LAB 11. 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, yarn, hanging weight set for tension, table-mounted pulley

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

String wave activity

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. The frequency at which the oscillator oscillates is controlled by the frequency generator. The wavelength of the standing waves can be measured by using a ruler, meter stick, or tape measure.

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 in one end of the cord to anchor the cord between the prongs of the reciprocating rod of the oscillator. Run the cord form the oscillator over the pulley. Tie a loop in the cord beyond the pulley to hook the hanging weight.
3. While the cord is 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 reach the ground. Now that the cord is stretched, measure the distance between the yarn markers. Determine the length density of the stretched cord and record in Table 1.
4. Turn on the frequency generator. Experiment with frequencies ranging from a few hertz to a few hundred hertz. Does every frequency create steady standing waves on the string?
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 points) equals *half* a wavelength. Also keep in mind that the oscillator 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, for a total of four frequencies. Try to get a wide range of frequencies.
9. Repeat step 3–8 with three more tensions in the cord, for a total of four different resonant frequencies at each of four different tensions.

Table 1. Standing Waves in a String

Tension ___________ N Length density ___________ kg/m

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

Tension ___________ N Length density ___________ kg/m

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

Data Processing

Calculate the speed (speed = distance/time = wavelength/period = wavelength · frequency) of each standing wave. Record the values in Table 1.

Analysis

1. 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.
   a. At a given tension, are the wave speeds for the different standing waves the same?

   b. Does the wave speed depend on tension?

   c. Do the experimental speeds match the theoretical predictions of $\sqrt{F/\mu}$?

2. Does the model adequately describe the behavior of transverse waves in the elastic string?

Resonance tube activity

In the "standing waves in a string" activity, you found frequencies that sustained standing transverse waves in a given length of string. 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 must find two resonant tube lengths. These lengths correspond to about 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. (Actually, the antinode is a bit beyond the open end of the tube.)

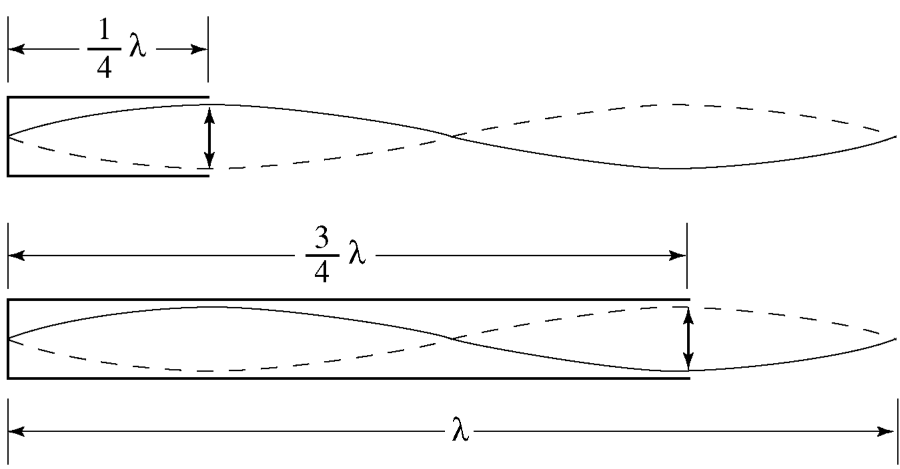
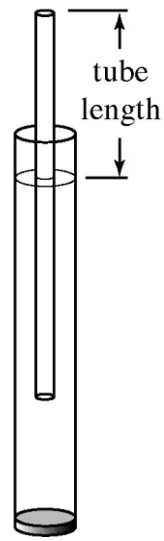


Figure 1. Resonance tubes and their standing waves. Standing waves have a node at the closed end of the tube and an antinode at the open end of the tube. **Note**: Sound waves are actually longitudinal, not transverse. The amplitudes drawn here represent how far the air molecules at the different positions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

a. Place the tube into the cylinder of water so that the tube is resting on the bottom of the cylinder.

b. 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.

c. 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.)



d. 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.

e. When you have located two different 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 opening of the inside tube to the water (see diagram).

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)

f. 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 2.

g. Repeat steps c–g using a second and third tuning forks.

Calculations

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:

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

   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/frequency, so speed = wavelength · frequency. Calculate and enter these values into Table 1.

4. If the three speeds 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.

Questions

1. Are the three values for the speed of sound in air for each frequency similar?

2. Should you expect sound of different frequencies to have the same or different speeds? Why?

3. The speed of sound in air varies with air temperature. As the air temperature increases, the speed of sound increases. (Can you imagine why?) The speed of sound in air at 0° C is 331.4 m/s, and increases by ~ 0.6 m/s for every degree in Celsius above 0° C. Is the speed that you found above consistent with this trend?

4. Sound travels slightly faster in humid air than in dry air. Can you explain why?

Extension: Overtone

1. Find the wavelength of a tuning fork overtone by the same procedure.

2. Using the wave speed determined earlier with the wavelength you just found, find the frequency of the overtone.

3. How does this frequency relate to the fork's fundamental frequency? Is it a whole-number multiple?