AIR RESONANCE IN A PLASTIC BOTTLE

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It is well known that if one blows across the neck of an empty bottle, a tone can be produced. The sound that is produced is a result of the air oscillating in and out of the bottle neck. This phenomenon is known as resonance. The resonant frequency of the tone is determined by several factors: the speed of sound in air, the length of the neck, the cross sectional area of the neck opening and the volume of air inside the bottle. If the volume of air inside is reduced, for example by adding water to the bottle, the resonant frequency will increase and the pitch of the tone will rise. This can be easily demonstrated by using a glass soft drink bottle. Similar results can be obtained using a plastic bottle such as a 2-liter soft drink bottle. If water is added to the bottle the resonant frequency will increase and the pitch will rise. However, if the sides of the plastic bottle are squeezed in order to decrease the volume, the resonant frequency appears to decrease and the pitch drops. This unexpected result was investigated in the following series of experiments.

**Experimental Setup**

Air resonance was obtained by using a loudspeaker (near the bottle opening) driven by a function generator with a sinusoidal output. See figure 1 below. A probe microphone was inserted into the bottom of the bottle through a small hole. The signal from the microphone was displayed on an oscilloscope. The frequency of the function generator output was varied in 0.5 Hz steps and the amplitude of the signal on the scope was recorded. From a plot of amplitude versus frequency the resonant frequency was determined.

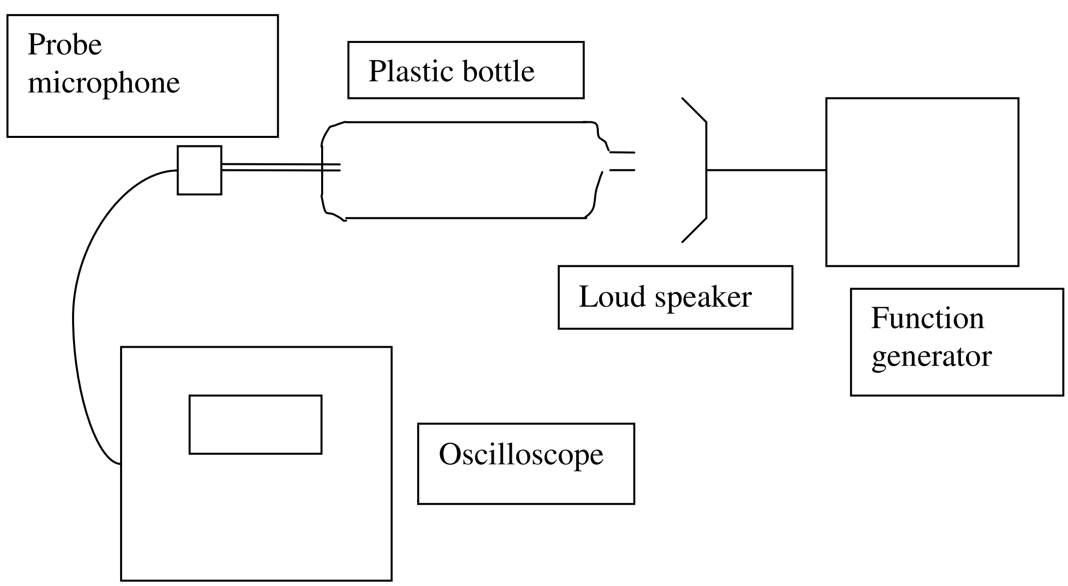


Fig. 1. Experimental setup.

**Helmholtz Resonator**

A Helmholtz resonator consists of a volume of enclosed air with a neck on it. At resonance the air in the neck oscillates along the axis of the neck. The air inside the bottle acts as a spring to provide a restoring force on the oscillating air. See figure 2.

**Measured and predicted frequencies for water along side of bottle**

V = Volume of air enclosed
(not including the neck)
L = Length of neck
S = Cross sectional area of the neck
c = Speed of sound in air
$f_{res}$ = resonant frequency

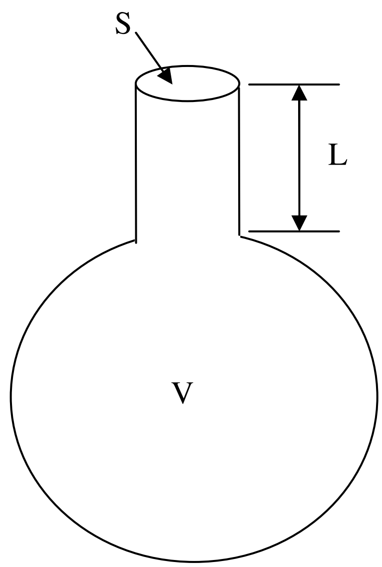


Fig. 2.

The resonant frequency for the Helmholtz resonator is given by

$$f_{res} = (c/2\pi)[S/VL]^{1/2}.$$

**Volume Change by Adding Water**

The volume of the bottle was first determined by measuring the amount of water needed to fill it up to the neck. A series of trials was then made finding the resonant frequency starting with the bottle empty and adding 40 cc of water each time. The bottle was lying on its side. The measured resonant frequencies and theoretical frequencies agreed quite well as shown in Table 1 below.

| Volume of water added ($cm^3$) | Volume of air ($cm^3$) | Theory Frequency (Hz) | Experimental Frequency (Hz) | % Difference |
|---|---|---|---|---|
| 0 | 2110 | 101.5 | 101.7 | (0.17) |
| 40 | 2070 | 102.5 | 102.5 | 0.00 |
| 80 | 2030 | 103.5 | 103.8 | (0.28) |
| 120 | 1990 | 104.5 | 104.7 | (0.15) |
| 160 | 1950 | 105.6 | 105.7 | (0.08) |
| 200 | 1910 | 106.7 | 106.7 | 0.01 |
| 240 | 1870 | 107.8 | 107.8 | 0.04 |
| 280 | 1830 | 109.0 | 109.0 | 0.02 |

Table 1.

**Volume Change by Squeezing Bottle**

The plastic bottle was squeezed by clamping two parallel strips of wood at the middle of the bottle. The width of the bottle could be varied by adjusting the nuts on the threaded rods at the two ends of the wooden pieces. See figure 3 below.

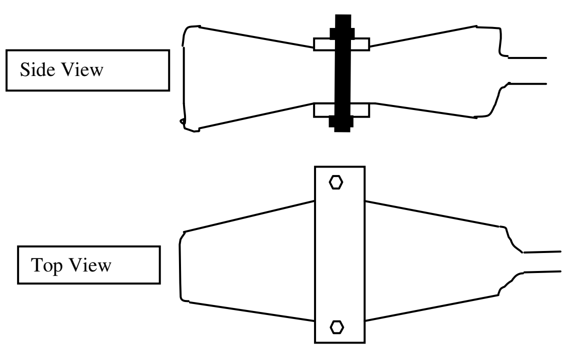


Fig. 3.

**Resonance with Squeezed Bottle**

A series of trials was made measuring the resonant frequencies as the volume of air inside the bottle was changed by squeezing it. In these trials the walls of the bottle were free to vibrate. There was a definite drop in the resonant frequency and a drop in pitch as the volume of air was decreased. Another series of trials was made to measure the resonant frequencies as the bottle was squeezed. However, this time the walls of the bottle were constrained from vibrating by packing sand all around the bottle. In these trials the frequency increased and the pitch rose as the volume of air in the bottle decreased. The measured frequencies and theoretical frequencies also show good agreement. See Table 2.

**Air Resonance in 2-Liter plastic soft drink bottle**

| | | | Rigid Bottle | Rigid Bottle | Free Bottle | |
|---|---|---|---|---|---|---|
| Volume decrease ($cm^3$) | Volume ($cm^3$) | Corrected volume ($cm^3$) | Theoretical frequency (Hz) | Measured frequency (Hz) | Measured frequency (Hz) | % Error |
| 0 | 2110 | 2110 | 101.5 | 101.2 | 97.5 | (0.3) |
| 95 | 2015 | 1905 | 106.8 | 109.0 | | 2.0 |
| | | 1928 | | | 79.2 | |
| 245 | 1865 | 1755 | 111.3 | 112.5 | | 1.0 |
| | | 1885 | | | 77.5 | |
| | | 1805 | | | 75.5 | |
| | | 1663 | | | 72.0 | |
| 460 | 1650 | 1540 | 118.8 | 121.0 | | 1.8 |
| | | 1540 | | | 68.0 | |

Table 2.

Figure 4 shows a plot of measured resonant frequency versus volume of air in the bottle with walls free to vibrate and constrained from vibrating. Also is shown the theoretical resonant frequency versus air volume. Clearly whether the pitch rises or falls when the bottle is squeezed depends on whether or not the walls are allowed to vibrate.

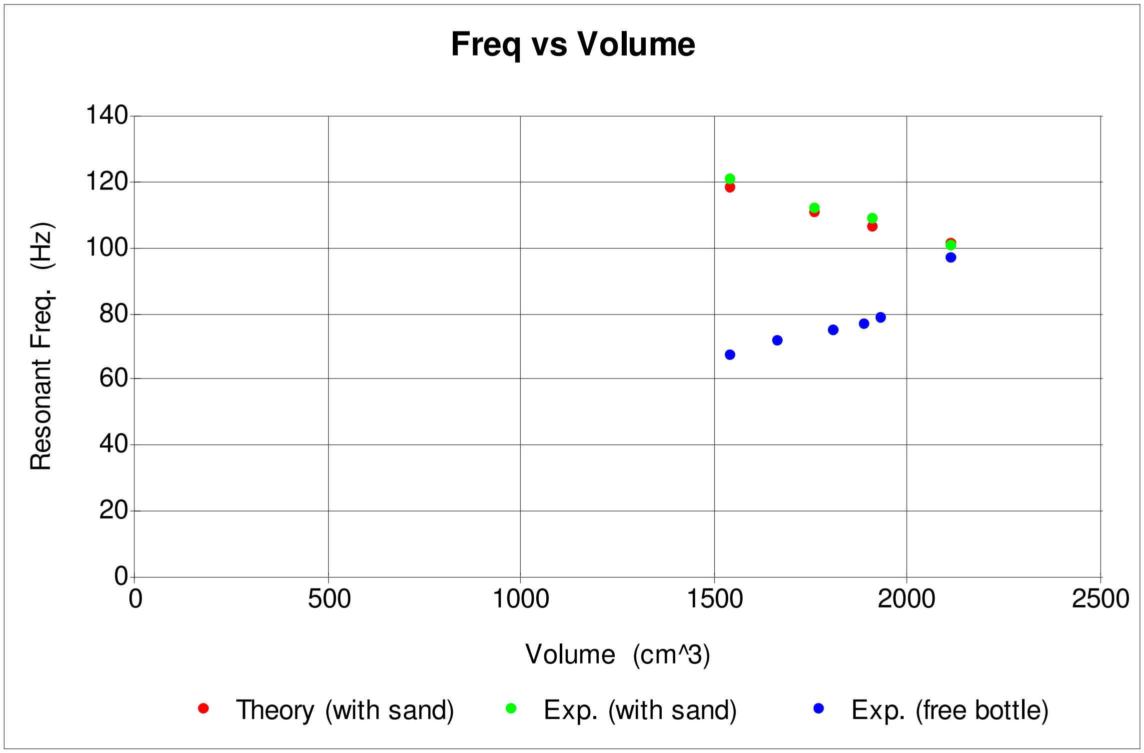


Fig.4.

**Discussion**

The experiments discussed above suggest that Helmholtz's theory predicts quite well the resonant frequency as long as the walls of the bottle are not allowed to vibrate.
The question that now arises is why the resonant frequency decreases when the sides are squeezed. A possible answer may lie in the fact that as the center is squeezed, relative flat areas are created next to the wooden strips. These flat areas have their own natural frequencies of vibration. As the bottle is squeezed more the areas increase in size and their natural frequencies should decrease. So we have two different natural frequencies competing. Even though the system is rather complex, it may be thought of as a system of coupled oscillators (the air mass oscillating in the neck of the bottle and the relatively flat oscillating surfaces of the bottle). These two oscillators are coupled by the varying air pressure inside the bottle. Attempts were made to look for resonances in the flat surfaces for the squeezed bottle. The top was cut out of the bottle to drastically change (raise) the air resonance frequency and a mechanical driver was used to excite vibrations of these surfaces. It was found that the lowest resonant frequencies decreased as the surface areas increased.