standing waves in the tube. For each frequency of sound, you must find two resonant tube lengths. These lengths correspond to 1/4 and 3/4 of the wavelength of the sound, so that the closed end of the tube is at a displacement node of the standing sound wave and the open end of the tube is at an antinode, as Figure 1 shows. (In fact, the antinode is a bit beyond the open end of the tube.)

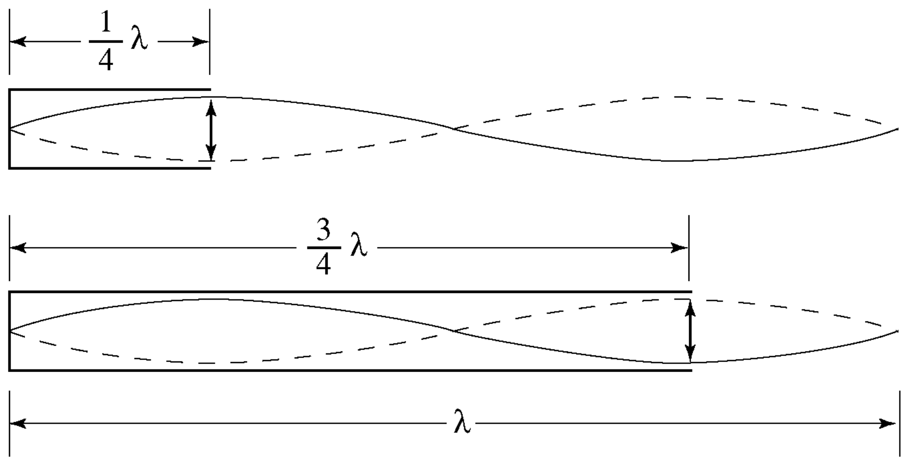
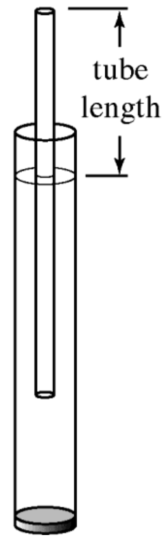


Figure 1. Resonance tubes and their standing waves. Standing waves have a displacement node at the closed end of the tube and an antinode near the open end of the tube. **Note**: Sound waves are longitudinal, not transverse. The amplitudes drawn here represent how much the air molecules at the different positions vibrate longitudinally, not the directions in which they move.

Procedure

1. Place the tube into the cylinder of water so that the tube is resting on the bottom of the cylinder.
2. Strike a tuning fork with the rubber mallet. (I recommend starting with a tuning fork of frequency 512 Hz, the note C.) Hold the fork above the open end of the tube.

3. While holding the ringing fork over the tube, move the tube upward slowly. (You may need to put the tube stand on the floor.) You should soon hear the sound intensify; this is the first resonant position of the tube. Continue raising the tube until you hear the sound intensify again at the second resonant position. If you do not hear the second resonance, your tuning fork probably makes sound with too long a wavelength. (Is the first resonance more than one-third up the length of the tube? If it is, you need a higher-frequency tuning fork.)



4. Make sure that you are hearing the fundamental tone of the fork and not an overtone! To be sure you don't have an overtone, raise the inside tube and check for lower-frequency resonances.
5. When you know that there are two resonances for the sound from the fundamental vibration of your tuning fork, measure their tube lengths. The tube length is the length of the air column in the tube when the tube is at resonance. It is the distance from the mouth of the inside tube to the waterline (see diagram).

Table 1. Resonance Tube Positions

Frequency (Hz)	1st Tube Length (m)	2nd Tube Length (m)	Difference (m)	Wavelength (m)	Average Wavelength (m)	Speed of Sound (m/s)

6. Repeat steps c–f twice more with the same tuning fork, checking your previous measurements. Enter your data into the first three columns of Table 1.
7. Repeat steps c–g using a second and third tuning forks.

Extension: Overtone

Measure two successive resonant tube lengths for an overtone of the tuning fork.

Data processing

1. Compute the difference in the tube length between the first and second resonance positions for each row. Enter in Table 1.
2. Compute the wavelength for each row from the difference. The wavelength is twice the difference between two successive resonant lengths.) Also find the average wavelength for each frequency. Enter all these values in Table 1.
3. Determine the speed of sound v for each tuning fork using the frequency f of the tuning fork and the corresponding average wavelength λ. Enter these values also into Table 1.
4. If the three values for the speed of sound for the different frequencies are similar, average them to obtain a single value for the speed of sound in air. If they are not similar, consult your instructor now.
5. If you found resonant tube lengths of an overtone, calculate the wavelength of the overtone. Using the speed of sound you found above, calculate the overtone's frequency.

Lab Report

Sure, this can be a group report.

Abstract

Briefly describe the system. Identify the quantities that were measured, the quantities that were inferred from the measurements, and the hypothesis being tested.

Purpose

What concept does this activity test or demonstrate?

Theory

You do not need to derive $v = \sqrt{F/\mu}$ here; that was challenging enough in lecture. But how can measurements on a standing wave tell us the propagation speed of a wave? Explain that, and identify what quantities determine the propagation speed according to our model.

Experimental

Describe the experimental apparatus you used, the measurements you took, and the conditions that you varied. Give the procedure you followed to make the measurements.

Observations and Data

You don't need to transcribe the data directly into a lab report, but you should clearly communicate what you found. If you choose to graph your data, it would make sense to use a spreadsheet. If your spreadsheet is online, you can link to it in your report.

Analysis and Discussion

String wave: What are the propagation speeds of the waves? Upon what quantities do they depend? Does the theoretical model account for your observations?

Sound wave: Is the speed of sound independent of frequency? How is the tuning fork's overtone frequency related to its fundamental frequency?

Conclusion

Does the model correctly predict the propagation speed of transverse waves in the elastic string?