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Laboratories and Demonstrations

Determination of Densities of Liquids and Solids Using a Gas

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An experiment for the determination of densities of solids and liquids is described. It uses Archimedes' Principle with air as the fluid. It can be used in general and introductory physical chemistry courses as a regular laboratory experiment or as a demonstration. A typical calibration curve and the values of some densities measured using this method are given as examples.

The equal treatment given to solids and liquids makes the concept of density more easily understood.

Introduction

The determination of density is often a subject for experimentation in introductory chemistry courses. Substances in the liquid or gaseous states are frequently used, following simple experimental procedures. Few references are found in the regular literature, however, that deal with measuring the

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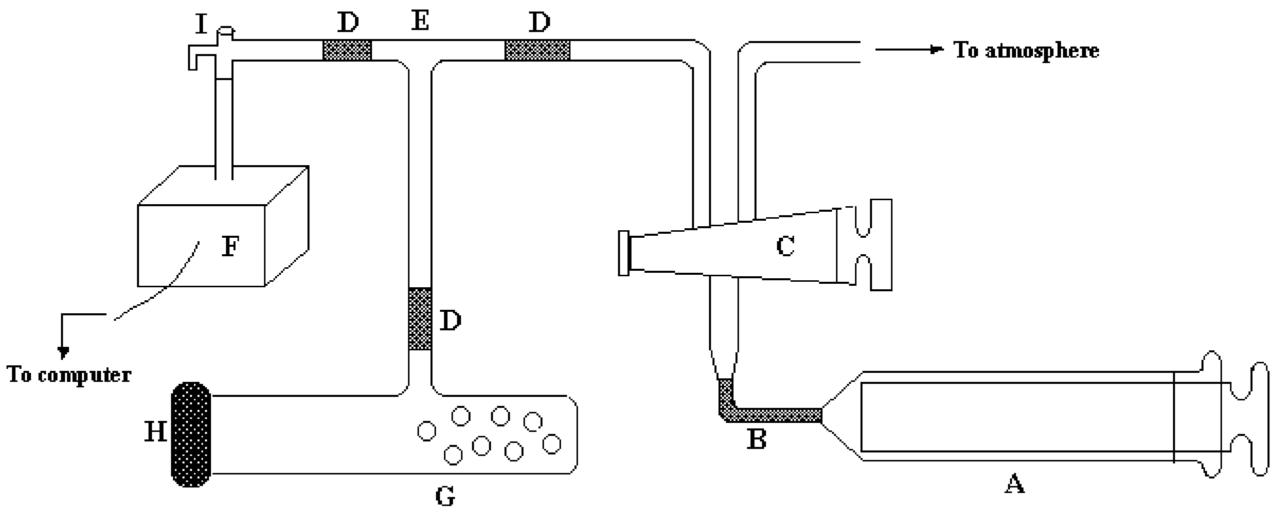

FIGURE 1. EXPERIMENTAL SET UP: A. PLASTIC SYRINGE, 20 mL CAPACITY; B. TYGON TUBING; C. THREE-WAY STOPCOCK; D. POLYETHYLENE TUBING; E. GLASS T; F. PRESSURE SENSOR; G. GLASS CELL; H. PLASTIC CAP; I. VENT.

density of solids [1–4]. In this paper we describe a method of density determination that can be used for solids and liquids by applying Archimedes' Principle and the ideal-gas law, using air as the fluid. It can be part of a general chemistry laboratory course both for chemistry majors and nonmajors. Also, it may be used in an introductory Physical Chemistry course.

Experimental

The volume occupied by the solid or the liquid is determined using the apparatus shown in Figure 1. A plastic syringe of 20-ml capacity is connected to a three-way stopcock using small-diameter Tygon® tubing. For this purpose, one of the stopcock's ends is reduced in diameter to obtain a size close to the syringe's smaller end. A second side of the stopcock is opened to the atmosphere and the remaining side is connected to a glass "T" by means of a piece of polyethylene tubing. The T, in turn, is connected to a pressure sensor and to a cell made using a screw-cap glass joint, whose volume should be approximately 20 ml. The pressure sensor was obtained from Vernier Software[1] and is readable to ± 0.1 mm Hg. The computer is a regular IBM-compatible PC compatible. The use of the plastic tubing could be avoided almost

[1] Vernier Software, 8565 S. W. Beaberton-Hillsdale Hwy, Portland, Oregon.

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TABLE 1. Calibration Using Glycerine At 23 °C.

Volume (cm^3)	ΔP(mm Hg)
0.000	0
1.127	30.7
1.445	42.3
2.033	58.7
2.558	77.9
3.021	94.2
3.453	113.9
3.960	129.7

completely by soldering the glass pieces, but then the entire apparatus becomes too fragile.

To calibrate the instrument, a weighed amount of a liquid of known density and very low vapor pressure is placed in the cell. We use glycerine for this purpose. A known volume, about 20 ml, of air from the syringe is injected and the pressure reading is recorded. The procedure is repeated six or seven times using different quantities of glycerine. The pressure reading corresponding to the empty cell is subtracted from each of the others. Table 1 and Figure 2 show the results of a typical calibration run.

The calibration curve can be made available to the class if the teacher so decides. We prefer to have the students obtain a new one using the following method, Twenty to thirty steel balls of approximately 6 mm in diameter are provided. Their volume has been previously determined by the instructor using the apparatus. This is necessary because the composition of the spheres is not known. The average volume of a ball is calculated and the balls are used instead of glycerine to calibrate the instrument. Five or six data pairs are taken using different numbers of balls. Next, a variety of solids are used as unknowns. The shape and other physical characteristics are chosen to show the possibilities of the method. Steel wool, granular zinc, steel objects, copper wire, glass beads, silver foil, among others, make good examples. Some liquids, difficult to handle by the usual methods, complete the set of substances whose densities are determined.

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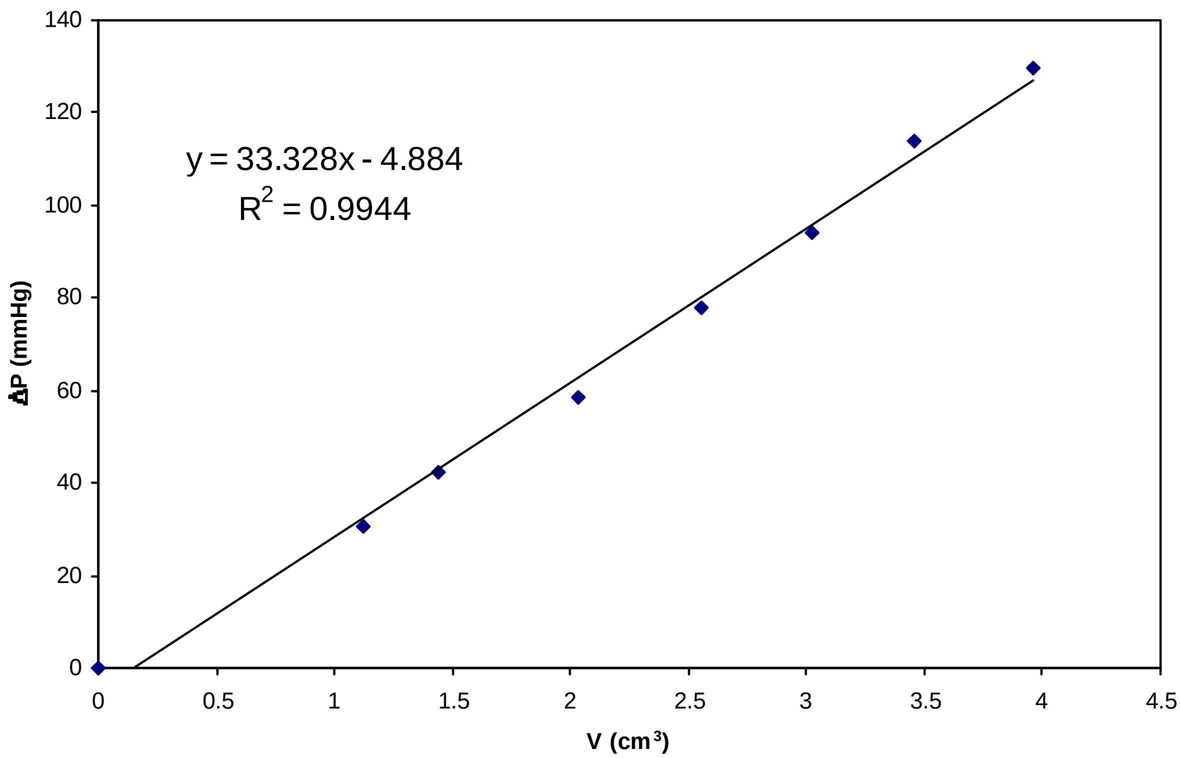

FIGURE 2. CALIBRATION CURVE USING GLYCERINE.

In a typical run, the volume of a weighed sample is determined by placing it in the glass cell. The same volume of air used for the calibration is injected and the pressure is read and recorded along with the temperature. The volume corresponding to the increase in pressure is obtained from the calibration curve and the density is calculated. Table 2 shows some of the results obtained. The agreement between the experimental values and those from literature is satisfactory, especially in those cases where the composition is well known.

Precision of the method

The lack of temperature control, because the apparatus is operated at ambient conditions, is the main source of uncertainty. Fortunately, the temperature fluctuations that usually occur during a laboratory session, two or three Celsius degrees, do not invalidate the results. Some of the solids used as unknowns are purchased in local stores and, for those, it is difficult to know the exact composition. This is discussed with the students to show the dependence of density on composition. The volume of

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TABLE 2. DENSITY OF SOME SUBSTANCES.

Substance	Presentation	ΔP (mm Hg)	V_{exp} (cm^3)	Weight (g)	Density (exp) (g/cm^3)	Density [5] (g/cm^3)[a]	Temperature (°C)
Zinc	Granular	42.9	1.43	10.09574	7.06	7.14	22.30
Glass	Beads	110.0	3.48	8.81837	2.53	2.4–2.8	22.30
Silver	Foil	8.4	0.398	4.09728	10.3	10.25	22.90
Steel	Wool	1.5	0.185	1.43367	7.75	7.95	22.80
Copper	Wire	17.2	0.660	5.80330	8.75	8.71	22.20
Cadmium	Filings	1.9	0.203	1.66776	8.22	8.38	22.60
1-Octanol	Liquid	81.0	2.58	2.15736	0.836	0.8234	22.80
1,2 propanediol	Liquid	127.4	3.97	4.10356	1.03	1.03488	20.60

[a] Corrected values with temperature.

air injected in each determination must be measured carefully, and marks on the body of the syringe help that purpose.

The precision of the results depends on the quality of the calibration curve. If enough care is taken, the results are reproducible to better than 1% in volume. This is the uncertainty that propagates in the density values, because the error in weight is negligible when an analytical balance is used. The values of volume in the tables are given with one uncertain digit, and the final densities are reported with three significant digits.

Conclusions

The method described in this paper has been used in several laboratory courses with good results. The use of air as the working fluid and the application of Archimedes' Principle offer opportunities for interesting discussion. The equal treatment given to solids and liquids makes the concept of density more easily understood. The use of a self-generated calibration curve helps in the introduction of ideas of data generation and treatment.

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