

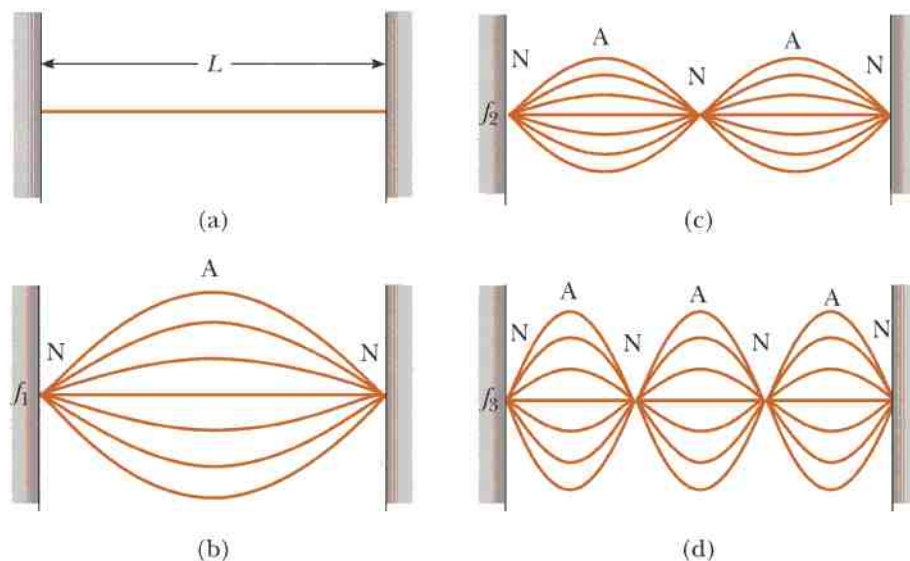
Introduction

This lab and the next are based on the physics of waves and sound. In this lab, transverse waves on a string and both transverse and longitudinal waves on a slinky are studied. To describe a wave we need to know how the displacement along the wave varies with position in space (this is the type of information you would be able to get from a photograph or snapshot). We also need to know how the amplitude of the wave changes as time passes at a fixed position in space (like standing on a pier and watching the ocean waves come past). This is referred to as a history graph. Mathematically all this information can be included in a single equation that describes how the displacement varies as a function of both time and position. If the displacement varies like a sine or cosine function the wave is called a harmonic wave. This type of wave is generated by an object moving with simple harmonic motion.

Standing Waves: The lab will also cover “standing waves” which are formed when two waves of identical frequency and amplitude travel in opposite directions down a rope at the same time. This often happens when a wave is reflected at one end of the rope. The resultant motion of the rope is often chaotic, but under some circumstances it can be surprisingly ordered. The ordered type of response is called a “standing wave” and is described in section 14.8 of your text book.

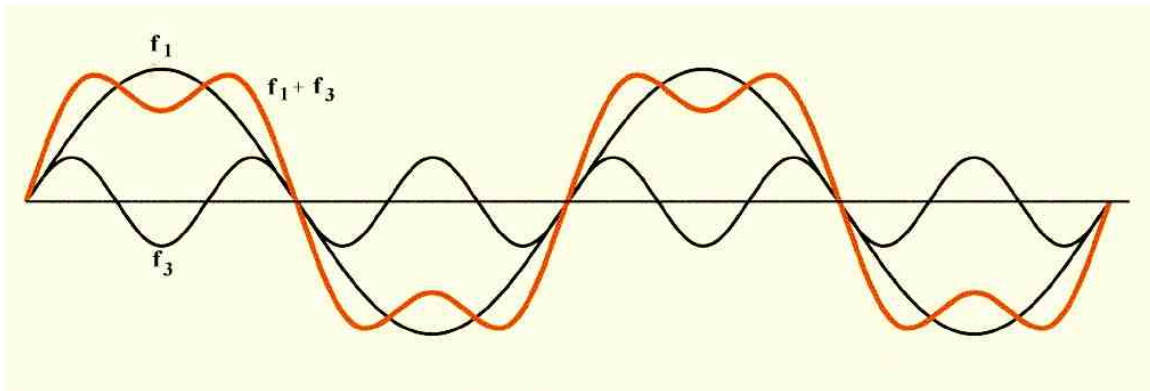
The figure shows the first three modes of standing waves. Positions where the displacement is a minimum are called nodes and where displacement is a maximum are called antinodes. Standing waves happen when the wavelength is related to the string length by the formula $\lambda = 2L / n$, where L is the string length and n is an integer, i.e., 1,2,3,etc. In figure (b) below, $n=1$, in (c) $n=2$ and in (d) $n=3$.

The situation in (b) is called the fundamental frequency, which is written as f_1 . The frequency of mode $n=2$ is twice the fundamental, and for $n=3$ is three times the fundamental, and so on. We will make standing waves with a rope and a slinky, then explore these patterns in more detail in experiments C and D of the lab.



Harmonic Content of a Wave: Experiments C and D in the lab explore waves that are not pure sinusoidal variations. A sound that is generated by something moving with pure simple harmonic motion makes a steady note with only one frequency present. A tuning fork comes very close to this when it is struck gently. The human voice can also generate almost a pure single frequency with an unforced hummmmm. But most musical instruments make a more complex waveform. For the same “pitch” of note, the character of the sound is different. Most people can recognise an organ from a cello or a saxophone, even when they all play the same note. For these instruments, their waveforms are not sinusoidal waves of a single fundamental frequency. The way they generate sound includes higher harmonics of the fundamental frequency, and each instrument has its own “fingerprint” showing the relative contributions of each of the harmonics. For waves on a the string, the fundamental has $f_1 = v/2L$, and the harmonics are $f_2 = 2f_1$, $f_3 = 3f_1$, etc. Characteristics of a stringed instrument will determine the relative amplitudes of the harmonics and this will determine whether the instrument “sounds good” and whether it costs a few dollars or a many thousands of dollars. Musicians sometimes refer to harmonics as “overtones”. This refers to the same idea of having frequencies present at twice the fundamental, three times the fundamental, etc.

The analysis of the “quality of sound” into its harmonic content, means finding the relative amplitudes of the harmonics. The mathematics of this process can be found in many math and physics texts, but is not necessary for the understanding of the idea of harmonic content. In this lab we will use the logger-pro analysis to calculate the exact harmonic content of the sounds we generate. The usual way of presenting this information is with a graph of amplitude for each frequency interval. The computer algorithm that generates this data is called a “Fast Fourier Transform”, or FFT. So the graph of amplitude as a function of frequency is also, by convention, labelled an FFT.

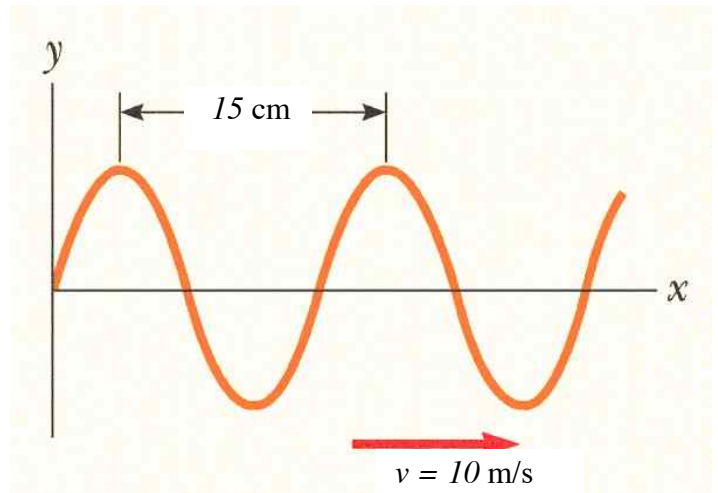


As an example the figure shows how a wave with frequency f_1 (the fundamental) adds with a wave of frequency $f_3 = 3 \cdot f_1$ to form another periodic wave that has a more complex structure. You can consider the complicated wave to consist of the sum of the two sinusoidal waves. Mathematically it can be shown that any periodic waveform can be represented to arbitrary accuracy by a sum of harmonic waves.

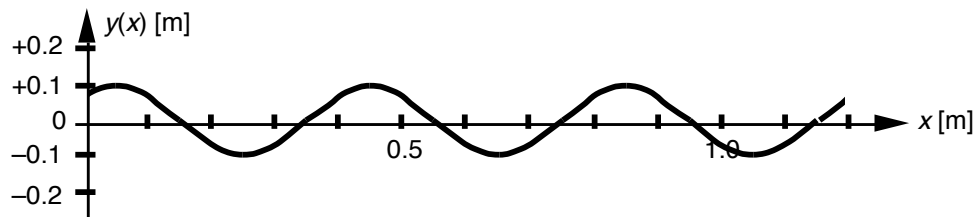
Before coming to lab you should read sections 13.8 to 13.13 of Chapter 13 and sections 14.1 to 14.4, 14.7 to 14.12 of Chapter 14 of Serway and Faughn.

Pre-Lab Questions:

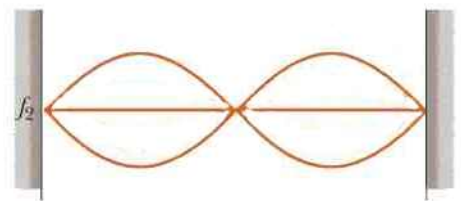
1. The figure shows a transverse harmonic wave moving to the right with a speed of 10 m/s and a wavelength of 15 cm.
- What is the period and frequency of this wave?
 - If the wave is on a string that is 28 m long and is under a tension of 80 N, what is the mass of the string?



2. A machine tugs sideways on an elastic rope with a frequency of 4.5 Hz. A graph of the transverse displacements of this rope wave at $t = 1.0$ s as a function of position is shown below.

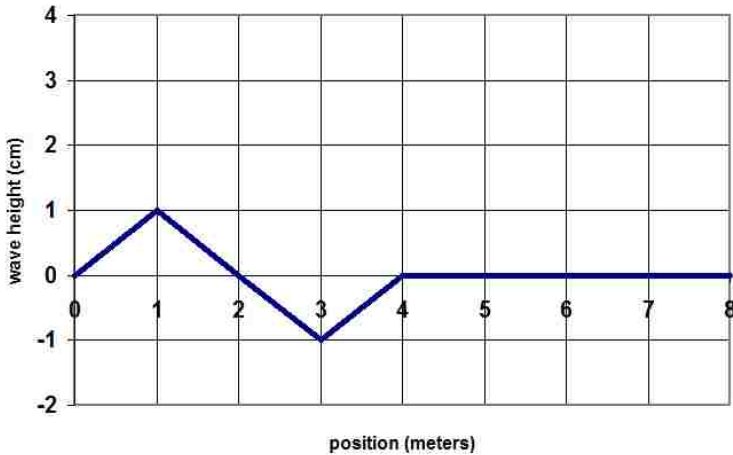
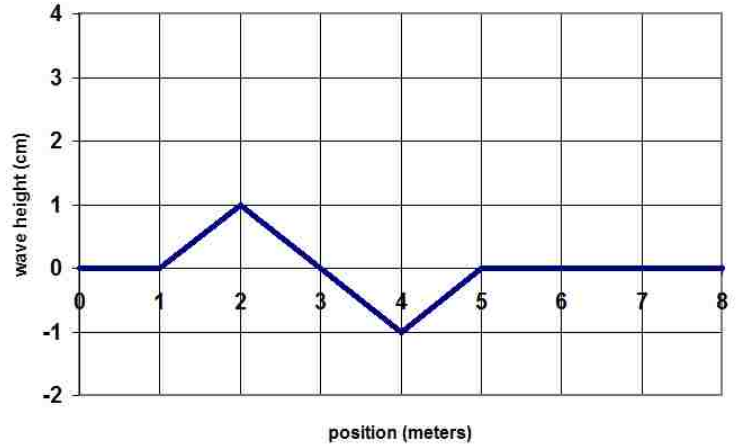


- What is the velocity of waves on this rope?
 - If the frequency of the machine tugging on the rope is doubled to $f = 9.0$ Hz yet the tension in the rope remains the same, what is the new wavelength of waves on this rope? What is the new velocity of waves on this rope?
3. The figure to the right shows a standing wave on a string.
- Draw the standing wave that occurs if the string tension is quadrupled while the frequency is held constant.
 - Suppose the tension is tripled while the frequency shaking the string is held constant. Will there be a standing wave? If so how many antinodes will it have? If not, why not?



Group Activity:

The following two graphs give snapshots of a wave pulse at $t = 0$ sec and $t = 1$ sec. What is the wave speed? Draw a **history graph** for $x = 4$ m, and for $x = 6$ m.

Wave at $t = 0$ secWave at $t = 1$ sec**Experiment A: Transverse Waves on a String**

You should have a piece of rope several meters long. Next to your lab bench you will find a length of red tape on the floor. With a person at each end of the rope stretch it out straight on the floor so the center of the rope is at the tape and the rope is perpendicular to the tape. You don't need to pull on the rope, let it be a little slack. Send a pulse down the rope by quickly moving one end about 6 inches out and back.

- Observe the motion of the mid point of the rope as the pulse passes through it. Wrap the rope with a small piece of colored tape at its mid point. This is also where the rope reaches the tape on the floor. Observe the motion of the tape on the rope at this point with reference to the tape on the floor.
- Which way does the pulse move? Which way does the piece of tape on the rope move? Are they in the same directions?
- Describe in words how the rope moves. What actually moves down the rope?
- Observe the reflection at the end. After reflection, is the pulse the same way up or is it upside down?

Now try to see if you can observe what happens when two pulses pass each other going in opposite directions. Both people holding the rope should now send pulses at the same time. This will take some practice.

- In your own words, write in your lab books what you understand from the "principle of superposition".
- If both pulses have displacements in the same direction would you expect the displacement where the pulses overlap to be larger or smaller than the individual pulses?
- Try making one positive displacement pulse and one negative displacement pulse

and observe the overlap region.

- Are your observations consistent with the principle of superposition?

Finally, see if you can create “standing waves” on the rope. Refer to the introduction (or Serway and Faughn section 14.8) to review how standing waves are formed. Hold the rope fairly loosely on the floor as you did before. Move one end of the rope backwards and forwards with a smooth periodic motion, and hold the other end still. Now you should have waves that are almost sine waves travelling down the rope all the time. They are reflected at the end and move back along the rope in the opposite direction and with inverted displacement.

With some practice you should be able to make standing waves like those shown in the figure in the introduction. The situation with two antinodes (f_2 , or $n=2$, part (c) of the figure in the introduction) is the one to try for first. Show your TA when you can do this. Then try for f_1 , $n=1$, which is also called the fundamental and is (b) in the figure, and finally for f_3 , $n=3$ which is harder to achieve. Are the frequency ratios approximately consistent with what you expect?

Experiment B1: Longitudinal Waves on a Slinky

Please do not hold the slinky vertically at any time. The slinky’s unsupported weight is enough to exceed its elastic limit and make permanent deformations. If this occurs students in following labs will not be able to do this activity.

- Gently stretch the slinky across the length of the lab bench with a person holding each end. Use the full length of the table and the full length of the slinky. Are the coils evenly spaced?
- Keeping one end fixed, move the other end about 5 cm (2 inches) in and then back out. Do this as quickly as you can. The motion shortens the slinky for a very short period of time and sends a pulse down the slinky. How can you tell a pulse is travelling along the slinky? Does the pulse reflect off the fixed end?
- Attach a small piece of colored tape to a coil near the middle of the slinky. Watch what happens to that coil as the pulse passes. Which way does it move first? Does it end up in the same position where it started? What is it that has actually travelled down the slinky?

Experiment B2: Transverse Waves on a Slinky

This is best done on the floor where you have more space. Stretch the slinky about the same amount as for experiment B1, but position it so the mid point of the slinky is at the red tape stuck on the floor. Hold one end still and move the other periodically sideways back and forth as you did with the rope at the end of experiment A. You should be able to find the frequencies needed for standing waves with one, two then three antinodes. When you can make the $n=3$ wave show your TA.

Experiment C: Measuring Frequency and Harmonic Content

We will start with a tuning fork and determine the frequency and “harmonic content” of the sound. Refer to the introduction or section 14.12 of your text for a review of the idea of harmonic content. Next we will use two tuning forks of slightly different frequencies to investigate the phenomenon of “beats” (Serway and Faughn section 14.11). Finally in this experiment we will investigate the harmonic content of the human voice when making different types of sound.

- C1.** Use the tuning fork attached to the wooden resonance box. Put the logger pro microphone inside the resonance cavity. Start the “*Mathematics of Music*” file. Page 1 shows the pressure wave and a graph showing the amplitudes of the harmonics or overtones. This is labelled FFT. Page 2 shows the table of data for the harmonic analysis. Samples are taken of the microphone output at 10,000 Hz for a time period of 0.2 sec. Hit the tuning fork with the rubber mallet and observe the pressure wave.
- From the graph measure the period of the pressure wave and calculate its frequency. (Do this by measuring the elapsed time between successive waves). Compare your observations with the marking on the fork. Observe the shape of wave. Is it a sinusoidal wave or is it more complicated?
 - Examine the graph of amplitude vs. frequency. Note where the maximum amplitude occurs. What frequency is this? Compare this to the frequency stamp on the fork. Are there other frequencies that contribute to the sound?
 - Go to page 2 and look at numbers for the FFT. Find the maximum amplitude in the table, and record the frequency. Is this consistent with the label on the tuning fork?
- C2.** Hum a note into the microphone. Try to hit same note as the tuning fork.
- Observe the shape of the waveform, measure the period, and calculate the frequency. Did you hit the exact same frequency?
 - Examine the FFT. Are any other frequencies present? Repeat, and test to see how close you can get to a perfect sine wave.
 - Have each student do this for their own hums, use different notes, and have fun.
- C3.** Nominate the group member who you think can best reproduce the tuning fork note. Let this student go first for this experiment, but then have each student examine their own hums and aaahs.
- Repeat the hum experiment, look at the FFT
 - Keeping the same note, sing “aaaaaaaaa” into the microphone, note what happens to the shape of the pressure wave, note what happens to the FFT
 - Keeping the same note, sing “eeeeeeee” into the microphone, does this have a different “harmonic content”?
 - Breathe through your teeth to make a hiss sound, and look at the FFT for this. “White noise” has all frequencies present with equal amplitudes. Is the hiss white noise?
 - Finally, leave the microphone open to room noise. Are there specific frequencies present? Can you identify their origin?

C4. This section uses two sound sources that are close but not identical in frequency. Review section 14.11 of your text for the mathematical details of the phenomenon of “beats”. Test the other tuning fork on your table.

- Both tuning forks should be identical. Are they at the same frequency?
- Place both tuning fork bases side by side with the open ends facing the same direction
- Add a clamp (or a lump of clay) to one leg of one of the forks about half way up. Hold the two forks so their resonant cavities touch, and hit both forks. Listen to both. What happens?
- Change the data acquisition time to 1 second and the graph limit to 1 second for data display. Put the microphone in one of the resonance boxes and record the pressure wave. Is this consistent with what your ears tell you?
- Move the clamp to the top of the leg and listen. Do the beats get faster or slower?
- Move the clamp to the bottom of the leg and listen. Do the beats get faster or slower?
- Adding the clamp changes the frequency of the tuning fork. Describe where to put the clamp to change the frequency the most.

Experiment D: Waves on string

The frequency of the fundamental wave on a string is given by $f_1 = v / 2L$ where v is the speed of the wave on the string and L is its length. We also know that the speed of the wave changes with the tension in the string and the mass per unit length with the formula $v = \sqrt{T/\mu}$, where μ = mass per unit length of the string. So we expect for a given string that as the tension increases, the speed of the wave increases and the fundamental frequency increases. In this experiment our “string” is a steel wire. The **total** mass of the wire is 1.1 g and the **total** length of the wire is 136 cm.

- What is the μ for the wire? If $T = 25\text{N}$ what is the speed of a wave on this wire? If the wire has $L=100$ cm what fundamental frequency would you expect? Can you hear this frequency with your ears?
- Take the blue box with single string. Add about 2 kg of mass to the 0.5 kg holder at the free end. **NOTE: Do not exceed 5 kg on the holder. The string will break.** Hold the microphone just outside the open hole of the blue resonance box, pointing at the box. Use the full length of the wire (100 cm). You may need to briefly lift the wire off the support to alleviate friction forces at the support. If frictional forces are small the tension in the horizontal part of the wire should be the same as the tension just above the hanging mass. Pluck the string gently with your fingers and record both the pressure wave and the FFT. What frequencies are present? Do this several times to test the repeatability of the sound you make. Can you see a difference between a gentle pluck with the soft part of your finger and a twang with the finger nail?
- Are the harmonics integer multiples of the fundamental? What is the frequency of the fundamental? How many harmonics can you see? Show that they are (or are not) integer multiples of the fundamental.
- If you lightly pluck the wire at 25 cm or 75 cm when you hold your finger just touching the wire at its center point (50 cm) what happens? Measure the lowest

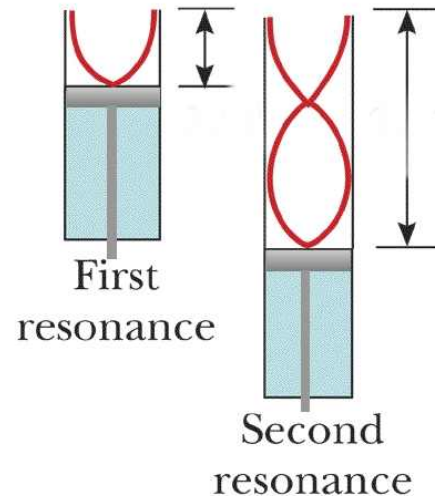
frequency of this configuration and observe with your eyes how the wire is moving. Is this a harmonic of the fundamental? Which one?

- Finally change the tension in the wire by doubling the mass it supports. How does this change the tension? Calculate what fundamental frequency you now expect for the full length of the wire with the new tension. Finally remeasure the fundamental frequency and compare your calculations with your measured data. Are your observations consistent with theory?

Experiment E: Resonance in a Pipe

You should have a sound source with a fixed frequency, like a tuning fork. You also have a pipe and a bucket of water. Hold the pipe with one end under the water. By raising or lowering the pipe you can vary the length of the air column in the pipe. Put the tuning fork close to the open end of the pipe and hold it fixed relative to the pipe. Slowly move the pipe and sound source up (both together) to make the air column in the pipe longer. To start, try the experiment to determine if you can find any resonances.

- Assume your sound source has a frequency of the tuning fork and that the speed of sound in air is 340 m/s. What is the wavelength of the sound?
- Is there a node or an antinode at the top end? Why?
- Is there a node or an antinode at the bottom end? Why?
- The first resonance is shown in the figure. What do the red lines represent? How does the length of the air column in the pipe relate to the wavelength of the sound?
- Repeat this exercise for the second resonance.
- Draw the third, and fourth resonances.
- Measure the pipe length and the water depth. What are the maximum and minimum air column lengths you can make?
- Record the frequency of your tuning fork and calculate the wavelength if $v_{\text{sound}} = 340 \text{ m/s}$. Calculate all the pipe lengths where you should get resonance for the frequency of your tuning fork.
- By experiment find and record the tube lengths for resonance.
- Calculate the wavelength of the sound wave from your data and compare with the calculation you made based on the marked frequency of the fork.



Conclusion:

1. Please write a conclusion for the section of the lab that your TAs specified.