The Corinthian

Volume 5 Article 1

2003

Low-Flow Helmholtz Resonator for Molar Mass Detection

Brackman Amy
Georgia College & State University

Amanda Kea
Georgia College & State University

Kenneth McGill
Georgia College & State University

Low-Flow Helmholtz Resonator for Molar Mass Detection

Amy Brackman, Amanda Kea, Ken McGill

Abstract

A simple apparatus was constructed for an undergraduate physical chemistry laboratory to determine a mathematical model of wavelike motion. The apparatus was assembled by attaching an air-flow valve connected to a tank of argon gas to a GC column, thus creating regulated airflow. The air was manipulated to gently flow over a small sensitive microphone that was attached to an inexpensive resonator. A model will be developed to measure the speed of sound that will lead to the measurement of the molar mass.

Introduction

A resonator, in the most basic sense, is a natural amplifier that will vibrate sympathetically with another vibrating system.[1] The air through which the sound waves are traveling may resonate. A Helmholtz resonator is a resonator containing a cavity that will vibrate only at a specific frequency, giving off little energy to the outer medium such as air, thus resulting in a standing wave lasting for an appreciable amount of time.[2]

Hermann von Helmholtz designed the Helmholtz resonator in the nineteenth century. A simple Helmholtz resonator or Helmholtz oscillator is usually constructed from a container of gas with an open neck. Gas flow around the opening creates vibrations in the cavity due to the wave-like properties of the cavity and the speed of sound of the gas. Compression of the gas initiates pressure increases in the cavity causing expansion of the air back to its original volume. Momentum from the expansion of the gas continues a minute distance outside the cavity causing rarefaction of the gas within. The rarified gas then sucks the gas back into the cavity. This motion of gas creates vibrations, providing the power to continue the oscillations.[3]

A basic example of a simple Helmholtz resonator is the whistling sound that occurs when a person blows air around the neck of a coke bottle as shown in Figure 1. The Helmholtz resonator models certain standing-wave behaviors in which the speed of sound can be calculated.[ibid] From this, the molar mass can be obtained for any gas.[4]

Apparatus Assembly and Experiment

In this experiment, a simple Helmholtz resonator was created. This was facilitated by connecting an argon gas tank to a gas chromatograph column. A flow gauge was assembled to the port of the gas to monitor the pressure of the gas flow. Argon gas was used because it is a noble gas, hence, many of its properties such as speed of sound, can easily be determined by simple calculations. The GC column was held tightly in place by mounting it inside a plastic pipette using epoxy. The gas was then allowed to flow over a small microphone, which is connected to an oscilloscope and a pre-amplifier, to measure the frequencies as shown in Figure 2.

An articulating mounting device was then manipulated to position the GC column through angles from a vertical position to a horizontal position relative to the microphone as shown in Figure 3.

Resonate frequencies were found at varying angles. The articulating mounting device supports the pipette at an angle to the x-axis as illustrated in Figure 4.

Data

The articulating mounting device was maneuvered measuring each angle. The best resonating point at each angle was found by moving the GC column in an x-axis and y-axis over the microphone. At a resonating moment through each angle, the frequency was recorded. Figure 5 illustrates the resonating frequency determined for each angle.

If a true resonance has been achieved, then as the argon flow is increased the intensity should increase, thus, the amplitude should increase as well.[5],2,3 This behavior was observed during resonance. Thus, the Helmholtz resonator created models the behavior of

$$G_v = c \qquad (1)$$

$$c^2 = \frac{\gamma RT}{M} \qquad (2)$$

where G is a geometrical cavity shape, v is the frequency, c is the speed of sound in air, R is a gas constant, T is the temperature, y is the heat capacity ratio, and M is the molar mass of the gas. [2,4] Using the above models of behavior, the molar mass can then be calculated for any gas.

Results

A Helmholtz resonator was easily constructed within an undergraduate laboratory. After measuring the resonating angle frequencies, it can be concluded that there is a periodic behavior displayed with the angle dependence of the resonance frequency. When different gases other than argon are used, the same periodic behavior should be observed. The molecular mass of any gas can now be calculated by using Equations 1 and 2.

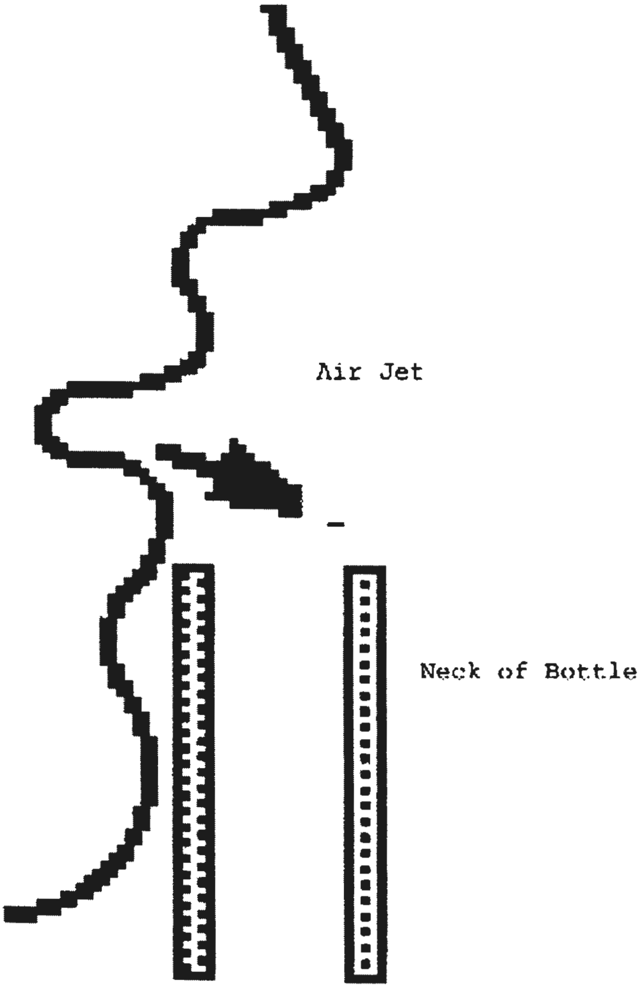

Figure 1. A simulation of a person blowing air around the neck of a bottle that creates a whistling noise. This is an example of a Helmholtz resonator.

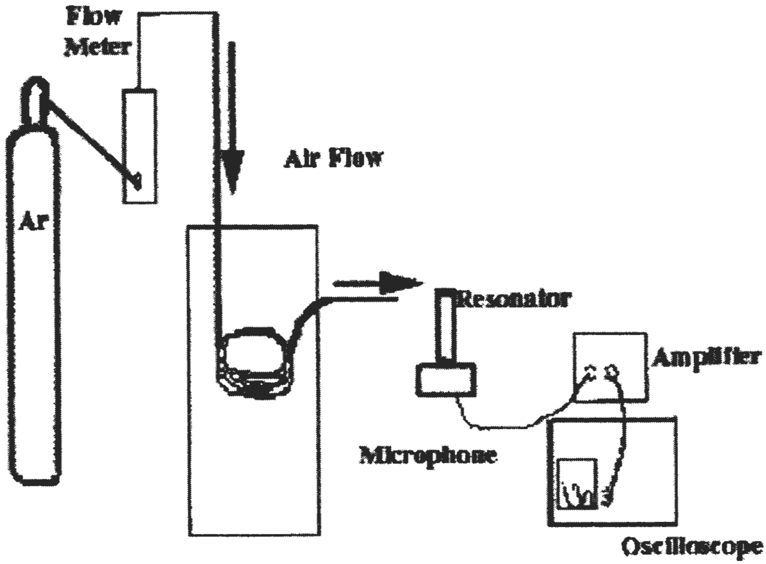

Figure 2. A constructed model of a Helmholtz resonator apparatus. Argon gas flows through a GC column to a sensitive microphone. The microphone is connected to an oscilloscope and an amplifier, which measures the frequencies.

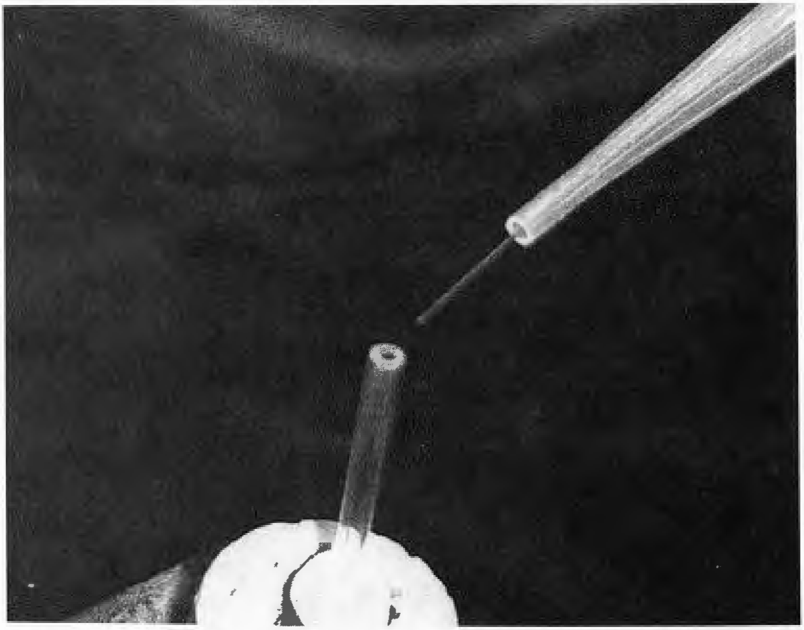

Figure 3. The angle created between the argon gas flowing through a GC column and the microphone. The angles are varied using an articulating mounting device and the resulting frequency is recorded.

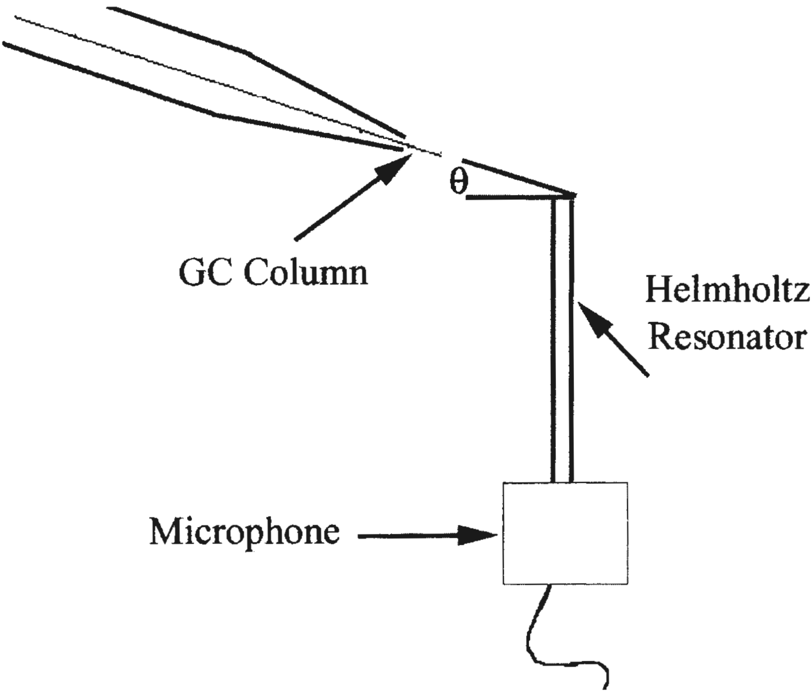

Figure 4. The pipette was supported by the articulating mounting device, which created an angle relative to the x-axis.

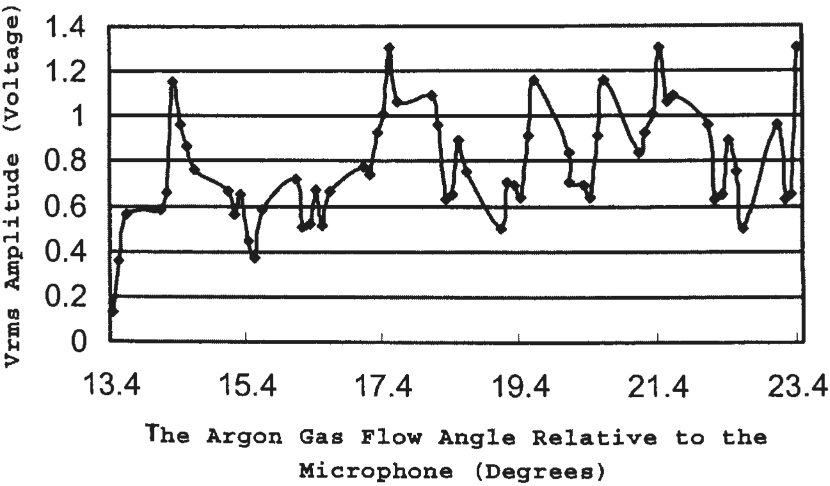

Figure 5. At each angle, the best resonating point was achieved by moving the GC column in the x- and y-axis directions. At a resonating moment, the frequency was recorded and plotted.

References

[1] Atkins, Peter; Paula, J. *Physical Chemistry*; W. H Freeman and Company, New York, **2002**, 7th edition, 579.

[2] Halliday, David; Resnick, R.; Walker, J. *Fundamentals of Physics*; John Wiley & Sons Inc., New York, **2001**, 6th edition, 372, 390, 399, 402-410.

[3] Morse, Phillip M. *Vibration and Sound*; *Acoustical Society of America* through the American Institute of Physics, **1981**, 238-239.

[4] Colgate, S. O.; Williams, K. R.; Reed, K. J. *Chem. Educ* **1987**, 64, 553-556.

[5] Morse, Phillip M. *Vibration and Sound; Acoustical Society of America* through the American Institute of Physics, **1981**, 238-239.