Vibrating strings are important sound sources, particularly for musical instruments. Violins, guitars, pianos, and a whole host of instruments make sounds which begin with vibrating strings. The vocal cords are similar to vibrating strings. Furthermore, strings provide an exact visual analogy to air columns, which are used in many other instruments and which allow humans to control the timber of the sounds that they make in speech.

The best way to "get a feel" for standing waves is to make some yourself on a long rope or spring. The waves that do not appear to move — are called standing waves. Their wavelike pattern results from the interference of two or more waves, in the case of strings, from an interference (superposition) of the generated wave and its reflection from the ends. A standing wave has regions of minimum and maximum amplitude called nodes and antinodes.

1 Standing Waves on a Spring with Fixed Ends

With the spring at 15 ft, oscillate your arm back and forth, sending regularly spaced pulses down the spring. Vary the frequency of oscillation until you set up a standing wave that looks like this:

Each hump is one half of a wavelength, so this spring now has one and a half wavelengths on it. Since the spring is 15 ft long, the wavelength of the standing wave is 10 ft. Wavelength is the length of two humps, and is symbolized by the lower case Greek letter λ (lambda).

With 3 humps on the spring, measure the amount of time required to make 20 complete oscillations. This is twenty periods.

What is one period of oscillation of this standing wave?

What is the frequency of oscillation?
I. Create a standing wave with one wavelength on the spring (two humps). What is \( \lambda \)? (It is not 2. If you think the wavelength is 2, ask for help.) Measure the amount of time required to make 20 complete oscillations. This is \( 20T \). What is the period of oscillation of this standing wave?

II. Put this and the previous data into the appropriate spaces in the table below. Then complete the table by setting up standing waves with two complete wavelengths and with one half of a wavelength, measuring \( 20T \) for each one. Include units. Leave the last column empty.

<table>
<thead>
<tr>
<th>looks like</th>
<th># humps</th>
<th>( \lambda )</th>
<th>( 20T )</th>
<th>( T )</th>
<th>( f )</th>
<th>( f_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>10 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

III. The frequencies should form a harmonic series. To find out if they do, divide each frequency by the fundamental frequency \( f_1 \). Label the last column \( \frac{f}{f_1} \) and fill it in.

IV. Are the other frequencies two, three, and four times the frequency of the fundamental?

Do not be discouraged if your results are not perfect. It is difficult to time the periods of the long spring accurately. Unfortunately, the fundamental is usually the least accurate of the measurements. If you find, for example, that the harmonics are 1.6, 2.5, and 3.4 times the fundamental, the problem is probably that the \( f_1 \) you calculated is too large. You might try assuming that the upper harmonics are correct and try to determine the expected fundamental.
2. Standing Waves on a Spring with a Free End (optional, extra credit)

Different kinds of standing waves can be created on a spring on which one end is free to move back and forth. To study these types of standing waves, have one person hold the end of the spring which is attached to the end of the spring. The spring itself should still be stretched to 15 ft; the string just serves as a way to hold the spring without restricting its side-to-side movement. If the spring is stretched to the same length as before, then the speed of waves on the spring will also be the same as before.

Set up a standing wave that looks like this:

This is one and a quarter wavelengths. Each bulge in the spring is \( \frac{1}{2} \lambda \), so the part left over at the end, half a bulge, is \( \frac{1}{4} \lambda \). Since the spring is 15 ft long, the wavelength is \( \frac{15 \text{ ft}}{1.25} = 12 \text{ ft} \). You should be able to check this by counting the number of floor tiles that are taken up by the full wavelength.

1. Vary the frequency to generate different patterns. Notice that every pattern you make has a quarter of a wavelength (half of a hump) at the end held by the string. The lowest frequency pattern should have only half a hump (one-quarter wavelength).

b. Measure the period of the four lowest frequency standing waves you can make, filling in the table below in the same way as you did for the fixed-end spring. Remember that the string is not part of the standing wave pattern, and should not be shown in the picture you put in the "looks like" column. It is more difficult to determine \( \lambda \) for the free-end standing waves. The easiest way is to divide the length of the spring (15 ft) by the number of wavelengths on the spring. For this reason, an extra column for "number of wavelengths" has been added to the table.

<table>
<thead>
<tr>
<th>looks like</th>
<th># humps</th>
<th># wavelengths</th>
<th>( \lambda )</th>
<th>( 2\hbar )</th>
<th>( T )</th>
<th>( f )</th>
<th>( f/\hbar )</th>
</tr>
</thead>
</table>

6: Standing Waves; Slinky -3
<table>
<thead>
<tr>
<th></th>
<th>2 1/2</th>
<th>1 1/4</th>
<th>12 ft</th>
</tr>
</thead>
</table>

c. How does the fundamental frequency compare to the fundamental for the fixed-end spring? Why?

d. Do the frequencies form a harmonic series?

6: Standing Wave; Slinky-4
1. **The Standing Wave Apparatus**

It is difficult to get accurate results for standing waves with the spring and stopwatch (last week’s Lab 4B). In contrast, very accurate results can be achieved using the apparatus provided in the lab room. A string is driven by a speaker which is controlled by the function generator. Measurements are made on the frequency counter.

1. Turn on the counter and function generator. Set the frequency to 90 Hz and turn the amplitude all the way up. Move the clear plastic “bridge” until you get a fundamental standing wave. Play with it until you get the largest possible amplitude. If the hanging mass which provides the tension is swinging around, it will make it hard to adjust, so you may want to stop the mass if it is swinging. Once you get the best standing wave, do not move the bridge until you see you should do so in the manual. Record the length of the string.

\[ L = \]

2. It is important to know the frequency of the fundamental as accurately as possible. Switch the GATE knob to the 10 s position, wait 20 seconds, and record the frequency (to the nearest 0.1 Hz) in the table below. Then switch the counter back to the 1 second gate for future measurements.

3. Turn the dial on the function generator to increase the frequency until you get the next standing wave, which should have two humps. Record the frequency in the table below.

4. Continue in this way until you get to the eighth harmonic. Then turn down the amplitude while you do the calculations in the next part.

<table>
<thead>
<tr>
<th># humps</th>
<th>f (Hz)</th>
<th>( f/1 )</th>
<th>Harmonic number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Calculate \( f_1 \). You should find that these values are very close to being whole numbers. Round these values to whole numbers and put the result under "Harmonic Number." It should be obvious that the number of humps is the number of the harmonic for a string fixed at both ends. Use this knowledge to predict the frequency which will be necessary to create the 9th harmonic. Then try it.

2. Speed and Harmonics

The speed of a wave on a string depends on the stiffness, density, and tension in the string. It does not depend on the wavelength of the wave sent down the string. In the same way, the speed of sound in air does not depend on the type of sound.

When standing waves are created on a string, the wavelength, frequency, and speed are related according to the formula \( v = \lambda f \).

In the lab last week (Lab 4B), you set up standing waves on the long spring. Copy your data from that lab for the long spring into the table below. Then calculate speed \( v \) for each standing wave. Notice that in this case (both ends fixed) the wavelength \( \lambda \) is equal to twice the length of the string, \( L \), divided by the number of humps: \( \lambda = 2 L / (\# \text{ humps}) \).

<table>
<thead>
<tr>
<th># humps</th>
<th>( \lambda )</th>
<th>( f )</th>
<th>( v )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Is \( v \) roughly constant?

2. Are these \( v \)'s similar to the \( v \) which you measured directly by timing a pulse going down the spring (recall that this was the first thing you did with the springs)?

The data you took with the standing wave apparatus should be much more accurate. Determine the velocity of waves on the string for the four harmonics indicated in the table.
<table>
<thead>
<tr>
<th># humps</th>
<th>$\lambda$</th>
<th>$f$</th>
<th>$v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Is the velocity constant?

3. LENGTH AND FREQUENCY

You have seen that a vibrating string can vibrate at a lowest frequency, called the fundamental, and also in an entire harmonic series of frequencies above the fundamental. The frequency of the fundamental can be increased either by making the string shorter or by making the speed higher. The speed can be increased either by increasing the tension in the string or by making the string lighter (for a given length).

Vocal chords are not really chords, but are more like flaps. Nonetheless, the factors of length, weight, and tension affect vocal chords and other vibrating objects in the same way that they affect strings. Thus, women’s voices are generally higher in pitch than men’s because they are both shorter and lighter. People can change the pitches of their voices by increasing the tension in the chords with muscles.

Speed, frequency, and wavelength are related by the equation

$$v = \lambda f$$

For a string of fixed length, only certain wavelengths will fit onto the string, resulting in a harmonic series. The least number of wavelengths which will fit onto a fixed string is one-half wavelength, so for this situation $\lambda = 2L$. Therefore, for a string fixed at both ends,

$$v = 2Lf_1,$$

where $f_1$ is the fundamental frequency. Since you have already studied the harmonic series in some detail, the standing waves referred to in this lab will always be fundamental standing waves.

1. Hang 500 g (50 g weight holder + 450 grams) from the end of the string. Put the plastic bridge at 90.0 cm (0.900 m).

6: Standing Wave in Strings - 3
2. Set the amplitude of the function generator to maximum. Find the frequency that gives the best fundamental standing wave. *Best*, in this case, means largest amplitude. Measure the frequency with the frequency counter. Record your data in the first row of the data table on the next page.

3. Repeat for $L = 45.0$ cm, 30.0 cm, and 22.5 cm. Look at your data. Use the space here to describe the pattern which you see.

<table>
<thead>
<tr>
<th>$L$ (m)</th>
<th>$f$ (Hz)</th>
<th>prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.900</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$f =$</td>
<td>$=$</td>
</tr>
<tr>
<td></td>
<td>$L =$</td>
<td></td>
</tr>
</tbody>
</table>

4. Use your data to predict what frequency will resonate for a string 50.0 cm long. Show your reasoning and calculations in the space below. Then determine the frequency experimentally and put it in the table above. Also put your prediction in the third column.

5. Repeat for a length of 72.0 cm.

6. Use your data to determine what length of string will vibrate at 280 Hz, show your work below. Then, set the function generator as close as you can to 280 Hz, which will take a little patience. Then move the bridge until you get the best standing wave. Fill in the table.

6: Standing Wave in Strings - 4
7. How well do your predictions compare with the actual values?

8. In the last column of the table put the heading \( v = 2Lf \) (m/s). Then calculate the speed of the wave for each row in the table. Is the speed constant?

You may have answered questions 4, 5, and 6 above using ratios. This is a good approach. However, if you have to answer several questions about the same spring, the table suggests a faster approach. Since the speed of the wave on the string is constant, the best approach is to use the first set of data to calculate the speed of the wave using \( v = 2Lf \). Then use that speed to calculate \( L \) or \( f \) for each new situation. Try it. Use the known speed of the string to calculate the resonant frequency for a length of 43 cm. Then test your result.

4. TENSION AND FREQUENCY (OPTIONAL)

For a string of fixed length it is possible to raise the fundamental frequency by increasing the tension in the string. This is because increasing the tension increases the wave speed. On your apparatus, tension is provided by the weight of a hanging mass; by changing the mass you can change the tension. The tension in the string is the mass multiplied by the earth gravitational constant \( g = 9.8 \text{ m/s}^2 \). In your data table, however, it will be easier to see what is going on if you record the total hanging mass \( m \). You must always remember that the mass hanger already has a mass of 50 g.

1. Put the bridge at 90 cm. Hang 125 g on the string (50 g + 75 g). Find the best fundamental standing wave, which will be quite low for such a small tension. Record the frequency in the table below (next page).

2. Double the mass. That is, put on a mass of 250 g (50 g + 200 g). Find the new frequency. Record your data in the table. Does doubling the tension double the frequency?

3. Measure the frequency for masses of 500 g and 1000 g; put the data in the table.

6: Standing Wave in Strings - 5
Frequency versus Tension
for a string with a fixed length

<table>
<thead>
<tr>
<th>m (g)</th>
<th>f (Hz)</th>
<th>( v_T ) (m/s)</th>
<th>( v_f ) (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Theoretically, the speed of a wave on a string is given by

\[ v = \sqrt{\frac{T}{\mu}} \]

where \( T = (9.8 \text{ m/s}^2) \times m \) is the tension and \( \mu \) is the mass density of the string (measured in g/m).

4. You now have two independent ways to calculate the speed of the wave on the string: from the theoretical equation above, and from \( v = 2Lf \). These speeds should be the same. Complete the table by calculating the speed both ways:

a. Use the equation with \( T \) and \( \mu \) to calculate \( v_T \), the subscript \( T \) standing for Tension. The density of the string has been measured with an accurate balance and determined to be 0.47 grams per meter. If you use mass in grams, \( g \) as 9.8 m/s\(^2\), and \( \mu \) in g/m, you will get the speed in meters per second (m/s).

b. Use the standard equation \( v = 2Lf \) to determine \( v_f \), where the subscript \( f \) stands for frequency.

Are the speeds \( v_T \) and \( v_f \) the same for each value of mass? (Of course, experimental uncertainties in the measurement mean that they will never be exactly the same. However, they should be within a few percent of each other.)

5. Predict the frequency which will resonate for a mass of 1125 g. That is, calculate the speed for a mass of 1125 g using the known density. Then use the speed and the length of the string to calculate the resonant frequency. After you have made your prediction, try it to see if you were right. Put your results below.

6: Standing Wave in Strings - 6
7: SOUND WAVES IN TUBES

INTRODUCTION

So far we have studied oscillations and waves on springs and strings. We have done this because it is comparatively easy to observe wave behavior directly in these media. Sound is also a wave. In this lab we will study the behavior of sound waves in tubes. It is important that you compare the things you observe in this lab to your observations of the more easily visible waves in previous labs. Wave behavior is universal.

A. TRAVELING WAVES IN TUBES

1. Getting Ready

Measure the length of your tube to the nearest millimeter. Then glue the glass plate to the one end of the tube with rubber cement.

L =

2. Hooking up the Pulse Generator

You can make pulses of sound with a pulse generator. You are provided with a pulse generator which is similar to the function generator you have been using, except that it only generates square pulses of various widths and spacings.

a. Hook the VARIABLE output of the 4001 Pulse Generator to the speaker.
b. There are two time adjustments on the pulse generator: Pulse Spacing and Pulse Width.

```
  Pulse Width
     +----------------+
     |                |
     |                |
     |                |
     +----------------+
```

Each one has a control knob with a course setting (which clicks into place) and a fine setting (which is continuously variable). Set the Pulse Spacing to 100 ms and turn the fine adjustment fully clockwise. Set the Pulse Width to 10 μs and turn the fine adjustment to 10 o'clock. Turn on the pulse generator and turn the Amplitude knob to 10 o'clock. You should hear a soft clicking sound coming from the speaker.

3. Looking at the Pulse on the Scope

7: Standing Waves In Tubes - 1
a. Connect a BNC/BNC cable from the TTL output of the generator to the TRIGGER input on the scope and set the Trigger Select to EXTERNAL. Set the sweep rate to 0.1 ms/div and the Trace MODE to NORMAL.

b. Connect Banana/Banana leads from the speaker to the CH1 input and ground. Set CH1 to 1 Volt/div and the input selector switch to AC. Look at channel 1. You should now be able to see the voltage pulse created by the pulse generator if you turn the intensity all the way up. Adjust the fine control of the Pulse Width until the pulse is 0.1 ms long and adjust the Amplitude until the height of the pulse is 1.0 V. The pulse will look like this:

\[
\begin{align*}
&\text{1 V} \\
&0.1 \text{ ms}
\end{align*}
\]

c. Connect the BNC terminal from the microphone to CH2. Set CH2 to 20 or 50 mV/div and the input selector to AC. Switch the scope to look at CH2. Turn on the mike and then hold the mike near the speaker. You should be able to see the pulse as detected by the microphone. This sort of very abrupt, square pulse is quite difficult for a speaker to reproduce, so the pulse you see detected by the microphone will have a more complicated shape, going sharply up but then overshooting and going slightly negative. Consider only the very first part of the pulse. A typical shape for the detected pulse is shown below. If the first part of the pulse goes negative, switch the leads going into the speaker to make it positive.

4. Seeing Reflections from the Closed End of the Tube

Change the sweep rate to 1 ms/div.

Put the microphone at the open end of the tube. Now place the speaker near the open end. You should now be able to see two pulses detected by the mike—the direct pulse and the same pulse after it has gone down the tube, bounced of the glass and returned. To make it easier to see, turn the fine spacing adjust fully clockwise, so that the pulses come more often. You may even be able to put the pulse spacing on 10 ms/div, depending on the length of your tube. However, if you want pulses too often, each individual pulse will not be able to get down the tube and back before a new one is sent out.

7: Standing Waves In Tubes - 2
5. Measuring the Speed of Sound

a. Place the mike just at the mouth of the tube. Now very carefully measure the time between the direct and reflected pulses. You may need to adjust the sweep rate on the scope settings to get the most accurate measurement for your particular length of tube.

b. Calculate the speed of the sound pulses in air. Compare your result to the accepted value of 340 m/s at room temperature.

6. Opening the Closed End

What do you think will happen to the reflected pulse when you open the closed end? (Write down your prediction before you open it.) Now slowly remove the glass. What does actually happen to the reflected pulse? Compare this to your experiences with pulses on springs.
7. End Correction

When you removed the glass plate you may have noticed that the reflected pulse shifts to a slightly later time implying that the open tube is effectively longer than the closed one. This is an interesting effect called the **end correction**. The end correction depends somewhat on the frequency of the sound but is approximately $0.61r$ for a tube of radius $r$. Try to measure the small shift in time between the open and closed case to estimate the end correction ($v$ - denotes speed of sound).

Time difference between open and closed tube: $\Delta t = \text{ms}$

Effective increase in tube length ($v \Delta t / 2$) =

Expected end correction ($0.61r$) =

**B. STANDING WAVES IN THE OPEN TUBE.**

1. Introduction

For the remainder of this laboratory you will concentrate on periodic waves where the wavelength, $\lambda$, the frequency, $f$, and the velocity, $v$ are related by

$$v = \lambda f$$

As with mechanical waves on strings, a reflected wave from the end of a tube will be superimposed on the original wave and a standing wave will result for certain frequencies and tube lengths.

Let’s study standing waves in a tube created by a periodic signal from a speaker near a tube which is open at both ends. If a speaker produces a positive pressure pulse, it will travel down the tube, reflect from the open end as a negative pulse because of the 180° phase shift. The negative pulse travels back, reflecting from the starting end, now as a positive pressure pulse because of the 180° shift, again. If, just at that moment the next positive pulse from the speaker starts down the tube reinforcing the pulse already in the tube, a standing wave will result. This happens, for example, when the time between speaker’s pulses (the period, $T$) is exactly the time for the pulse to travel down the tube and back (2$L$). This period is $T = 2L / v$, where $L$ is the length of the tube and $v$ velocity of sound. The corresponding frequency is

$$f = v / 2L$$

This is the lowest frequency which will resonate in the tube and is called the
fundamental frequency, \( f_1 \). Resonances (i.e., standing waves) will also occur at multiples of the fundamental frequency, \( f_2 = 2f_1 \), \( f_3 = 3f_1 \), \( f_4 = 4f_1 \), \ldots. This is the same harmonic series we found for a string fixed at each end. For both fixed ends of strings and open ends of tubes, the wave is inverted on reflection. The open ends of the tube correspond to pressure nodes (the fixed ends of strings were displacement nodes).

2. Predictions for the fundamental frequency

Calculate the expected value of the fundamental frequency using the measured length of your tube and velocity of sound. For the velocity of sound use either \( v = 346 \text{ m/s} \), corresponding to the room temperature of 25 deg. Celsius, or, more precisely, the value calculated from Eq. (1) in the Lab #4 section. Do your calculations twice, first without the end correction:

\[
f_1 = \frac{v}{2L} = \ldots \ldots
\]

then, taking into account the end correction, EC, determined on the previous page with the end correction:

\[
f_1 = \frac{v}{2(L + 2 \text{ EC})} = \ldots \ldots
\]

3 Switching to the 2002 Function Generator.

When you made waves on springs, you could either watch individual pulses, or you could send continuous signals to create standing waves. Recall that it was only possible to create standing waves for certain frequencies. You can also do this with sound waves in tubes. To do so you need to switch to the function generator.

a. Turn off your 4001 pulse generator and disconnect it. Disconnect the cable from the trigger input of the scope and switch the trigger select to INTernal and the mode to AUTO. Disconnect the speaker from the pulse generator and the scope and then reconnect the speaker to the 50 \( \Omega \) output of the 2002 Function Generator. Hook the TTL output of the function generator into the high level input of the frequency counter. Take the mike out of the tube, turn it off, and set it aside.

b. Set the speaker at the mouth of the tube (which is open on both ends) so that there is only about 1/4 inch between the speaker and the tube. Set the amplitude of the function generator to 12 o'clock, the frequency multiplier to 1k, and the frequency knob fully clockwise, all the way down past 0.2. Slowly turn up the frequency until you hear a resonance. The resonance should sound comparatively loud and very "pure" and "hollow." If you're not sure what a resonance sounds like, ask your instructor for help. The lowest resonance is the easiest to find, so it may be helpful to listen to higher resonances for practice.

c. The lowest frequency is called the fundamental or first harmonic and is denoted by \( f_1 \). Record it and the next six or seven resonances above it in the first column of a data table that looks like this:

7: Standing Waves In Tubes - 5
<table>
<thead>
<tr>
<th>Harmonic</th>
<th># antinodes</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since the fundamental is the hardest frequency to measure, go back now and check it (without looking at the frequency counter).

d. Fill in the \( f_f \) column by dividing each resonant frequency by the fundamental. Then fill in the “Harmonic” column by rounding this number to the nearest whole number.
What pattern do you see? Are any harmonics missing? How does this compare to your experience with springs?

e. Compare the measured fundamental frequency with your predictions. Do you need the end corrections to predict the measured value?

f. Now tape the microphone on to the meter stick as shown:

Once again set the frequency so that the tube is resonating in its second harmonic mode. Use the meterstick to slide the mike slowly into the tube. Watch the pressure variations on the scope, and observe the number of nodes (no oscillations) and antinodes (maximum oscillations) that occur in the tube. Record the number of antinodes in the data table. Repeat for the first, third, and fourth harmonics. Does this agree with your expectations?

We will consider the case of tubes closed at one end next week.

7: Standing Waves In Tubes - 6