The Ideal Gas Law Illustrated Using a Disposable Cigarette Lighter

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Abstract: Three experiments are described. They illustrate the ideal gas law and cover the determination of molecular weight, the dependence of volume on the number of moles, and pressure as a function of the number of moles. A disposable lighter is used as the gas source. The experiments are suggested for use as regular laboratory exercises or as lecture demonstrations.

Introduction

One of the topics that is covered in general chemistry courses is the ideal gas law; it may also be covered in introductory physical chemistry. Experiments designed to illustrate this law and its applications appear frequently in the literature. There are a number of very good compilations of lecture demonstrations available. (See, for instance, references 1–5). The use of different techniques and of new approaches to experimentation may be the reason for the continuous interest in this field.

Often the choice of gas sources used to perform these experiments becomes a problem. The use of compressed gas tanks or lecture bottles is usually precluded by cost and safety considerations, given the number and level of the students for whom the experiments are intended. To overcome this situation the use of low-pressure air and of carbon dioxide generated from dry ice has been suggested [6, 7]. Some authors recommend the use of butanes obtained from disposable lighters or refill canisters for nondisposable butane lighters as the source of gases to be studied [4, 6, 8–10]. In some cases the unknown composition of the gas mixture is a problem [8]; in others the pressure-measuring devices are not good enough to render accurate results [8, 9]. In this paper we describe three experiments: determination of molecular weight; volume as a function of the number of moles, *n*; and pressure as a function of *n*. All use a disposable gas lighter and a pressure sensor. The experiments give accurate results at reasonable costs.

Experimental

The lighters are filled with a mixture of butane isomers and small quantities of other hydrocarbons. As a check the composition of the mixture was determined by gas chromatography; however this is not necessary for the purposes of these experiments because the molecular weight of the mixtures can be determined by one of the usual techniques. The molecular weight so determined can be given to the students as known data for the pressure (P) versus n determination. In our case the molecular weight was found to be near 58 g mol^{-1} as expected from the composition of the mixture.

For pressure measurement we used a sensor Model PS-DIN obtained from Vernier Software[1] coupled with a personal computer. The sensor works in the range from 0 to 6.8 atm (0 to 100 psi) and 0 to 0.454 V output voltage. Any of the commercially available sensors, coupled either with calculators or with computers, can be used as well. The easy and clean operation of these devices compensates for the added cost. The experimental setups can be adapted for use as lecture demonstrations given their simplicity. If necessary, mercury manometers can replace the pressure sensors; however, this practice is discouraged due to the inconvenience and danger of mercury use. A small piece of Tygon tubing, 0.57-mm i.d., is slipped over the lighter's exit tube. This allows an easy connection to the stopcock by means of a piece of rubber tubing. The lighter is weighed with the piece of rubber tubing attached. This makes repetitive assembling easy.

Experiment 1. Determination of Molecular Weight. In this experiment the pressure effect that results from the addition of a known weight of gas is measured. The apparatus used is shown in Figure 1. A fixed volume is selected, typically 25 mL, and a calibration mark is made on the plastic syringe. The volume is determined by weighing the syringe filled to the mark with water; the volume of the stopcock and of the connecting tubing is also determined and added to obtain the total volume. This value is given as known data to the students. No correction for the volume of the connecting tubing between C and G is necessary as it is kept as short as possible. The vent is opened to the atmosphere and then closed again.

The gas lighter is weighed, then connected to the syringe. An amount of gas is introduced and the pressure is read and recorded along with the new weight of the lighter. A typical lighter has around 2 grams of hydrocarbons. The pressure sensor used gives readings to ±0.1 mm Hg in the range of interest and the balance we use weighs to the milligram. Supporting Material 1 (42lb1897.pdf) gives a sample of student results. An average value of 58 ± 2 g mol^{-1} was obtained for 16 independent determinations. Given the method and the level of the students, we feel that the results are good enough for the purpose.

Experiment 2. Volume as a Function of the Number of Moles. The apparatus used is shown in Figure 2. A known amount of gas is taken from the lighter and collected in a buret. The pressure is equilibrated with atmospheric pressure using a leveling bulb and water as the fluid. The pressure of the gas is the atmospheric pressure less the value of the vapor pressure of water at room temperature. The procedure is repeated at least eight times and the results are plotted as V (L) versus n. Supporting Material 1 (42lb1897.pdf) shows the results of a typical run. The slope of the straight line is m = RT/P from which a value of 0.084 L atm mol^{-1} K^{-1} is obtained for R, the gas constant.

Experiment 3. Pressure as a Function of the Number of Moles. This experimental set up is the same as that used for Experiment 1. Pressure is measured for several additions of gas keeping the volume constant and using the apparatus shown in Figure 1. The value of molecular weight is given to the students and values for P and n are calculated. In Supporting Material 1 (42lb1897.pdf) we show a

[1] Vernier Software 18565 S.W Beaberton-Hillsdale Hwy Portland, Oregon.

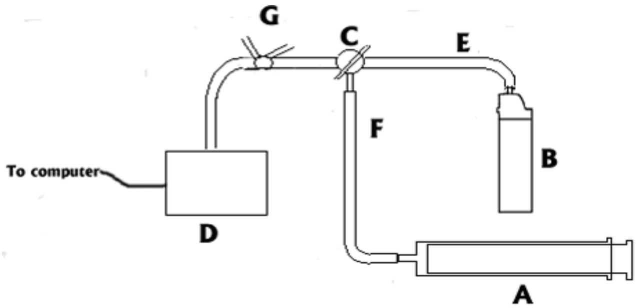

Figure 1. The Apparatus for the Determination of Molecular Weight

A - Plastic syringe
B - Cigarette lighter
C - Three way stopcock
D - Pressure sensor
E - Rubber and Tygon connection
F - Rubber tubing
G - Vent

Figure 1. Apparatus for the measurement of molecular weight: plastic syringe (A); disposable lighter (B); stopcock (C), the size of the glass tubing has been reduced to facilitate the connections; pressure sensor (D); tygon tubing (E, F); vent (G).

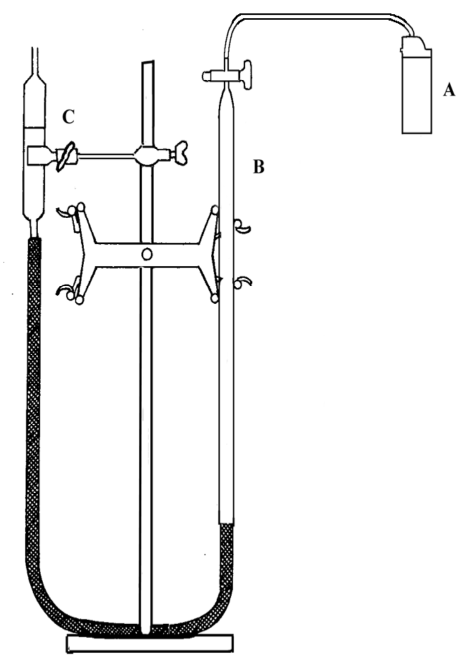

Figure 2. Apparatus for the determination of volume as a function of numer of moles

A - Cigarette lighter
B - Burette
C - Leveling bulb

Figure 2. Experimental setup for the determination of volume versus number of moles: cigarette lighter (A), tygon tubing (B), stopcock (C), buret (D), rubber stopper (E), rubber tubing (F), leveling bulb (G).

sample of student results. The value of R calculated from the slope of the straight line is 0.082 L atm mol^{-1} K^{-1}. The intercept corresponds to the local atmospheric pressure, which is around 560 mm Hg locally (in Bogotá).

Conclusions

These experiments are easy to perform either as lecture demonstrations or as regular laboratory experiments. The results obtained are quantitative and of a quality good enough for the level and purpose of the courses for which they are intended. The ideal gas law and Dalton's law are illustrated in an easy way.

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