Sci A49 lab: Resonances in an air column

Spring 2001, 45 minutes. Comments to Alex Barnett, barnett@tornado.harvard.edu

**Purpose:** To investigate the lowest few resonant modes of the air in a glass tube, and from this calculate an accurate estimate of the speed of sound in air.

**Apparatus:** Glass tubes, stand and clamp, Pasco digital signal generator with built-in amplifier, loudspeaker, mini electret microphone, oscilloscope.

**Write-ups:** Discuss within your group and fill in this worksheet as you go: give brief answers to the questions printed in **bold**.

**Notes on use of signal generator and loudspeaker:**
- Always keep the sound level as low as you can get away with (this lowers ambient noise)
- Frequency being generated is shown digitally in Hz (cycles per second)
- Keep the waveform setting on sine wave (uppermost choice)
- Adjusting the frequency is slightly bizarre: it can sweep suddenly over a large range if you spin the dial at all fast. Go slowly if you are trying to locate a resonance. This effect is reduced if you choose a range (using the ‘range’ buttons) **without** a decimal point

1. **Passive listening to a tube**

Unclamp the glass tube and hold one end near to (but not pressed against) your ear. **a) How is the ambient noise changed by the tube?**

   **b) Is there a definite note or pitch you can identify?** (You should try to hum it or find the same note with the signal generator).

2. **Finding the resonant frequencies**

Gently reclamp the glass tube back in place. Adjust the signal generator to give a quiet tone. Place the speaker a couple of cm from one end of the tube; place your ear a few cm from the other end. Sweeping the frequency, see if you can find the fundamental of the air column. Listen for a suddenly strong tone. **a) How does the pitch found relate to 1b? How do you know it is the fundamental?**
Make a table of resonances (modes) you can find, in increasing order of frequency. In the first column put the mode number \( n = 1 \) for the fundamental, \( n = 2, 3 \cdots \) for higher modes; in the second column put the frequency \( f_n \) (in Hz) of mode \( n \). Leave space for 3 more columns. Estimate the error in locating each \( f_n \) by seeing how much \( f_n \) has to change so that you can tell it is no longer maximally on resonance. Then you can quote each \( f_n \) with a \( \pm \) error, e.g. \( 412 \pm 8 \) Hz. Don’t go above 3 kHz, but you should collect at least 6 resonances. Make your table here:

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<thead>
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<th>Mode Number ( n )</th>
<th>Frequency ( f_n ) (in Hz)</th>
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b) What is the pattern of frequencies? What musical intervals do they form?

c) Now looking back at Part 1, what do you think is happening when you place a shell up to your ear and ‘hear the sea’?

3. Shapes of the modes

Place the microphone in the tube while looking at the signal amplitude on the oscilloscope. The oscilloscope plots a graph of signal vs time. (Play with the ‘timebase’ control to verify that the graph is being plotted by a dot moving in time. Return the timebase to 0.5ms/div). The overall
microphone signal amplitude may help you relocate the frequencies \( f_n \) more accurately.

The microphone detects pressure variation. Each mode is a *standing wave*, with pressure *nodes* (minima) and *anti-nodes* (maxima). For each of the modes in your table, slide the microphone down the tube. **Add a column in your table with little sketches of the pressure variation along the tube. Add a column on your table giving how many anti-nodes there are for mode number \( n \).** a) Are the *ends* of the tube pressure nodes or anti-nodes?

Adjacent nodes in a standing wave are always separated by \( \lambda/2 \), where \( \lambda \) is the wavelength. **Add a column in your table which gives \( L \) the tube length as a multiple or fraction of \( \lambda_n \) the wavelength, for each mode.** b) What is the general formula valid for any \( n \)?

4. Speed of sound in air

For any wave, the speed of travel \( v \) is related to the wavelength and frequency by

\[
v = f \lambda.
\]  

(1)

Measure the length \( L \) of the tube in meters. a) Use the first row \((n = 1)\) of your table to calculate a value for \( v \), the speed of sound in air:

b) How does this value compare to \( v \) found using other \( n \)? Does this influence the error on your estimation of \( v \)?

c) How does the restriction you discovered in 3a, via the general formula from 3b, cause the resonance frequencies to have the pattern they (approximately) do have?

d) In fact the values of \( f_n/n \) are not constant. Does the *effective* length of the tube go up or down at higher frequency?