EXPERIMENT: Resonance in a Closed End Pipe.
Subtitle: Principles of an organ pipe

OBJECTIVES: 1)To determine the resonant frequencies of a closed end pipe, exposed to sound waves. Verify the relationship between the frequency of the sound(ν), the speed of sound in air (c) and the length of the pipe (L)

APPARATUS:

A frequency generator, with digital readout and which was also used to produce standing waves on a string, will be used to drive a small speaker and generate sound waves of a given frequency. The sound waves enter a closed pipe, filled with air. The length of the pipe (L) can be varied by moving an insert back and forth.

THEORY

When a speaker produces a sound wave, it generates a pressure difference in air and this pressure variation propagates through air with a specific speed c. In the experiment with standing waves on a string, the oscillation was perpendicular to the direction in which the wave traveled. This is called a transverse wave. A sound wave is a longitudinal wave, where the oscillation is along (or opposite to) the direction of propagation i.e speed. This does not change any of the equations used before. If the sound generated by the speaker corresponds to a frequency ν, then this results in a travelling wave with wavelength: $\lambda = \frac{c}{\nu}$. For a given frequency the wavelength depends on the speed of propagation c. This speed depends on the medium through which the wave travels. For example the speed of sound in air is c=343 m/s at room temperature. But in helium the speed of sound is much larger and is c=965 m/s. So a sound wave of a given frequency will have different wavelengths in air and in helium.

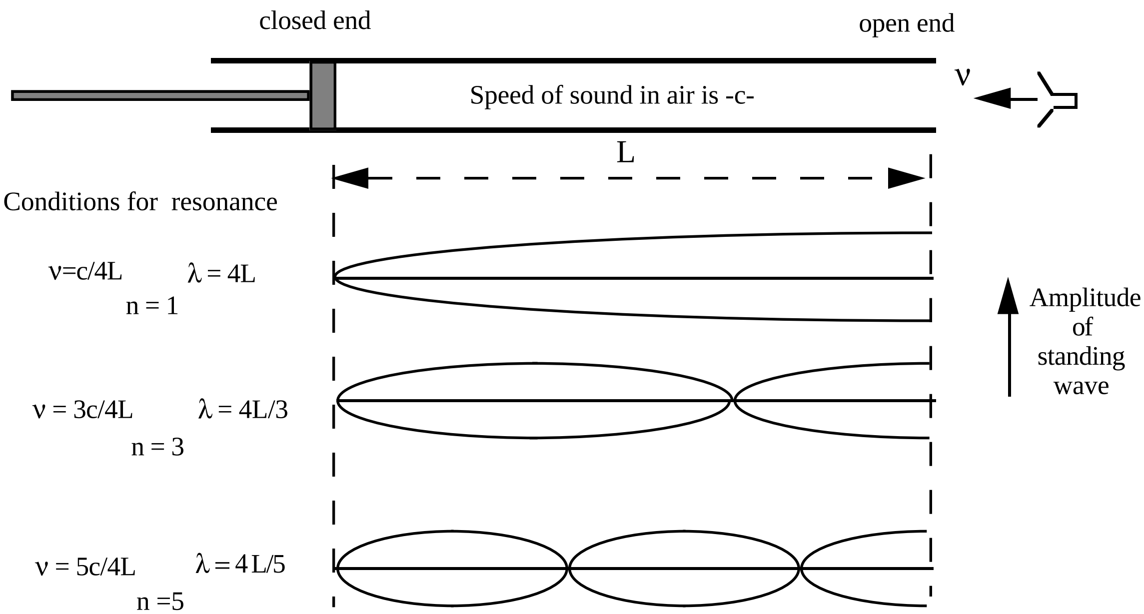
Similar to the conditions for standing waves on a string, we can define conditions for a standing wave in a closed pipe. At the closed end of a pipe we have a node in the standing wave and at the open end we have a maximum. Only certain combinations of wavelength and length of the pipe will result in a standing wave or resonance. The conditions are given by:

$$\lambda_n = \frac{4L}{n} \quad \text{for } n=1,3,5,7, \text{ etc}$$

$$\nu_n = \frac{c}{\lambda_n} = \frac{nc}{4L} \quad \text{for } n=1,3,5,7, \text{ etc}$$

The frequencies ν_n are called the resonant frequencies of the pipe. This implies that a pipe with a fixed length has only certain resonant (i.e. audible) frequencies. This is the principle behind organ pipes, where many different lengths are needed to produce all frequencies. All woodwind instruments operate according to these conditions. The conditions for resonance are graphically displayed in the following figure.

Conditions for resonance in a closed end pipe



As we observed for standing waves (= resonance) on a string, the amplitude of a standing wave, at a maximum, can be several times the amplitude of the incoming wave. Since the intensity of sound is proportional to the amplitude of a wave, the presence of a standing wave can be easily identified because the sound intensity is multiplied several times. In this particular experiment the sound intensity of the speaker can be set such that it is not audible. By changing the frequency and tuning it for a resonance the resonant frequencies can be determined.

PROCEDURE

The formulaes and explanations given above are correct in an ideal case. In practice in the lab, we have a problem setting up an air column which is closed on one end and open on the other. The closed end is supplied by the plunger, but the open end contains the speaker, so strictly speaking it is not exactly an open end nor is it another closed end. In the ideal case we would increase L and find a maximum in intensity. The first maximum would be for $n=1$, the next one for $n=2$, etc. By using $\lambda_n = \frac{4L}{n}$ the wavelength would be determined. In practice this is difficult, because the first maximum that is heard does not necessarily satisfy : $\lambda = 4L$.

So in order to determine the wavelength for a certain frequency, we will use the fact that the distance between maxima in the intensity is always : $\frac{\lambda}{2}$. This will be done the following way: set up a certain frequency ν. Move the plunger to end of the tube (speaker end). Now slowly move it in until you hear the first maximum. Record this position as L_1. Keep moving the plunger until you hear the next maximum. This is L_2. The distance between L_1 and L_2 is the distance between two maxima, so it is equal to $\frac{\lambda}{2} = L_2 - L_1$. We will use this to determine the wavelength for each frequency.

- Turn on the frequency generator and make sure the amplitude is turned down. Tune it to about a frequency of about 1000Hz and make sure you can hear the sound from the speaker. Move the piston to the end of the pipe and pick a frequency between 400 and 2500Hz (start at the higher end). Set the frequency and measure it with the frequncy meter, by disconnecting the speaker from the frequency generator and connecting the meter. After this is done disconnect the meter and reconnect the speaker.
- Slowly move the piston into the pipe (you are now increasing L) until you hear a maximum in the sound intensity. Try to choose an amplituude (on the frequency generator) such that the sound is only audible when you are at a resonance maximum. Use the 89 dB scale on the intensity meter.*Otherwise everbody will leave the lab with their head buzzing !!!!* At this maximum adjust the intensity meter scale such that it is reading in the center of the scale and use this scale for all your measurements at one frequency. Measure the position of the plunger L_1 and record the frequency ν . Assign an error (ΔL)to the measurement of L and use this to calculate the error for the wavelength. Move the plunger further into the pipe and measure all the positions at which you hear a maximum: L_2, L_3, L_4, etc . From the distances between the different positions determine the wavelength λ ., for each combination. Do the wavelengths agree within error ?
- Repeat these steps for 5 different frequencies.in total.
- For all your measurements graph ν vs. $\frac{1}{\lambda}$. For one frequency you will have several values for the wavelength. Either graph them all (they will be close together) or graph the average of them. From the slope of the line calculate the speed of sound in air and compare it to the nominal value.

QUESTIONS

1) If the experiment was done in a helium atmosphere, would the resonant frequencies be the same? Why ?
2) If the time between you seeing the flash of lightning and hearing the sound of the thunder is about 5 seconds, how far is the thunderstorm away from you ?
3) For an organ pipe to have a fundamental (n=1) frequency of 100Hz, how long does it have to be ?