A SIMPLE APPARATUS FOR DETERMINING THE RELATIONSHIP BETWEEN PRESSURE AND TEMPERATURE OF GASES

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Abstract—Nearly every high school and first-year college chemistry and physics course presents the topic of the gas laws. However, there are very few experiments effectively demonstrate the relationship between pressure and temperature of gases with a fixed volume, often referred to as the Gay-Lussac Law. This simple and cost effective apparatus is designed to allow students a hands-on experience when studying this concept. The apparatus consists of a pressurized stainless steel sphere connected to a pressure gauge. Testing of the apparatus determined that sphere sizes greater than 5.1 cm had significantly less error than smaller sizes. Sphere sizes between 6.4 and 11.4 cm had no statistical difference between them and had percent error values less than 4%. This apparatus could be an effective means of providing a hands-on exercise to demonstrate the Gay-Lussac Law in an introductory chemistry course.

Keywords—Gay-Lussac's Law; Amonton's Law; Apparatus

INTRODUCTION

The relationship between pressure and temperature of gases at a constant volume is well known and was first identified by Amontons and later revisited by Gay-Lussac (Zumdahl and Zumdahl 2014). This concept is presented in most high school and college level curriculum; however, there are very few hands-on experiments that are safe, practical, and cost effective for students to easily and accurately conduct and demonstrate this concept (Blanco and Romero 1995). When the laws are presented visually, it is by classical classroom demonstration conducted by an instructor (Dannelly and Lash 1950). The primary commercially available apparatus known as the "Absolute Zero Apparatus" effectively demonstrates this pressure/temperature relationship, but is too large for most student use and is not cost effective to have multiple devices in a single laboratory setting (Science First 2009). Recently, Vernier Software has developed a laboratory experiment using a digital pressure probe and a sealed Erlenmeyer flask (Randall 2004). Although this is fairly simple and straight forward, it requires an investment that many not be practical for many schools.

The apparatus described in this paper is a modification of the "Absolute Zero Apparatus." This apparatus is designed to be smaller, less expensive, and easily assembled in order for students to effectively use in a smaller setting. The simplicity and cost effectiveness of the design allows for several of these devices to be built so that many students can conduct the same laboratory exercise simultaneously.

CONSTRUCTION

All parts of this apparatus, except the stainless steel sphere, can be purchased at most any hardware or home improvement store. The apparatus consists of five pieces:

A. Threaded stainless steel sphere.
B. Male to male hex connector.
C. Threaded tee.
D. Schrader valve.
E. Pressure gauge.

The pressure gauge used was a Campbell 0.25 inch npt (national pipe thread) with a range from 0-30 psi (0-2 kg/cm^2). The pressure gauge was threaded into a brass tee which was connected on one side to a Schrader valve and on the other a 0.25 npt hex nipple that was then threaded into the sphere. The sphere with the pipe thread welded to the top was manufactured by Arthur Harris (Chicago, IL, USA) and is made of 16 gauge stainless steel. A small hole was drilled into the sphere using a standard drill press where the threads were attached (Figure 1).

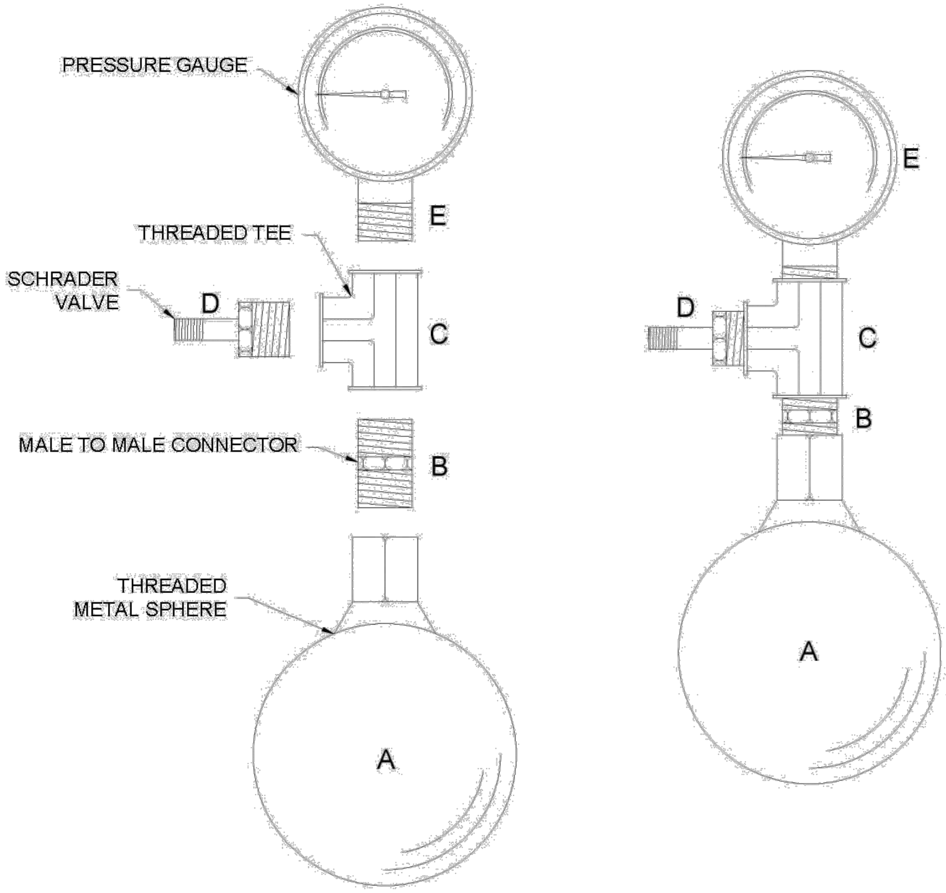

Figure 1. An assembly diagram of the apparatus used to demonstrate the relationship between pressure and temperature of a gas at a fixed volume.

METHODS

The experiment was designed to simulate a short laboratory exercise at a high school or introductory college setting and not a full-length laboratory experiment. A sphere of a certain diameter was connected to the rest of the apparatus and pressurized using a manual bicycle tire pump to between 20-30 psi. The apparatus was then submerged into a 1500 mL beaker containing room temperature water, leaving only the pressure gauge and Schrader valve out of the water (Figure 2).

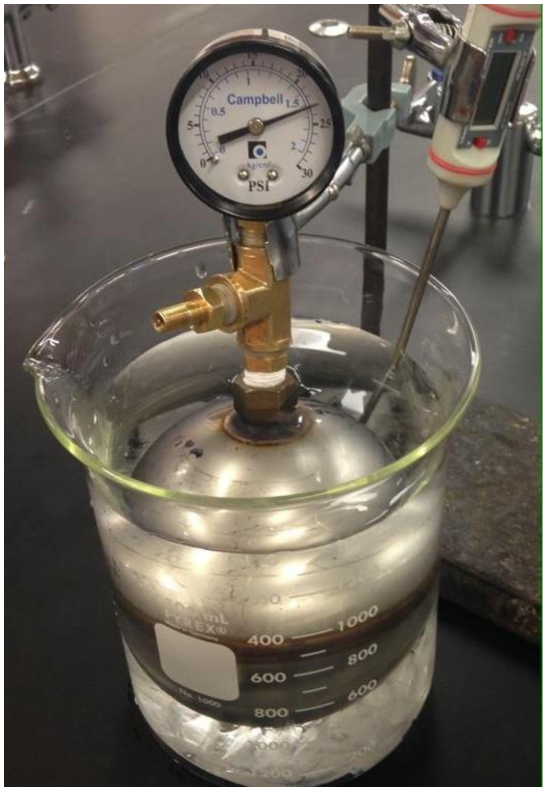

Figure 2. The apparatus used in demonstrating the relationship between pressure and temperature of a gas and a fixed volume.

After several minutes, to allow for the gas temperature inside the apparatus to reach equilibrium, the initial temperature and pressure were recorded. The apparatus was next submerged into an ice water bath in the same manner allowing for the gas inside reaching equilibrium. The second temperature and pressure were recorded. Gauge pressures where then converted to actual pressure by adding the atmospheric pressure to each gauge measurement.

The Gay-Lussac Law equation (1) was used and percent error was calculated and recorded (Zumdahl and Zumdahl 2014).

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \text{ This implies that } \frac{P_1 T_2}{P_2 T_1} = 1 \quad (1)$$

P = Actual Pressure (Gauge Pressure + Atmospheric Pressure)
T = Temperature (Kelvin)

Seven different sphere sizes were tested with four replications in a completely randomized design. Spheres with diameters of 11.4 cm or less were used as that is the maximum size that can fit into a 1500 mL beaker, the largest size beaker many schools would have multiples of to conduct this experiment. The experiment was repeated five times using five separate college level chemistry classes. No statistical difference or variance was shown between classes so data was pooled and compared using ANOVA.

RESULTS AND DISCUSSION

Data indicates that the sphere size of 3.8 cm had significantly greater error than larger sphere sizes. Spheres of 5.1 cm were also shown to be different than those of 11.4 cm, while all spheres between 6.4 and 11.4 cm showed no statistical differences in error values. (Table 1).

Table 1. Percent error of the Gay-Lussac Law for each sphere size of the apparatus.

Sphere Diameter cm (in)	Percent Error
3.8 (1.5)	6.2
5.1 (2.0)	3.7
6.4 (2.5)	2.6
7.6 (3.0)	1.6
8.9 (3.5)	1.8
10.2 (4.0)	3.5
11.4 (4.5)	0.7
LSD (p=0.05)	2.9

It was expected that the smaller sphere sizes would have greater error since the portion of the apparatus above the water level did contain some air and this would be a larger portion of the total air volume in the smaller spheres. One of the intentions of this study was to determine how small of a sphere size could effectively demonstrate the Gay-Lussac Law and it appears that spheres with diameters as small as 6.4 cm are the most effective.

It was surprising to see how low the percent error values were for all of the sphere sizes. Many of the students collecting the data were not chemistry majors and about half were not science majors, they were students taking a chemistry course for their general education requirement. With error values below 5% for most of the spheres measured by novice college students, it can be expected that most high school students would be able to collect acceptable data to effectively gain a valuable hands-on experience with the Gay-Lussac Law.

CONCLUSION

The results show that the apparatus built to demonstrate the Gay-Lussac law in this paper was an effective and simple device that can be used to provide a hands-on exercise for students. The assembly diagram should simplify the construction process. Since the sphere size greater than 6.4 cm had no effect on the percent error, adjustments to the size and type of sphere would allow an instructor to use whatever is available in their area.

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