

Steady state is defined here as invariance with time of the pressure difference across the capillary during a run. Strictly speaking, such steady-state behavior is impossible in a constant-volume apparatus, since the pressure difference steadily increases with time¹¹; however, we have shown¹⁰ that this increase is negligible for the dimensions of our apparatus. A more serious problem is the relaxation of the transient process set in motion when a run begins: in particular, the rapid imposition of the pressure difference is an essentially adiabatic process, producing a temperature difference across the capillary. For most of the measurements reported here, we in fact observed the attainment of steady state (constant within ~ 0.001 in. Hg) with the pressure gauge as noted above. In addition a rough but adequate model of the transient behavior has been derived¹⁰ and approximately confirmed experimentally, to the extent that we believe steady state to have been reached in virtually all the previous measurements with this apparatus. (This applies even for injector flow rates up to $0.05 \text{ cm}^2/\text{sec}$, although we now work only at $\lesssim 0.03 \text{ cm}^2/\text{sec}$.)

Three capillaries were used in the present work, all about 36 cm long and 0.019 cm in diameter. The last two were calibrated by the electrical-resistance method, which we have found to be both more convenient and more precise than the gravimetric method.¹² More careful analysis of our previous techniques with the latter method led us to the conclusion¹⁰ that the viscosity values in Refs. 1 and 2 should be decreased by about 0.12%.¹³

For each capillary the value of the kinetic-energy constant m was determined in the same way as before,¹ except that individual runs were weighted in accordance with their *a priori* precision.¹⁰ We again took an upper Reynolds-number limit of 1600, below which we found no correlation of m with Reynolds number or other variables. For the three capillaries the values of m obtained were 1.199 ± 0.013 , 1.162 ± 0.016 , and 1.199 ± 0.025 ; these values were used to calculate the viscosities in Table I.

EXPERIMENTAL RESULTS

Our measured viscosities are given in Table I and plotted in Figs. 1-4; the deviations listed in the table indicate primarily the scatter of the measurements at

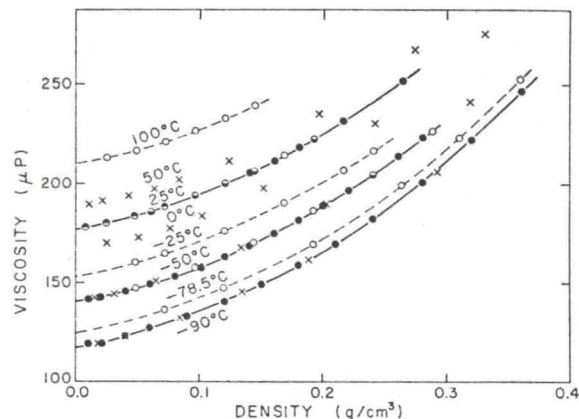


FIG. 1. Viscosity of nitrogen vs density: ●, present results; ○, Flynn, Hanks, Lemaire, and Ross¹ (points nearly coinciding with present data indicated by ⊙); ×, Kao and Kobayashi.³

each pressure. The paragraphs which follow give our density sources and some discussion of the results. More extensive comparisons with previous work can be found in Ref. 10.

Nitrogen

Nitrogen¹⁴ was studied up to 253 atm at 25°C; at -50 and 90°C , as for the other gases, limits were chosen in the range 150–175 atm. The results are shown in Fig. 1. The densities used were those of Michels *et al.*¹⁵ at 25°C and of Canfield *et al.*¹⁶ at lower temperatures. Our results are in good agreement¹⁷ with our previous work,¹ and thus are still about 0.4% lower than those of Kestin and Leidenfrost¹⁸ and Michels and Gibson¹⁹ at 25°C and moderate pressures. Agreement with Kao and Kobayashi³ at -50 and -90°C is within their precision. On the other hand, our disagreement with Ross and Brown²⁰ is as reported before,¹ and Filippova and Ishkin's²¹ measurements deviate from ours in the same way; Goldman's²² data at -61 and -78.5°C are 1%–6% higher than values interpolated from ours, and

¹⁴ Purity 99.998%, from Air Reduction Co.

¹⁵ A. Michels, R. J. Lunbeck, and G. J. Wolkers, *Physica* **17**, 801 (1951).

¹⁶ F. B. Canfield, T. W. Leland, and R. Kobayashi, *J. Chem. Eng. Data* **10**, 92 (1965). These densities (for both N_2 and He) differ appreciably from those used in Ref. 1. For reduction of our earlier data to the same basis as the present data, see Ref. 10; the values thus obtained are used in Figs. 1–2 and in the discussion of comparative results below.

¹⁷ "Good agreement" with our previous work, for all the gases in this paper, means agreement within the combined postulated limits of accuracy (see section "Accuracy" below), after correction^{13,16} of the earlier data.

¹⁸ J. Kestin and W. Leidenfrost, *Physica* **25**, 1033 (1959); see also several more recent papers by Kestin *et al.*, primarily devoted to mixtures at 20–30°C.

¹⁹ A. Michels and R. O. Gibson, *Proc. Roy. Soc. (London)* **A134**, 288 (1931).

²⁰ J. F. Ross and G. M. Brown, *Ind. Eng. Chem.* **49**, 2026 (1957).

²¹ G. P. Filippova and I. P. Ishkin, *Inzh.-Fiz. Zh., Akad. Nauk Belorus. SSR* **4**, 105 (1961).

²² K. Goldman, *Physica* **29**, 499 (1963).

¹¹ K. R. Van Doren, R. A. Guereca, H. P. Richardson, and D. Cummins, *J. Appl. Mech.* **36**, 171 (1969).

¹² For these methods, see J. F. Swindells, J. R. Coe, Jr., and T. B. Godfrey, *J. Res. Natl. Bur. Std.* **48**, 1 (1952).

¹³ In addition, the measurements reported at -50°C in Refs. 1 and 2 were actually made at -49.90°C , so that these values should be corrected by an additional amount. The correction is in most cases only slightly pressure-dependent, and averages $-0.05 \mu\text{P}$ for H_2 , -0.07 for D_2 , -0.11 for He , -0.12 for N_2 and CO , -0.17 for Ar , and -0.19 for Ne ; for CH_4 (near its critical temperature) the pressure variation is too great for accurate estimation of the correction.

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