Summary of the Introduction to *the Standing Waves and Acoustic Resonance* Experiment

This document is a companion to a web-based document on the Standing Waves and Acoustic Resonance Experiment in the Physics laboratories of the University of Toronto. The web-document may be accessed at:

http://www.upscale.utoronto.ca/IYearLab/Intros/StandingWaves/StandingWaves.html

Since this is a *summary*, we do not duplicate the more complete discussion contained in that web-document.

Sound Waves

- Can characterise as a *pressure wave* or a *displacement wave*.
  - As a pressure wave, the pressure varies sinusoidally about atmospheric pressure.
  - As a displacement wave, the displacement of the air molecules about their equilibrium position varies sinusoidally.
  - Microphones measure pressure waves.
  - It is conceptually easier to discuss the associated displacement wave.
  - A *node* in the pressure wave corresponds to an *antinode* in the displacement wave and vice versa.
- The accepted value for speed of sound, in m/s^2 , as a function of temperature t in Celsius is:

$$v = 331.4 + 0.61t \qquad (1)$$

Standing Waves

- When the distance between two reflecting barriers is a half-integral number of wavelengths, a sound wave reflecting back and forth between them will add up to form a *standing wave*.
- The wavelength λ of the two waves forming the standing wave is related to the distance d between the nodes by:

$$\lambda = 2d \qquad (2)$$

- The possible standing waves are given by:

$$\lambda = \frac{2L}{n}, n = 1,2,3,... \qquad (3)$$

  where λ is the wavelength and L is the length of the tube.

- For *all* waves, the relationship between the wavelength λ and the frequency f of a wave travelling at speed v is: $\lambda f = v$ (4)
- Standing waves can also exist when one end of the tube is open
  - There is an *antinode* in the displacement wave (a *node* in the pressure wave) at the effective position of the open end of the tube.
  - The effective length of the tube L_{eff} is related to the length of the tube L as:

$$L_{eff} = L + 0.3\, D \tag{5}$$

where D is the diameter of the tube.

Adjusting for a Standing Wave

1. Place the microphone as close as possible to the loudspeaker.
2. Carefully adjust the frequency of the signal generator so the microphone measures a maximum.
3. Place the microphone at a *node* in the pressure wave.
4. Slowly adjust the frequency to make the measured amplitude as small as possible. You will need to decrease the volts per division on the oscilloscope as you make these adjustments.

The Experiments – First Term

Preliminaries

- Connect the signal generator to the oscilloscope, and adjust the voltage to a few hundred Hz and display the wave on the oscilloscope.
- Measure the frequency of the voltage using the oscilloscope and:

$$f = \frac{1}{T} \tag{6}$$

  where f is the frequency and T is the period. Compare to the frequency as read on the signal generator.
- Also connect the signal generator to the loudspeaker, and connect the microphone to the second beam of the oscilloscope. Adjust the display so that you can see the input voltage from the signal generator and the output of the microphone simultaneously.

Part 1

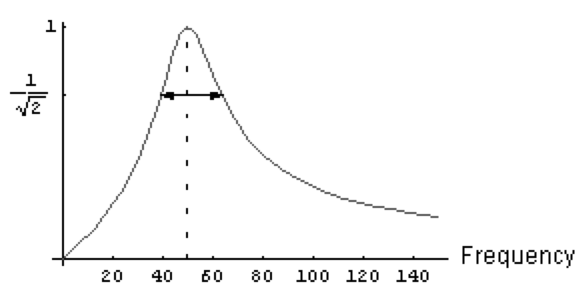
- Close the tube on both ends and adjust the frequency for a standing wave between 200 Hz and 2 kHz.
- How does the sound level that you hear with your ear close to the tube correlate with whether or not a standing wave exists in the tube? Can you think why this is so?
- From the positions of the nodes and/or antinodes, determine the wavelength of the standing wave.
    - Determine the speed of sound.
    - Repeat for a few different frequencies.
    - Give a final best value for the speed of sound, and compare to the accepted value.
- For one of the higher frequency standing waves, determine the length of the tube.
    - Compare to a direct measurement of the length.
    - Are the two values the same within errors?

Part 2

- Open one end of the tube and adjust for a standing wave.
- From the speed of sound, the frequency of the wave, and your measurements of the nodes and/or antinodes, calculate the length of the tube.
    - Compare to your result from Part 1.
    - Does your data confirm Equation 5? Prove your answer using your data.

Energy Dissipation (Information for a 2nd Term Experiment)

- The *Quality Factor Q* measures the degree to which the system is perfect.
- For a real system, as the frequency is moved away from the resonance value the amplitude of the wave decreases. In the figure to the right the resonance frequency is 50 Hz. We shall call that frequency f_0.



- The full width of the curve, Δf, when the amplitude is $\frac{1}{\sqrt{2}}$ times the maximum value determines Q according to:

$$Q \equiv \frac{f_0}{\Delta f} \tag{7}$$

Experiment Part 3 – Second Term Experiment

- Close the tube at both ends and adjust for a standing wave between 200 Hz and 2 kHz.
- Place the microphone at a maximum of the pressure wave.
- Measure the amplitude as a function of the frequency for frequencies close to the resonant frequency.
- Calculate the Quality Factor Q of the tube.

Preparatory Questions

1. From Equations 3 and 4, what are the *frequencies* of the standing waves that can exist on a string fixed at both ends?
2. What is the equivalent equation to Equation 3 for a tube that is open on one end?
3. If someone designs a pipe organ without being aware of Equation 5, what will be the consequences?
4. Sound waves do not travel far through air; eventually the waves "die out." What happens to the *energy* of the sound wave?
5. (Second Term Experiment) For a given resonant frequency f_0 how does the width of the curve of amplitude versus frequency depend on the Quality Factor Q?
6. (Second Term Experiment) When the Quality Factor Q is zero, the maximum amplitude A_0 is zero. When Q is infinite so is the maximum amplitude. Explain.