A COMPARISON OF EXISTING METHODS FOR THE MEASUREMENT OF THE COEFFICIENT OF VISCOSITY OF A GAS

Duane Roller and Dean Woolridge
University of Oklahoma

Few, if any, elementary laboratory manuals include any sort of experiment on the viscosity of gases. However, we believe that such an experiment would be of considerable value as an aid to the development of the kinetic-molecular theory and, more particularly, as a means of determining one of the molecular constants of a gas—its mean free path. The following is a brief account of work which has been done with the end of developing such an experiment. Since the aim of this work is the development of an elementary laboratory experiment we believe that it is a type of research which can advantageously be pursued by an undergraduate student.

The specific purpose of this series of experiments is to work with several of the existing types of apparatus for the measurement of the viscosity of a gas, compare their advantages and disadvantages, and select from among them the particular apparatus and method which seem best suited to meet the needs of an elementary laboratory class in physics. Work has been done with two capillary flow viscometers of different designs, and plans are being made for the immediate construction of a revolving disk viscometer, with which the experiments will be continued.

The first apparatus with which we worked was Rankine's simple U-tube arrangement.* With this design a pellet of mercury is allowed to slide down one arm of a glass U-tube, forcing air out through the other arm and through a capillary tube which is attached, by pressure tubing, to the other end of the U. By measuring the time required for a given volume of gas to be forced through this capillary, the coefficient of viscosity of the gas may be calculated. Besides being a classical experiment, this method has the obvious advantage of simplicity. Its chief disadvantage was found to lie in the extreme difficulty of measuring the diameter of the capillary tube to a sufficient degree of accuracy, as this diameter must be of the order of .2 mm. or less, or the mercury pellet will slide down the U-tube so rapidly that observations cannot be taken. With this apparatus, however, about eighty runs were taken with capillary tubes of different lengths and diameters, in each case using mercury pellets of lengths varying from 2 cm. to 10 cm. In each case it was found that, when an average was taken of all values for the viscosity of air obtained with a particular tube, the maximum deviation from this average was less than 2 per cent, which is about the accuracy expected. It was also found, however, that the average values obtained in this way with different tubes were as much as 2 per cent at variance with each other, a discrepancy attributed to errors in the measurement of the diameter of the tubes. From all our runs we would set the value of the coefficient of viscosity of the air at 27° C. at from 188 to 192 micropoises, which is in fair agreement with the values obtained by other experimenters.

The second apparatus with which we have worked is an instrument designed recently by Professor I. S. Bowen, of the California Institute of Technology, which he was kind enough to lend us with permission to use and develop it in any way. This apparatus is designed on the U-tube

*—See, for example, Edser, "General Physics for Students," Macmillan (1922), p. 517

principle and consists essentially of three coaxial iron cylinders, of radii of about 4, 5, and 6 cm. respectively, and each 15 cm. in height. The smallest and the largest cylinders are welded into the same iron base, and the space between them is filled with mercury. Down into this mercury slides the third cylinder, the upper end of which is closed. This cylinder is weighted, and therefore forces air out through a capillary tube which is firmly fixed into its otherwise solid top. The coefficient of viscosity of air may be determined by measuring the time required for the cylinder to slide down some measured distance. The apparent value of this method lies in the fact that large quantities of gas may be used, attended by a corresponding magnitude of other measured quantities, which diminishes the significance of observational errors and increases the accuracy of the results. The chief disadvantage of this method, as will be seen, is that so many corrections must be applied to the simple equation used for calculating the viscosity of a fluid that the final, working equation is a very complicated expression, causing the usefulness of this method for elementary laboratory instruction to be considerably impaired.

Before the coefficient of viscosity of a gas can be determined by Bowen's method, there are at least three corrections which must be applied to the simple equation used with Rankine's U-tube apparatus. The first correction is required to take into account the fact that the pressure on the gas is a varying quantity, since the sliding cylinder displaces more and more mercury as it slips down over the inner cylinder. The second correction has to do with the drop in pressure due to gain in velocity of the air as it enters the capillary tube, while there is a third decrease in pressure caused by the force of the sliding cylinder due to the surface tension of mercury.

Despite the fact that the foregoing effects have all been taken into account in our calculations, the results of some thirty runs made with three different sizes of capillary tubes yield values for the coefficient of viscosity of air that are much too high, for they vary from 204 to 298 micropoises, depending upon the speed with which the sliding cylinder falls in the mercury. The highest values were obtained with the largest capillary and can be shown to be due to the fact that the critical speed for the air was there approached. The lowest values were obtained with the smallest tube, in which the speeds were low, while successively higher values were obtained when successively higher speeds were used, although there have been some exceptions to this steady progression.

The explanation of these phenomena seems to be found in a consideration of the frictional losses in the apparatus. Thus, the rise of values with the rise of the speed with which the sliding cylinder moved through the mercury may be attributed to the increased viscous drag of the mercury, while the excessive magnitude of even those results obtained with very low speeds of the sliding cylinder may be attributed to the effects of solid friction, which, from its construction, exists between certain parts of the apparatus. If frictional effects are, as we believe, the cause of our error, it will be necessary to make some slight modifications to Bowen's apparatus in order to minimize these losses.

In comparing Bowen's apparatus for measuring the coefficient of viscosity of air with that of Rankine, it seems obvious that the latter is more nearly adapted to the needs of an elementary laboratory class than the former, because of the extreme simplicity of the equations and procedure. On the other hand, a development of Bowen's apparatus might very conceivably give a considerably greater accuracy of results than those obtained with the U-tube. The greatest disadvantage of the U-tube method, the necessity of measuring extremely small diameters, is eliminated in Bowen's apparatus, but the number of corrections required, and the errors introduced by friction in this apparatus are, we believe, productive of even greater difficulties.