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.

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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.

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

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
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:

![Pulse Diagram]

- Positive
- Negative

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 send pulses too often, each individual pulse will not be able to get down the tube and back before a new one is sent out.

a. Slide the mike farther into the tube. What happens to the two pulses? Why?
b. Is the pulse inverted when it is reflected? Is this similar to a fixed or a free end on the spring?

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 or 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 ($v \cdot \Delta t$ denotes speed of sound).

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

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

Expected end correction ($0.61 \cdot r$) =

B. Standing Waves in the Open Tube.

1. Introduction

For the reminder 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 $180^\circ$ phase shift. The negative pulse travels back, reflecting from the starting end, now as a positive pressure pulse because of the $180^\circ$ 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 ($2L$). 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, $f_2 = 2 f_1, f_3 = 3 f_1, f_4 = 4 f_1, \ldots$. 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 $v = 340 \text{ m/s}$. Do your calculations twice, first

**without the end correction**: $f_1 = \frac{v}{2L} = \ldots$

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

**with the end correction**: $f_1 = \frac{v}{2(L+2EC)} = \ldots$

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 hardest 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:
Resonant Frequencies for a Tube Open at Both Ends

<table>
<thead>
<tr>
<th>$f$ (Hz)</th>
<th>$f/f_1$</th>
<th>Harmonic</th>
<th># antinodes</th>
<th>Comments</th>
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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 “$f/f_1$” 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 forth harmonics. Does this agree with your expectations?
C. STANDING WAVES IN A TUBE CLOSED AT ONE END

1. Introduction

We use the term closed tube when discussing a tube with one closed end and one open end. A periodic sound wave, generated by a small speaker near the open end, travels down the tube, reflects from the closed end of the tube and is superimposed on the original wave. One would expect a standing wave or resonance to occur if the next wave to start down the tube reinforces the waves already bouncing up and down the tube.

When a positive pressure pulse hits a closed tube end, it is reflected as a positive, not a negative, pulse (no phase shift). If a positive pulse is started at an open end, it travels down the tube, reflects back as a positive pulse, reflects at an open end as a negative pulse, reflects at the close end as a negative pulse and finally, after two round trips, (4L), reflects down the tube again as a positive pulse, reinforced by the next pulse from the speaker. The fundamental frequency, \( f_1 \), is thus:

\[
f_1 = \frac{v}{4L}
\]

Now, consider what happens if the frequency is doubled to produce the second harmonic. One pulse goes down, comes back and turns into a negative pulse at the same time that the next positive pulse is applied. Instead of adding amplitudes to make a stronger wave, the old and the new wave cancel each other so that the resonance does not occur for the second harmonics. Resonances will occur for odd harmonics only.

2. Predict the expected fundamental frequency for your tube

Calculate the expected fundamental frequency using the measured length of your tube. Use \( v = 340 \text{ m/s} \).

Tube length: ......................

Fundamental frequency (no end correction, \( f_1 = \frac{v}{4L} \)):

Fundamental frequency (after an end correction, \( f_1 = \frac{v}{4(L+EC)} \)):

3. Measure resonance frequencies

a. Close up again one end of the tube: First completely cover the end with masking tape. Then glue the glass plate over the tape. It is critical to get an air-tight seal. If the seal
is not complete, you will essentially have a mixture of a closed and an open tube, and it will be very difficult to interpret your results.

b Measure the frequencies at which the closed tube resonates (using the hints listed below). You should be able to measure at least five resonances above the fundamental. Record your results in the data table on the attached page.

**Hints:**
- In the noisy room it is much easier to find resonances with the aid of the microphone. Put the microphone just inside the open end of the tube. It is important to watch the microphone signal on the scope and listen to the sound.
- The resonances will be louder if you hold the speaker very close to the tube. However, this end of the tube must remain open, so don’t press the speaker hard against the tube. A good way is to hold the speaker slightly off to the side, which also gives room to put the microphone in.
- The lowest frequency is hardest to find. Look for several higher ones first and look for a pattern which might help you find the lowest one. Leave space in your data table for this.
- Most of the speakers have a resonance in the range from 250 to 300 Hz, which can give you very confusing results. Be suspicious of all resonances in this range.

### Resonant Frequencies for a Tube Closed at One End

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D. COMPARISON OF STANDING WAVES IN THE TUBE CLOSED AT ONE END AND OPEN AT BOTH ENDS

Please, discuss the following questions:

a. How does the new series of frequencies compare to the harmonic series generated in the open tube?

b. How does the fundamental frequency of the closed tube compare to the fundamental when the tube is open?

c. How does the period of the fundamental for each tube compare to the time it takes for a single pulse to go down the tube and back? **Try to explain the observed relation.**

Here is a hint. Recall, that a standing wave is a result of a constructive interference between incident pulses and pulses reflected from the ends of the tube. Calculate for each case (open-open, closed-open tube) the number of reflections a pulse has to undergo to reach the same polarity as the incoming pulse. Hopefully, you will find that the period of the fundamental is equal to the time the reflected pulse needs to travel within the tube before its polarity matches that of the incident pulse.

d. What are the similarities between wave behavior in tubes and on strings?