LAB 3. WAVES

Questions

- How can we measure the velocity of a wave?
- How are the wavelength, period, and speed of a wave related?
- What types of behavior do waves exhibit?

Background

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 leaf 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 leaf bobs up and down as the ripples pass the leaf's position. Why did the leaf move up and down? How is this example different from the case of a leaf that is carried 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 complex combination of these two limiting types.

Equipment

long coil spring, mounting hardware, stopwatch, meter stick, tape measure, loose coil spring (Slinky), stopwatch; open-ended tube placed in a cylinder of water, meter stick; set of tuning forks, striker

Activities

You may do the activities in any order.

1. Longitudinal waves in a slinky

1. Lay the Slinky on the floor or table and hold one end securely. Move the free end of the spring to try to create a pulse that compresses the spring. How do you accomplish this? Is the coil compressed along its entire length at any instant?

2. Estimate the speed of a pulse. Do this by making rough measurements of the time the pulse takes to travel a known distance. Show your measurements, calculation, and estimate. Also determine if it is possible to change the wave speed, and describe what factors you must change to accomplish this.

3. Set up a standing wave pattern in the Slinky. This takes some work, because the pulse encounters a lot of friction. Do a victory dance.

2. Transverse waves in a coil spring

1. Clamp both ends of the spring. Practice making single wave pulses that travel from one end of the spring to the other (and back). I find that the simplest way to do this is to sharply tap the spring near one end.
2. Estimate the speed of a single wave pulse by measuring how long it takes to travel a known distance. Show your measurements and calculations below.

3. Identify the factors you must control to do change the speed (*not* frequency: *speed!*) of the wave.

4. Generate another wave pulse on the spring. Observe the reflection of this pulse at the end of the spring. The wave that arrives at the end is called the **incident** wave. What is the displacement of the coils as the incident wave passes? Is it positive (up) or negative (down)?

5. What is the direction of the displacement of the coils as the reflected wave passes? A sketch may help.

3. Wavelength and frequency of a standing wave

Now you will study standing waves in the same coil spring. You will need to create and maintain at least three different wave patterns. The wavelength of the standing waves can be measured by using a ruler, measuring tape, or meter stick.

1. Practice creating and maintaining several different standing wave patterns.
2. Find the period of one pattern by timing a large number (say, 25) of cycles. Enter the timing data into the Table 1 and calculate the period
3. Measure the wavelength of the standing wave. Note that the distance between adjacent nodes (stationary positions) equals *half* a wavelength.
4. Without changing the tension or length of the spring, create a standing wave pattern with a different number of nodes. Repeat parts 2 and 3 for the new standing wave.
5. Repeat parts 2 and 3 again with one more frequency, for a total of three sets of data. Try to get a wide range of frequencies and wavelengths!

Table 1. Standing Waves in a coil spring

Oscillations	Total Time (s)	Period (s)	Wavelength (m)	Speed (m/s)

Data Workup

1. Calculate the speed (speed = distance/time = wavelength/period) of the wave for each set of measurements. Record the values in Table 1.

2. Using a spreadsheet or your own graph paper, make a graph of the wavelength (vertical axis) vs. period (horizontal axis) from your data in Table 1. Scale your graph to use at least half of each axis. Enter the units in the axis labels. Title your graph.
3. Fit the graph with a straight line. What is the slope of the line?
4. What is the physical meaning of the slope of the line?
5. If you change the period of a wave in the string, does the speed of the wave increase, decrease, or stay the same? Do your data and your graph support your answer?

4. Resonance tubes and the speed of sound

In the other station you found frequencies that sustained standing transverse waves in a given length of spring. Here, you will find column lengths that sustain standing longitudinal waves for given frequencies of sound.

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 will form standing waves in the tube. For each frequency of sound, you will 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 node of the standing sound wave and the open end of the tube is at an antinode (See Figure 1).

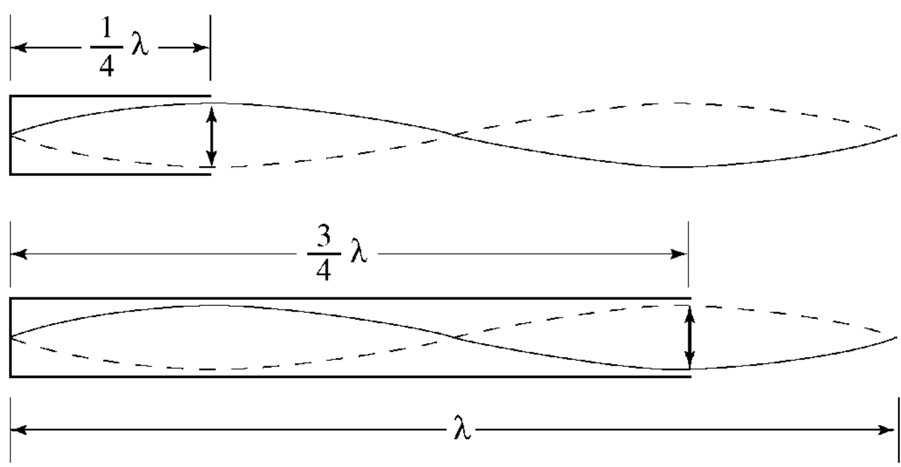

Figure 1. Resonance tubes and their standing waves. Standing waves have a node at the closed end of the tube and an antinode at the open end of the tube. **Note**: Sound waves are actually longitudinal, not transverse. The amplitudes drawn here represent how much the air molecules at the different positions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

1. Raise the water reservoir or lower the tube so that the tube nearly fills with water.
2. Strike a tuning fork with the striker. Hold the fork above the open end of the tube.
3. While holding the ringing fork over the tube, lower the water reservoir so that the water level in the tube drops. You should soon hear the sound intensify; this is the first resonant position of the tube. Record the position. Continue lowering the water level 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, further lower the water level 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 top of the inside tube to the water.
6. steps 2–5 twice more with the same tuning fork, checking your previous measurements. Enter your data into the first three columns of Table 2.
7. Repeat steps 2–6 using a second and third tuning forks, with different frequencies.

Table 2. Resonance Tube Lengths

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

Data Workup

1. Compute the difference in the tube length between the first and second resonance positions for each row. Enter in Table 2.
2. Compute the wavelength for each row from the difference. The difference between resonance positions is one-half the wavelength. (Thus, the wavelength is twice the difference between the two resonant lengths.) Also find the average wavelength for each frequency. Enter all these values in Table 2.
3. Determine the speed of sound for each tuning fork using the frequency of the tuning fork and the corresponding average wavelength. Frequency is given in units of hertz, Hz. A hertz is the inverse of a second:

   $$1 \text{ Hz} = 1/\text{s}$$

   The speed of sound can be determined from the time it takes the wave to travel one wavelength. Recall that

   $$\text{speed} = \frac{\Delta \text{ distance}}{\Delta \text{ time}};$$

   here, Δ distance = wavelength, and Δ time $= 1/\text{frequency}$, so speed = wavelength × frequency. Enter these values also into Table 2.

Lab Report

Complete all the observations, calculations, and graphs. Answer all the questions in this sheet. Submit the graph with the sheet.