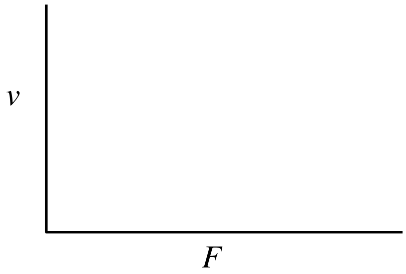
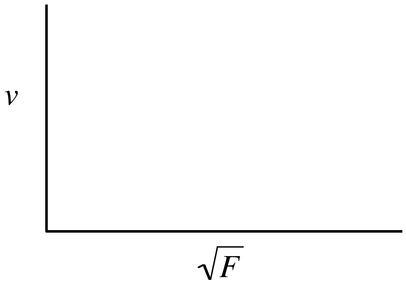
Lab B. Waves

Pre-Lab Assignment

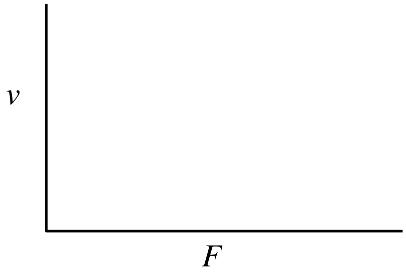
1. The theoretical speed v of a transverse wave in a flexible cord of length density (mass per unit length) μ under tension F is $v = \sqrt{F/\mu}$. Suppose a particular cord does not elongate under tension. If, in an experiment, you pull the cord to different tensions F and measure the speed v of transverse waves in the cord at those different tensions, what should (theoretically) a graph of v vs. F look like? A graph of v vs. $\sqrt{F}$? Sketch both predictions in the axes provided.

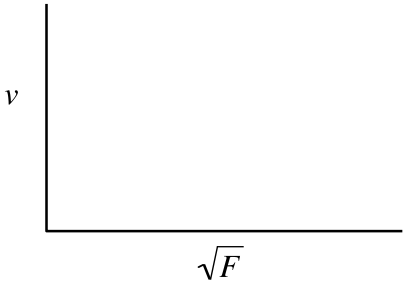




2. Suppose that the cord does elongate under tension, like a bungee cord. How should length density μ change as tension F increases?

3. If the cord elongates under tension, what should a graph of v vs. F look like? A graph of v vs. $\sqrt{F}$? Sketch both predictions in the axes provided.





Lab B. Waves

MECHANICAL WAVES

Problem

- 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?

Equipment

long coil spring mounted at one end to the wall; loose coil spring (Slinky); electronic frequency generator, vibrator, elastic cord, hanging weight for tension, table-mounted pulley; ripple tank, motorized straight pulse generator, straight barriers

Apparatus

In this lab, you will use four systems. The first, as shown in Figure 1, is a long coil spring that is attached to the wall at one end. You can create and examine a variety of waves in the spring.

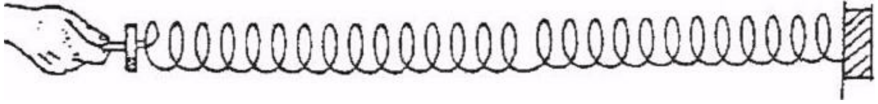


Figure 1. A coil spring.

The second system consists of a mechanical vibrator, frequency generator, stretchable string, clamp, pulley, and hanging weights, as shown schematically in Figure 2. This system will be used to generate standing waves on the string.

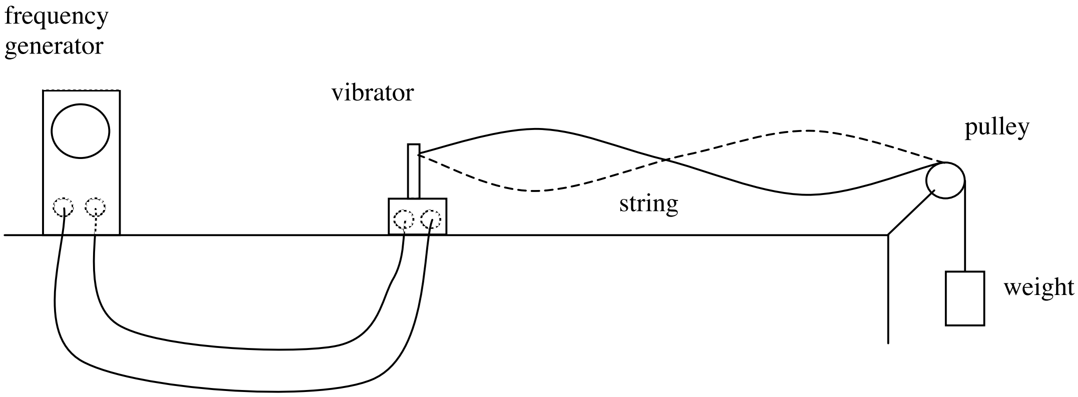


Figure 2. Diagram of a mechanical vibrator and string.

The third, as shown in Figure 3, is a ripple tank. The tank is a transparent pan of water which is elevated above the table. A motorized probe is used to disturb the surface of the water. A lamp is placed above and directed onto the tank, while a white screen is placed below the tank. The lamp and screen are used to project the water disturbance patterns in the same manner that a film is projected onto a movie screen. Several differently shaped barriers can be placed in the pan of water.

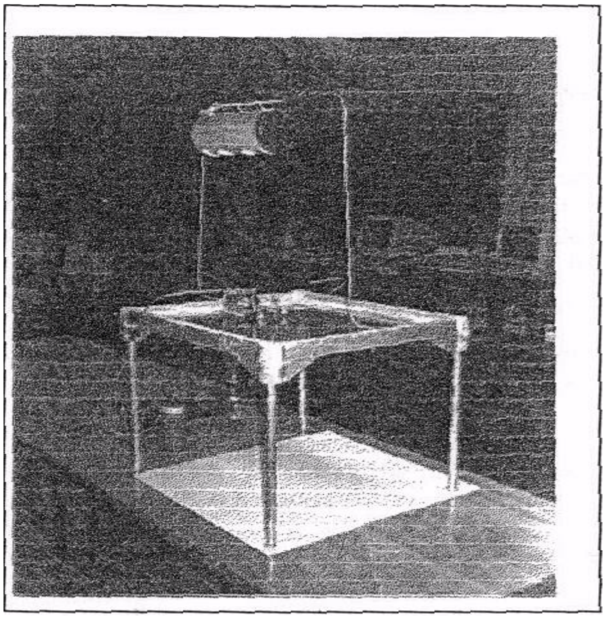


Figure 3. A ripple tank.

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 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.

Any wave shape that repeats 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 complete cycle of a wave takes to pass that position is the wave period, T. The period is related to the frequency by $T = 1/f$. The speed at which the wave travels through its medium is its propagation speed.

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 complex combinations of these two limiting types.

INVESTIGTION 1: TRANSVERSE WAVES ON A SPRING

1. We begin by studying waves traveling in one dimension using the coil spring. Grasp the free end of the coil with your hand and stand at a distance from the secured end so that the spring is slightly stretched. Generate single and multiple pulses with your hand. Try to make different wave shapes. What different shapes did you try to make? How did you try to make them? What shape were the resulting waves?

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. Change the propagation speed (*not* frequency) and describe what factors you must adjust to do this.

4. Place a piece of tape or yarn around one coil of the spring at any point along the length of the spring. Watch the motion of the tape as a wave pulse goes by. Does the tape move? If so, in what direction? Is this direction different from the direction that the wave travels?

5. Generate another wave pulse on the spring. Observe the reflection of this pulse from the fixed end of the spring. The wave that arrives at the fixed 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)? What is the direction of the displacement of the coils as the **reflected** wave passes? Describe *both* the incident and reflected waves. A sketch may help.

6. Generate a standing wave on the spring. The wave has a particular wavelength. How can you change the wavelength? Find two different ways to do this.

INVESTIGATION 2: LONGITUDINAL WAVES ON A SPRING

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

2. Estimate the speed of one of the pulses. 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. Place a piece of tape around one coil of the spring at any point along the length of the spring. Watch the tape as a wave pulse goes by. Does the tape move as the wave travels through it? If so, in what direction? Is this direction different from the direction that the wave pulse travels?

4. Set up a wave train of compressions and rarefactions. Can you set up longitudinal standing waves in the spring? Describe what happens in the spring.

INVESTIGATION 3: WAVELENGTH AND FREQUENCY OF A STANDING WAVE

You will use the mechanical vibrator 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 2. 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.

1. The cord may have many knots in it when you receive it. Untie the knots and measure the length and mass of the slack 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 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. Do all frequencies 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 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, for a total of four sets of data. Try to get a wide range of frequencies and wavelengths!

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; Slack length ______ m; Stretched length ________ m

Length density _______ kg/m

Frequency (Hz)	Wavelength (m)	Speed (m/s)	$\sqrt{F/\mu}$

Tension _______ N; Slack length ______ m; Stretched length ________ m

Length density _______ kg/m

Frequency (Hz)	Wavelength (m)	Speed (m/s)	$\sqrt{F/\mu}$

Tension _______ N; Slack length ______ m; Stretched length ________ m

Length density _______ kg/m

Frequency (Hz)	Wavelength (m)	Speed (m/s)	$\sqrt{F/\mu}$

Tension _______ N; Slack length ______ m; Stretched length ________ m

Length density _______ kg/m

Frequency (Hz)	Wavelength (m)	Speed (m/s)	$\sqrt{F/\mu}$

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

11. The theoretical speed of a wave in a string is $v = \sqrt{F/m}$, where v is wave speed, F is tension, and μ is length density.

(a) Verify the units in this formula. Show your work.

(b) Compare v to $\sqrt{F/m}$ for the different waves you observed. Does the formula apply?

INVESTIGATION 4: THE RIPPLE TANK

1. Using the supplied motorized agitators, produce a series of straight wave pulses. Observe their propagation by looking at their projection on the table. Now produce a series of circular wave pulses by dipping a pen or other pointed object into the water. Sketch an instantaneous position of wave fronts for each type of pulse. Draw the wave rays on your sketch. Remember that wave rays show the direction the waves travel. Wave rays are always perpendicular to the wave fronts.

straight pulse	circular pulse

2. Using a *single straight pulse*, observe the incident and reflected waves as they collide with a straight barrier. Vary the angle between the straight barrier and the wave pulse. How is the direction of the reflected pulse affected? Sketch the wave pattern, showing both wave fronts (to show the momentary positions and shapes of the wave crests) and representative wave rays (to show the direction of wave travel).

3. Place two long, straight-edge barriers into the tank in a line parallel to the wave front of the straight pulse, leaving a small gap between the two barriers, as — —. What happens to the pulse after it encounters the gap? Again, sketch the wave pattern, including wave fronts and representative wave rays.

4. Using a single circular pulse, observe and describe the incident and reflected waves as they collide with a long, straight barrier. The reflected waves, like the incident waves, each make an arc of a circle. From what point do the reflected waves appear to emanate? (That is, where is the center of their circle?)

5. Where does the center of the reflected waves appear to lie relative to the source (center) of the incident waves?

6. Sketch the pattern of the incident and reflected waves. Include in your diagram some representative rays for both the incident and reflected waves.

THE NATURE OF SOUND

Problem

- What is resonance?
- How is sound created and propagated?
- How can we determine the speed of sound in air through the use of air column resonance?

Equipment

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

INVESTIGATION: RESONANCE TUBES AND THE SPEED OF SOUND

This station is similar to the "standing waves in a string" activity of last week. There, 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 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, as Figure 1 shows. (Actually, the antinode is a bit beyond the open end of the tube.)

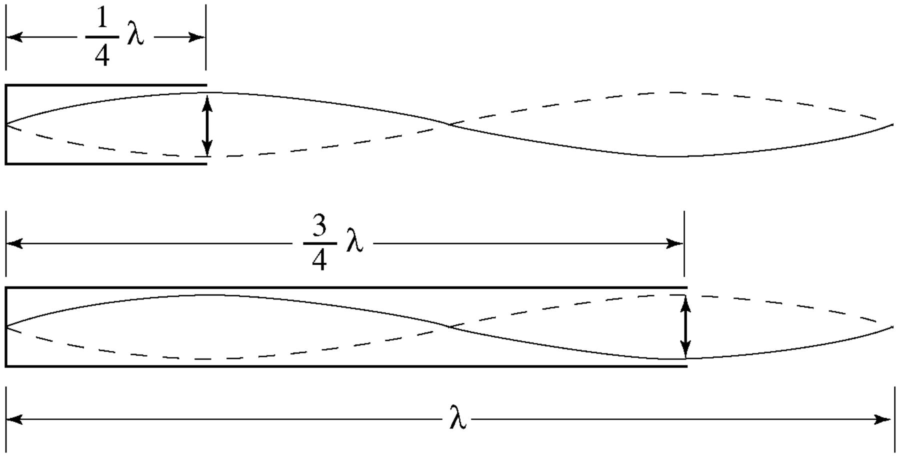


Figure 1. Resonance tubes and their standing waves. Standing waves have a node at the closed end of the tube and an antinode at the open end of the tube. **Note**: Sound waves are actually longitudinal, not transverse. The amplitudes drawn here represent how much the air molecules at the different positions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

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 top opening of the inside tube to the water (see diagram).

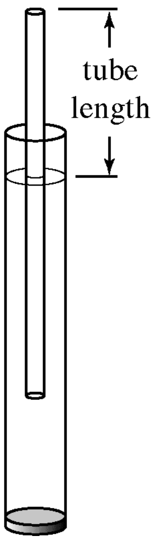


Table 1. Resonance Tube Positions

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.

Questions:

1. Compute the difference in the tube length between the first and second resonance positions for each trial. Enter in Table 1.
2. Compute the wavelength for each trial 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 1.
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/frequency, so
   speed = wavelength · frequency. Enter these values also into Table 1.
4. Are the three values for the speed of sound in air for each frequency similar? Why should or shouldn't they be similar? If the three 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. The speed of sound in air varies with air temperature. As the air temperature increases, the speed of sound increases. 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 value for the speed of sound in air that you found above consistent with this trend?

6. Sound travels slightly faster in humid air than in dry air. Why?

EXTENSION: OVERTONE

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

2. Using the wave velocity determined earlier, find the frequency of the overtone.

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

Lab B. Waves

Post-lab Assignment

1. For some types of waves, the speed of the wave is different for different frequencies. This phenomenon is known as *dispersion*. Do the transverse waves in the stretched cords show dispersion?

2. Do the sound waves in the resonance tubes show dispersion?

3. Using a spreadsheet or the Vernier software, make a plot of v vs. $\sqrt{F}$ for the transverse string waves. Fit it with a $y = Ax$ curve. Is the fit fairly good?

4. Now plot v vs. $\sqrt{F/\mu}$ using the length densities μ you determined for each F. Fit it with a $y = Ax$ curve. Is the fit any better or worse than the fit to v vs. $\sqrt{F}$?

5. When you worked with the resonance tubes, you determined the speed of sound from measurements of tube heights. There is uncertainty in your tube height measurements. How does it affect your final estimates of wave speed?

   Download the spreadsheet from http://www.barransclass.com/phys1210/LabB.xls.

   The spreadsheet has spaces to enter your measured tube heights and their estimated uncertainties σ. It adds normally-distributed random "measurement errors" with standard deviation σ to the tube heights, and calculates wavelength and wave speed from those simulated "measurements." It generates new random numbers whenever a new quantity is entered in any cell in the spreadsheet: typing "1" in the cell to the right of the table is a convenient way to trigger a new batch of random "measurement errors."

   Enter your measured tube height values and estimated uncertainties. Run a dozen or so batches of random numbers, recording the calculated wave speeds from each batch. The standard deviation of those speeds is a good estimate of σ_v, the uncertainty in the calculated speed of sound. What is σ_v for each frequency?

f (Hz)	simulated wave speeds v	σ_v