A VERY SIMPLE TEACHING DEVICE FOR STUDYING THE PRESSURE-TEMPERATURE RELATIONSHIP OF A GAS

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ABSTRACT

The relationships between the properties of gases are not mere "curiosities" and have important implications in areas such as chemistry, chemical engineering, materials science and engineering, mechanical engineering, aerospace engineering, meteorology, etc. In the present work, we describe a practical device to study the pressure – air temperature relationship in constant volume that can be built and tested by students in the first years of science courses. The simplicity and reliability of the device make the proposal effectively capable of being used in experimental practices in several high school courses, or even in higher education and even in teacher training courses. *[African Journal of Chemical Education—AJCE 11(2), July 2021]*

INTRODUCTION

Phenomenological thermodynamics deals with easily measurable properties of a big number of particles of a gas, namely: pressure, temperature, and volume. This macroscopic view is fundamental for understanding the behavior of matter, and is based on mathematical relationships called equations of state.

Well-known phenomenon, the volume (V) of the gas increases as the pressure (P) exerted on the gas decreases, according to the mathematical relationship experimentally established by Edme Mariotte (1620 – 1684) and Robert Boyle (1627 – 1691) [1]:

$$P.V = c_1 \qquad (1)$$

Continuing the same reasoning, the volume of an inflated balloon increases when the temperature (T) of the gas inside the balloon increases and, conversely, decreases when the temperature of the gas decreases, according to the mathematical relationship experimentally established in 1787 by Jacques Charles (1746 – 1823), and posteriorly by Louis Joseph Gay-Lussac (1778 – 1850) [1, 2]:

$$V/T = c_2 \qquad (2)$$

The experiments on the variation of the pressure of a gas as a function of its temperature resulted in the so-called second law of Charles – Lussac, mathematically expressed by:

$$P/T = c_3 \qquad (3)$$

The relationships between temperature, volume and pressure of gases have important implications for the industry. Thus, it is necessary to give the student of physics, chemistry, chemical engineering, materials science and engineering, mechanical engineering, aerospace engineering, meteorology, etc., basic knowledge about the description of the behaviour of gases. As what is known about gases was the result of experimental studies, it is interesting to provide students with the same type of knowledge. Therefore, it is interesting to use simple and practical devices (easy to assemble and made with low-cost materials) for educational purposes, capable of allowing not only qualitative, but also quantitative studies of the relations P x V x T, which can be applied to teaching middle school or even at university. In the present work, we propose a device for this purpose.

METHODOLOGY

The assembled system consists essentially of the following parts: a PET bottle (the container that contains the gas), a high-powered lamp (about 200 W or more, to heat the air inside the bottle), a digital thermometer and a pressure gauge (Bourdon tube), as shown in Figure 1.

Fig. 1. The main components of the assembled experimental system: (a) pressure gauge; (b) thermometer; (c) PET bottle; (d) thermocouple; (e) hose; (f) high-powered lamp; (g) base stand.

A thermocouple was attached (by means of a duck tape) to the side of the PET bottle. The surface temperature of the bottle was assumed to be approximately equal to the temperature of the air inside the bottle.

A copper tube was passed through the bottle cap. A hose was connected to the copper tube and then to the pressure gauge.

The high-powered lamp was positioned about 0.20 m above the bottle. When the lamp was turned on, the heat due to thermal radiation caused a rapid increase in the temperature of the air confined in the bottle. As the bottle is rigid and undergoes little expansion, the heated air had its pressure increased. The variation in air pressure was easily monitored using the Bourdon pressure gauge.

The procedures can be performed in an air-conditioned environment (constant temperature). It is suggested to consider the collection of data for both heating and cooling of the air contained in the bottle (after turning off the lamp). To facilitate the data collection process, it is suggested to film the experiment (using a cell phone).

RESULTS AND DISCUSSION

It was found that the system reacts very quickly: right after the lamp is turned on, the temperature and air pressure inside the bottle start to increase. As it is an isometric process (constant volume), the increase in the kinetic energy of the gas molecules inside the bottle results in a direct increase in pressure.

Figures 2 and 3 show the results obtained in the experiments, where the temperature is expressed in Kelvin and the pressure in millimeters of water (1 mmH2O = 9.80638 Pa). Figure 2 shows the heating curve, while Figure 3 shows the cooling curve.

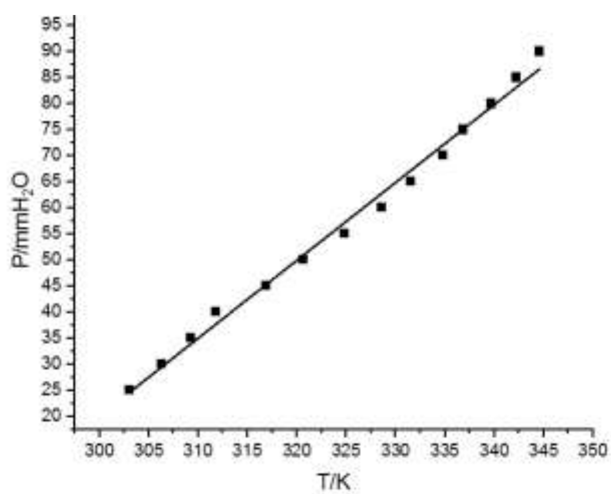

Fig. 2. Heating curve for the experimental setup shown in Fig.1.

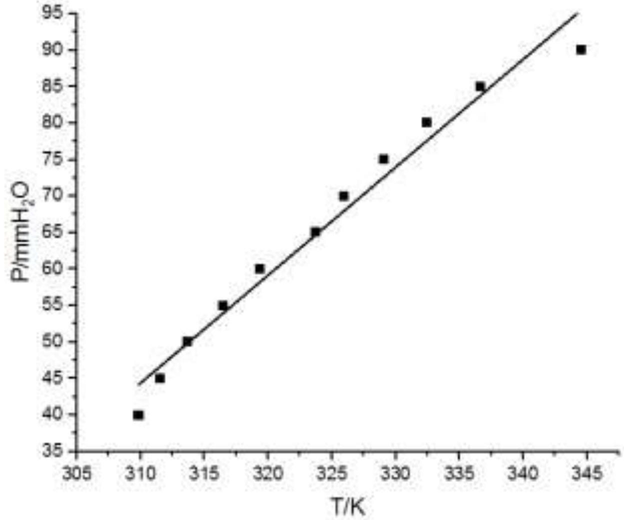

Fig. 3. Cooling curve for the experimental setup shown in Fig.1.

From the curve of Figures 2 and 3, the following equation is derived:

$$P = 1.49\ T - 428.18 \qquad (4)$$

where the coefficient of variation is r = 0.992.

And from the curve in Figure 3, we get:

$$P = 1.48\ T - 414.14 \qquad (5)$$

where the coefficient of variation is r = 0.971.

The coefficients of variation obtained for the heating curve (r = 0.992) and for the cooling curve (r = 0.971) showed good agreement with the experimental results.

CONCLUSION

The results obtained show the reliability of the proposed experimental system, despite its simplicity. In addition, both pressure and temperature are measured using low-cost and easy-toobtain devices (in addition to the system being easy to assemble and handle), making the proposed experiment effectively usable in experimental classes of various undergraduate courses.

REFERENCES

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2. The New Encyclopaedia Britannica. Vol. 7, pp. 914 – 915.