Experiment 1: Ratio of Specific Heat Capacities

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Abstract

This experiment determined the ratio of specific heat capacities for three different gases: air, Argon, and CO_2*. The results for the ratios were* 1.461 ± 0.01*,* 1.604 ± 0.01*, and* 1.337 ± 0.01*, respectively. I also verify that the damping effect on the period is insignificant if the inequality of equation 6 true.*

1 Introduction

In this experiment, the ratios of specific heat capacities is measured for Air, Argon, and CO_2. Using a steel ball inside a glass tube with cross-sectional area A, where the ball is able to move freely inside the tube with the diameter of the tube and ball matching. The theory behind calculating the ratio involves using the simple harmonic oscillation produced when this steel tube and ball is inserted into an aspirator filled with a gas. Letting gravity do it's work, the ball will drop compressing the gas and rise. This creates a simple harmonic oscillation which can be used to find the period. Using the period, the ratio of specific heat capacities can be determined. This system is adiabatic since the system is insulated enough from it's surroundings by the aspirator as well as the steel ball. The equilibrium pressure is dependent on the mass of the ball, m, and the cross-sectional area of the tube, A, along with the atmospheric pressure, P_0. The period, T, can be found using a graph of the simple harmonic motion of the ball in the system filled with a specific gas. The final objective is to measure γ using the equation 5 for air, Argon, and CO_2 and verify the inequality of equation 6.

1.1 Equations

$$PV = constant \tag{1}$$

$$PV^{\gamma} = constant \tag{2}$$

$$P_{eq} = p_0 + \frac{mg}{A} \tag{3}$$

$$T = 2\pi\sqrt{\frac{mV}{A^2\gamma P_{eq}}} \tag{4}$$

$$\gamma = \frac{64mV}{d^4 P_{eq} T^2} \tag{5}$$

$$\frac{k^2T_1^2}{4} << 4\pi^2 \tag{6}$$

$$\frac{kT_1}{2} = \frac{lnA_{(n)} - lnA_{(n+l)}}{l} \tag{7}$$

2 Experimental Procedure and Design

The experiment procedure will need to measure three γ values for air, Argon, and CO_2.
The steps taken in the following section can be repeated for different gases.

1. The final result will be in the form of a graph that is produced from the simple harmonic motion of the ball. This will be accomplished on LoggerPro software using a pressure sensor to measure the pressure inside the aspirator as time passes. The sampling rate was set to 20 samples/sec for a duration of 15s. This is because the ball will oscillate for only a short duration.

2. Before putting in a specific gas in the aspirator to be measured, the aspirator was released of any other gas that's currently within it using compressed air for about a minute or two. The next step was to input a certain gas, such as Argon, into the aspirator and letting the entire container be filled with the new gas.

3. After the aspirator is filled with the gas to be measured, the glass tube containing the steel ball was inserted into the top of the aspirator. The ball was held inside the top of the tube by the system being "closed" using a stopper on the glass tube, which also sealed the gas from escaping into the environment.

4. We now drop the ball by unplugging the stopper on top of the tube. Doing this will drop the steel ball, which then performed a simple harmonic motion using the gas. The gas pressure during this motion was recorded using LoggerPro. Using the graph, the period was measured by taking the difference in time between the first and second amplitude's. Equation 5 was used with the newly acquired period, along with other quantities to calculate γ.

3 Sample Calculations

$$\begin{aligned}\gamma_{air} &= \frac{64(16.5x10^{-3}kg \pm 0.1x10^{-3}kg)(10.75x10^{-3}m^3 \pm 0.03x10^{-3}m^3)}{(13.74x10^{-3}m \pm 1x10^{-5}m)^4(104.6x10^3pa \pm 36pa)(1.1s)^2} \\ &= \frac{0.0114 \pm 0.007}{4.51x10^{-3} \pm 0.003} \\ &= 1.461 \pm 0.01\end{aligned} \tag{8}$$

$$\begin{aligned}\frac{kT_1}{2} &= \frac{ln105.16kPa - ln104.88kPa}{2} \\ &= 0.347\end{aligned} \tag{9}$$

$$(\frac{kT_1}{2})^2 = 0.347^2 = 0.120 << 4\pi^2 = 39.48 \tag{10}$$

$$\begin{aligned}&Consistency \\ \gamma_{air-theo} &= 1.403 \\ |1.461 - 1.403| &\leq 0.01 \\ 0.058 &\leq 0.01 \\ &Inconsistent\end{aligned} \tag{11}$$

4 Results and Graphs

The final results of the γ values for air, Argon, and CO_2 were 1.461 ± 0.01, 1.604 ± 0.01, and 1.337 ± 0.01, respectively. The theoretical values were 1.403, 1.67, and 1.30 for air, Argon, and CO_2, respectively. The results for all gases were inconsistent with the theoretical values, but the results were close to the theoretical values and the inconsistency can be accounted for with a discussion into some sources of errors. The inequality given by equation 6 holds for air, as seen in the sample calculation result (10). The graphs show the oscillation for each type of gas over time, which is slightly different depending on the gas. The time stamps of the first and second amplitude's were used to determine the period, maybe a larger difference in the amplitude number would improve the result. As the oscillation dies down, it settles to the equilibrium pressure, P_{eq}, which is the sum of atmospheric pressure and the pressure due to the steel ball, as shown in equation 3. This equilibrium pressure can be seen at the end of the graph as the oscillations are being completed.

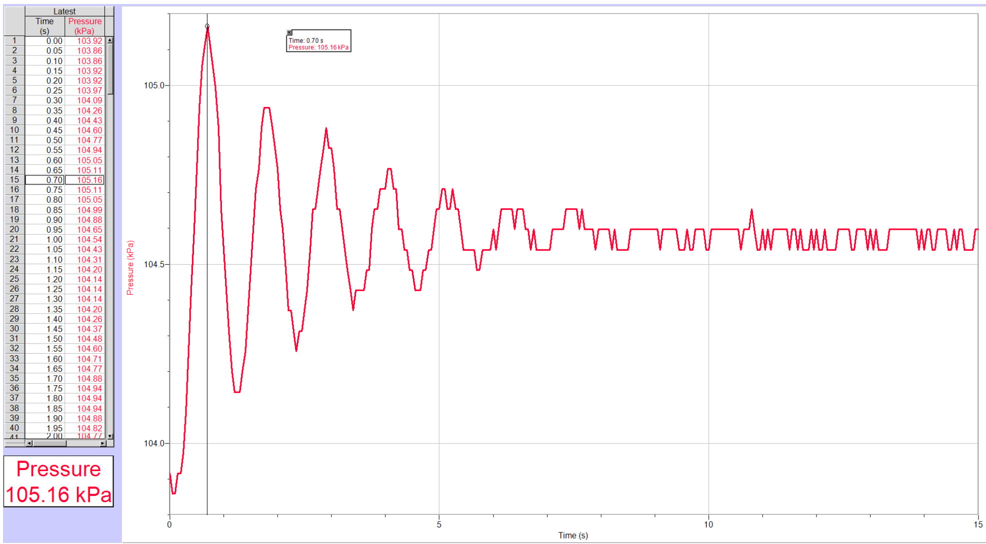

Figure 1: Graph of the simple harmonic motion produced by the steel ball in air.

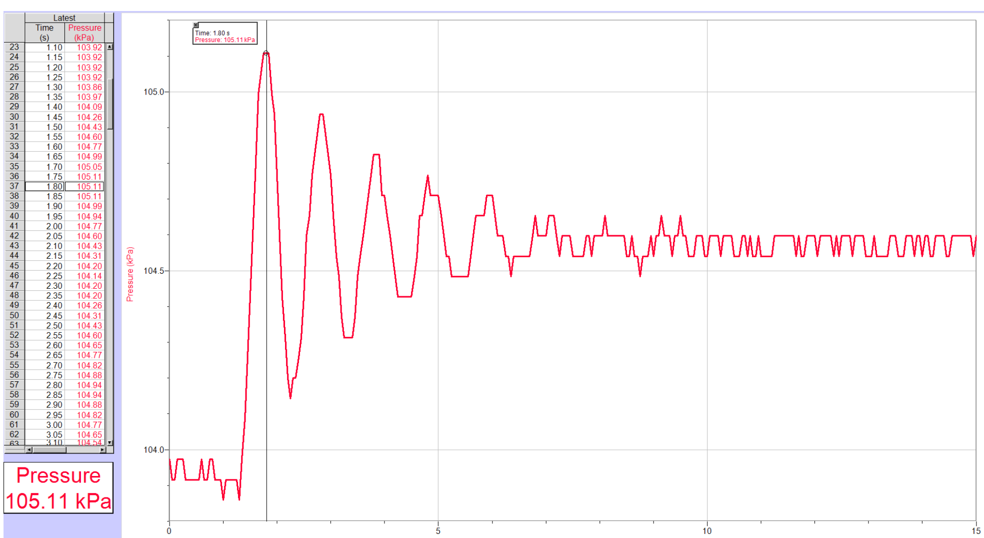

Figure 2: Graph of the simple harmonic motion produced by the steel ball in Argon.

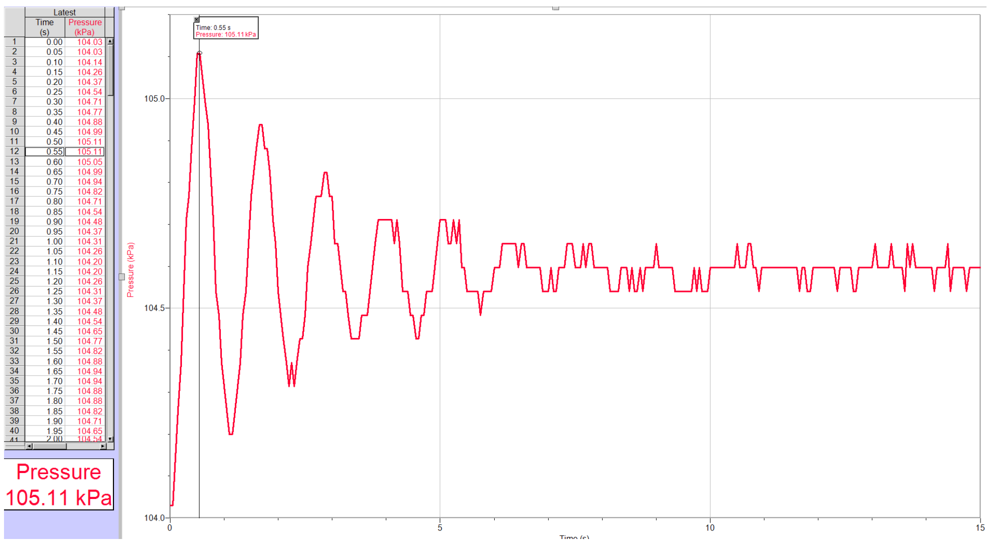

Figure 3: Graph of the simple harmonic motion produced by the steel ball in CO_2.

5 Discussion

The experiment produced inconsistent results compared to the theoretical results for the ratios, however, the results were very close to the theoretical values and the inconsistency can be by explained by possible sources of error that occurred during the experiment. One potential source of air might be that the aspirator might not have been perfectly filled with the gas that was to be tested or cleared of a gas previously used, since the process of using compressed air to clear the aspirator of gas might not have been enough to completely void it, and the time that was used to fill the aspirator might not be enough. The time for clearing and filling was approximately 2 minutes for each. Maybe an increase to 5 minutes would improve the results. However, the flow rate when clearing or filling the aspirator using compressed air and a new gas was high enough to almost account for the little time spent on clearing and filling. Other sources of error might have been in the weighing of the steel ball. Weighing the ball required the ball to be stationary on the scale, but since that wasn't possible, a leather glove was placed on the scale under the steel ball to keep it stationary. The scale was zeroed before weighing the ball. The ball was able to "freely" roll inside the tube, however since there was contact being made with the tube, it is the case that there was a very low level of friction present during the oscillation. Although the results were inconsistent with the theoretical values, the experimental values can be more accurate with repeated measurements for each gas. Why should air, Argon, and CO_2 has different values for the ratio of specific heat? This is due to the weight of the particular gas which is dependent on the molecular weight(s) of the atoms that form the gas. this slight difference in the weights of the gases would produce different pressure values.

6 Conclusion

The point of the experiment was to measure the ratio of the specific heat capacities using the simple harmonic motion of a steel ball in a glass tube due to the pressure of the gas in an aspirator. The final results of the γ values for air, Argon, and CO_2 were 1.461 ± 0.01, 1.604 ± 0.01, and 1.337 ± 0.01, respectively, which were inconsistent with the theoretical values.

References

[1] Physics 317, Laboratory Manual. University of Victoria, 2019.