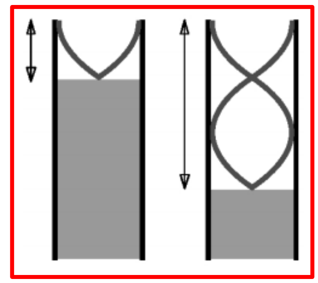
AP Lab #14: Harmonics in a Closed Tube (Big Idea 6)

6.D.4.2: The student is able to calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples should include musical instruments.

In this investigation you will experimentally determine the speed of sound by exploring the harmonics and resonance of a closed-end air column.

Harmonics in a Closed Tube Pre-Lab:

Sound waves are longitudinal waves that involve oscillations that are parallel to the direction of the wave and can travel through solids, liquids, and gases. The speed of sound in a medium depends on the density of the particles that make up the medium. The speed also depends on the temperature, especially in a gas like air. The speed of sound, v_s, may be determined by the equation: $v_s = 331.5 + 0.607\ T$, where T is the air temperature measured in ˚C. In this lab, the speed of sound will be determined using a tuning fork that induces resonance in a tube closed at one end. The sound waves will resonate at discrete intervals that correspond with the harmonics. Across the open end there is an antinode and on the closed end a node is produced. A full wavelength must be $\lambda = 4L$. When a pipe is closed at one end and open on the other, or a string is only attached to one end and free at the other end, the standing wave in this pipe must have a node at the closed end and an antinode at the open end. The frequency can be expressed as: $f = \frac{nv}{4L}$, with the speed being speed of sound and the harmonic number (n) must be an odd integer. The wavelength is now $\lambda = \frac{4L}{n}$, as shown in the diagram to the right. Consequently, $v = f\ (4L)$ for the fundamental frequency of a closed tube. Although this equation will provide a rough calculation of the speed of sound, the results are not perfect. The resonance frequency of the tube is also affected by the diameter of the tube. Consequently, a correction factor dealing with the diameter must be included in the previous equation. It has been found that a correction factor equal to 0.4 times the diameter of the tube must be added to the length of the tube and can be expressed as: $v = 4f\ (L + 0.4d)$ for the fundamental frequency of a closed tube.



P1. Explain how standing waves are formed. In your answer be sure to use the terms wave superposition, constructive interference, destructive interference, reflection, and resonate (or resonance).

P2. The speed of sound waves in air is 340 m/s. Determine the fundamental frequency (n = 1) of a closed-end air column that has a length of 67.5 cm. Refer to the diagram to the right.

Diagram:

1st Harmonic

P3. Make a sketch of a tube open at both ends with 1 ½ waves inside (n = 3). Explain what is heard in this tube, when compared to the fundamental frequency.

P4. Make a sketch of a tube open at one end with 1 ½ waves inside (n = 6). Explain what is heard in this tube, when compared to the fundamental frequency.

P5. Sketch and calculate the first three audible frequencies in an open-ended tube that has a length of 96 cm.

P6. Sketch and calculate the first three audible frequencies in a closed tube that has a length of 96 cm.

P7. Compare the patterns you drew for the audible frequencies in an open tube versus a closed tube. Make a general statement regarding audible frequencies in these tubes, in terms of the nodes and antinodes of the wave pattern.

Harmonics in a Closed Tube Lab:

Materials: sound resonance apparatus, tall ring stand, right angle clamp, iron ring with clamp, tuning forks (3 different; 300-1040 Hz), rubber mallet, thermometer.

The sound resonance apparatus (see figure 1) is a device specifically designed for this activity. The system provides the ability to create an air column of any length. As water enters the tube, the length of the air column decreases. If the length of the column is suitably matched to the frequency of the sound entering the column, the column will resonate. The resonance indicates a suitable match between the frequency and the length. The tines of the tuning fork should be held about 1 cm above the opening of the tube. Please only strike the tuning forks with a rubber mallet.

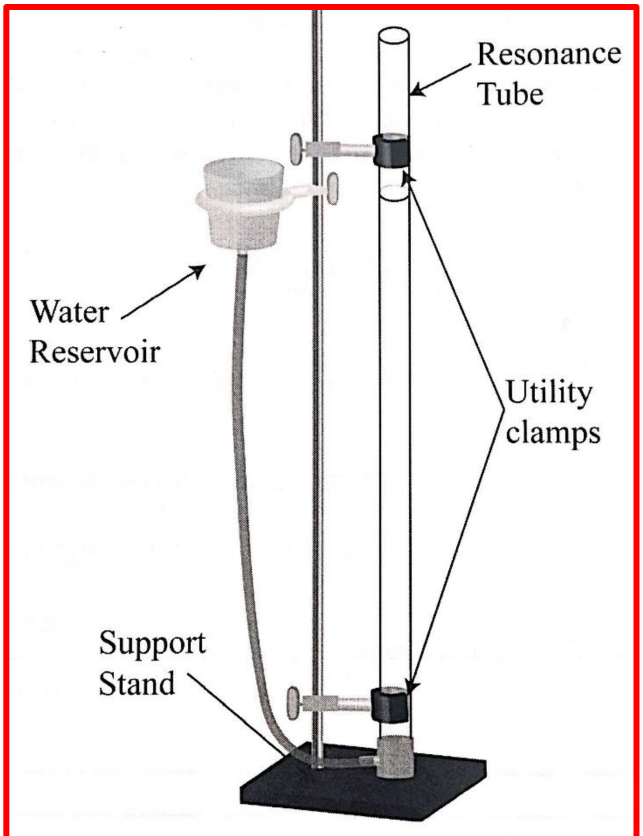


Figure 1: Sound Resonance Apparatus

Part 1: Locating Multiple Harmonics: *In this investigation, you will experimentally determine lengths of the tube that will produce the most harmonics. You will need to choose one tuning fork, so think things over before you begin. Gradually increase the length of the air column by lowering the can to find the first position of resonance, where the sound coming out of the air column is loudest. You may have to strike the fork several times and move the water column up and down to precisely locate the resonance position.*

Q1. Which frequency tuning fork did you choose? Justify your response using semi-quantitative reasoning.

Q2. Which lengths of the tube did you hear harmonics?

Q3. Repeat this process for one additional tuning fork of your choice. Be sure to include all relevant calculations and also to compare this tuning fork with your first choice.

Part 2: Design an Experiment: *In this part of the lab you will design an experiment to measure the speed of sound inside the resonance tube.*

Q4. State the objective and hypothesis for your experiment.

Q5. Outline the procedure, in a step-by-step fashion, that you plan to use to address your objective. Be sure to include relevant sketches and data tables. Please be detailed in your experimental design. Conduct several trials and repeat your procedure using tuning forks with different frequencies to ensure your conclusion is convincing.

Please self-assess your lab report using the rubric/checklist.