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Critical Reassessment of Viscosities of 11 Common Gases

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Recommended values of the coefficients of viscosity of 11 common gases (He, Ne, Ar, Kr, Xe, N_2, H_2, O_2, CO_2, CH_4, air) are given over the temperature range for which reliable data exist. A critical reassessment of all available data confirms the recently expressed view that most of the early measurements of high-temperature viscosities are seriously in error (by up to 8% at 1700K). These results have been rejected in favor of more recent data in establishing the values recommended in this paper and estimated to be accurate to 1.0–1.5%.

The values of the viscosities of even the most common gases have been the subject of some controversy in recent years. Accurate values of this property are most important both from the practical standpoint, in flow and heat exchange problems, and also in theoretical problems where a knowledge of gas viscosities over a wide range of temperature can play an important part in furthering our understanding of the forces between molecules (*3*, *43*). The controversy which has surrounded this property arises from a gross discrepancy between the mutually consistent values of Trautz (*64–76*) and Vasilesco (*80*), obtained during the 1930's and '40's, and the determinations of recent workers, which are not always so mutually consistent. Indications that the earlier results are almost certainly in error have been reported by several workers on the basis of both theoretical (*28*, *45*) and experimental observations (*13*, *15*, *26*). This fact, together with the abundance of viscosity data scattered throughout the literature, makes the need for a critical analysis of the available values very pressing.

The objectives of this survey are threefold: to collect together the many measurements of the viscosities of a number of simple gases; to make a critical assessment of this data in order to decide which data can be accepted as reliable; and using these selected viscosities, to give recommended values over the whole temperature range for which data exist and to give quantitative estimates of their accuracy. The gases studied in this work are the inert gases—helium, neon, argon, krypton, and xenon—the diatomic gases nitrogen, hydrogen, and oxygen and, in addition, carbon dioxide, methane, and air.

DEFINITION AND MEASUREMENT

This survey is concerned with the coefficient of shear viscosity, η, of dilute gases (i.e., gases at low pressures, <2 atm). η is defined as the tangential force per unit area required to maintain a unit velocity gradient when a fluid flows past a stationary plane surface. Its units are g cm^{-1} sec^{-1}, commonly called the poise; a convenient unit for gas viscosities is the micropoise, μP, 10^{-6} g cm^{-1} sec^{-1} or 10^{-7} kg m^{-1} sec^{-1}. It has been measured using a variety of techniques, the most common of which are the capillary flow method (indicated in the subsequent text by CF) and the oscillating disc (OD) method. Other techniques which have been used to a lesser extent are the rotating cylinder (RC) method and the observation of the retardation from free fall of a body, commonly an oil drop, through the gas.

PROCEDURE

Criteria for Selection of Data. Recent measurements of the viscosities of the inert gases by three separate sets of workers using different techniques [Kestin et al. (OD) (*15–17*, *33–40*), Guevara et al. (CF) (*22*, *26*, *27*) and Smith et al. (CF) (*8*, *9*, *12*, *13*, *44*)] have indicated that at high temperatures the hitherto accepted data of Trautz et al. and Vasilesco (both CF) are in error by up to 10%. These serious discrepancies have not yet been satisfactorily explained but may have arisen from inadequate correction of their data and inaccurate temperature measurement (*25*). The data of the three recent workers are not completely consistent with each other, the spread of results being 2.0–2.5%. Here we have attempted to estimate "best" values based on these more recent data.

Below room temperature, measurements by Clarke and Smith (CF) (*8*, *9*) have again suggested errors in the older data of Johnston et al. (OD) (*31*, *32*), but here the discrepancies are much smaller than those at high temperatures and are not considered significant enough to justify rejection of the earlier work.

The general criteria for accepting data were thus based on the plausible assumption that the recent values for the eleven gases of Kestin et al., Guevara et al., and Smith et al. (with a maximum spread of 2.5%) form a reliable body of data on which to base the recommended values. Where the data of a worker

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Table I. Selected Data on Which Recommended Values Are Based

Gas	Workers	Refs	Methods[a]	Temp range
N_2	Johnston and McCloskey	*32*	OD	90–300
	Flynn et al.	*20*	CF(HP)	196–373
	Kestin and Whitelaw	*39*	OD	298–538
	Kestin and DiPippo	*15*	OD	298–773
	Guevara et al.	*26*	CF	1100–2150
	Dawe and Smith	*13*	CF	293–1600
	Clarke and Smith	*8, 9*	CF	120–360
	Wobser and Muller	*81*	FB	293–371
He	Johnston and Grilly	*31*	OD	80–300
	Flynn et al.	*20*	CF(HP)	223–373
	Kestin and DiPippo	*15*	OD	298–673
	Kestin and Whitelaw	*39*	OD	296–521
	Kestin and Kalelkar	*33*	OD	298–1121
	Guevara et al.	*26*	CF	1100–2150
	Dawe and Smith	*13*	CF	293–1600
	Clarke and Smith	*9*	CF	80–360
	Wobser and Muller	*81*	FB	293–371
	Reynes and Thodos	*56*	CF(HP)	373–473
	Nasini and Rossi	*48*	CF	273–373
Ne	Johnston and Grilly	*31*	OD	80–300
	Flynn et al.	*20*	CF(HP)	223–373
	Kestin and DiPippo	*15*	OD	298–453
	Kestin and Whitelaw	*39*	OD	296–519
	Kestin et al.	*38*	OD	298–873
	Guevara and Stensland	*27*	CF	1100–2100
	Dawe and Smith	*13*	CF	293–1600
	Clarke and Smith	*9*	CF	80–360
	Wobser and Muller	*81*	FB	293–371
	Edwards	*18*	CF	288–718
Ar	Johnston and Grilly	*31*	OD	80–300
	Flynn et al.	*20*	CF(HP)	223–373
	Kestin and DiPippo	*15*	OD	298–513
	Kestin and Whitelaw	*39*	OD	296–537
	Kestin and Kalelkar	*33*	OD	298–1124
	Kestin et al.	*38*	OD	298–973
	Anfilogoff	*1*	CF	297–1288
	Guevara et al.	*27*	CF	1100–2100
	Dawe and Smith	*13*	CF	293–1600
	Clarke and Smith	*8*	CF	120–360
	De Rocco and Halford	*14*	CF	210–471
	Wobser and Muller	*81*	FB	293–371
Kr	Kestin and DiPippo	*15*	OD	303–473
	Kestin and Kalelkar	*33*	OD	298–1151
	Kestin et al.	*38*	OD	298–973
	Guevara et al.	*22*	CF	1100–2000
	Dawe and Smith	*13*	CF	293–1600
	Clarke and Smith	*8*	CF	140–360
	Rankine	*52*	CF	284–373
	Nasini and Rossi	*48*	CF	273–373
	Trappeniers et al.	*63*	CF	298–348
Xe	Kestin and Leidenfrost	*35*	OD	298
	Dawe and Smith	*13*	CF	293–1600
	Clarke and Smith	*8*	CF	180–360
	Rankine	*52, 53*	CF	284–288
	Thornton	*59*	CF	291
	Nasini and Rossi	*48*		273–373
H_2	Johnston and McCloskey	*32*	OD	90–300
	Kestin and Leidenfrost	*35*	OD	293
	Guevara et al.	*26*	CF	1102–2128
	Coremans et al.	*11*	OD	20–80
	Barua et al.	*4*	CF	223–423
	Gracki et al.	*24*	CF	173–298
	Yen	*82*	RC	296
O_2	Johnston and McCloskey	*32*	OD	90–300
	Kestin and Leidenfrost	*35*	OD	293–298
	Yen	*82*	RC	296
CO_2	Johnston and McCloskey	*32*	OD	190–300
	Kestin and DiPippo	*15*	OD	298–773
	Kestin and Whitelaw	*39*	OD	295–525
	Breetveld et al.	*7*	OD	293–303
	Maitland and Smith	*44*	CF	293–1500
	Hope et al.	*23*	CF	203–310
	Bailey	*2*	CF	293–719
	Michels et al.	*46*	CF	273–353
CH_4	Johnston and McCloskey	*32*	OD	90–300
	Clarke and Smith	*9*	CF	120–360
	Dawe et al.	*12*	CF	293–1050
	De Rocco and Halford	*14*	CF	211–473
	Rankine and Smith	*54*	CF	290–373
Air	Johnston and McCloskey	*32*	OD	90–300
	Kestin and Leidenfrost	*35*	OD	293–298
	Kestin and DiPippo	*15*	OD	298–773
	Bearden	*5*	RC	293.2

[a] CF = capillary flow; OD = oscillating disc; RC = rotating cylinder; FB = falling ball; HP = high pressure.

differed by more than ±3% from all three recent workers over a substantial temperature range, then all the results of that worker for the particular gas under study were neglected in the smoothing of data to give "best" values. Where certain workers are seen to give results which deviate consistently from the recent determinations for a number of gases, their viscosities have been rejected in establishing recommended values for all eleven gases. This eliminated the data of Trautz and Vasilesco together with a few other workers. However, the deviations of all available data from the recommended values will be illustrated later. The workers whose data were selected are listed in Table I.

Treatment of Selected Data. To obtain best values from the large body of viscosity data selected, data were fitted to smooth curves using a least-squares regression analysis. Earlier work (*13*) has shown that a suitable function sufficiently flexible to fit data over a wide temperature range is

$$\ln\left[\eta(T)/S\right] = A \ln T + B/T + C/T^2 + D \qquad (1)$$

where A, B, C, and D are the regression coefficients, T the absolute temperature, η the viscosity in μP, and S a standard viscosity as defined below.

The estimated precision of viscosity data varies widely with the worker and the method used; it is also often very different from the accuracy of the measurement. The oscillating disc method, as used by Kestin et al., is capable of very high precision (0.1%), whereas the capillary flow method, as used by Smith et al. and Guevara et al., gives much lower precision (~0.5%). A consideration of the actual accuracy of the measured data as judged by the degree of agreement between different workers in the same laboratory, using the same or similar apparatus, reveals a smaller difference between the accuracy of the two methods. The maximum spread of oscillating disc results is 0.5% and that for capillary flow results is 1%. It is therefore apparent that any attempt to weight values according to the quoted precision would be unrealistic. It was decided to weight all data equally in the regression analysis. This procedure means adopting an equal density of points for each worker, so as not to give too high a weighting to results which consisted of many measurements in a relatively small temperature range. The following method was used: Smoothed viscosity values for each worker were taken at 20° intervals in the temperature range 0-360K and at 100° intervals in the range 400-2100K.

Standards. Most viscosity measurements are made relative to a standard gas whose viscosity is assumed to be known. Kestin (*34*) has suggested the use of nitrogen as standard since it can be obtained pure, is readily available, and has the advantage over air of not being a mixture. Our conclusions below confirm nitrogen as being the most satisfactory standard gas. Consequently the basic standard used in this work, which is the one used by most recent workers, is

$$\eta_{N_2}(293.2K) = 175.7\ \mu P$$

This is consistent with the air standard used by Johnston et al. (*31*, *32*) of $\eta_{air}(296.2K) = 183.3\ \mu P$ which is based on the accurate value of Bearden (RC) (*5*) at 293.2K. Where necessary, all viscosities have been corrected to the above primary nitrogen standard.

Despite the large discrepancies in viscosity data which exist at the extremes of temperature, nearly all the results at room temperature, when corrected to the same standard, agree very closely indeed. By a careful examination of the room temperature data of the remaining 10 gases investigated, secondary standards at 293.2K have been chosen. The data which have been fitted to smooth curves are the ratios of the viscosity at a temperature T to the standard viscosity for that gas at 293.2K —i.e., $\eta(T)/S$. Thus, any change in the accepted values of either the primary or secondary standard viscosities can easily be taken into account by the use of Equation 1.

RECOMMENDED VISCOSITIES

The regression coefficients A, B, C, and D together with the standard viscosity, S, are given for each of the 11 gases in Table II. Table III shows the number of data points used in the regression analysis for each gas, the standard deviation of these points from the fitted curve, and an estimate of the overall accuracy of the smoothed viscosities recommended in this work. This estimate, sometimes dependent on the temperature range concerned, is largely based on the spread of the data about the smooth curves and is subject to considerable uncertainty. Recommended best values for the viscosities of each gas investigated are given at regular intervals in the temperature range studied in Table IV.

Table II. Values of Coefficients of Smoothed Curves

$$\text{Ln}\ (\eta/S) = A\ \ln\ (T) + B/T + C/(T^2) + D$$

Gas	A	B	C	D	$S(\mu P)$
N_2	0.60097	−57.005	1029.1	−3.2322	175.7
He	0.71938	12.451	−295.67	−4.1249	196.0
Ne	0.65004	−5.8537	−406.31	−3.6702	313.8
Ar	0.59077	−92.577	2990.4	−3.0755	222.8
Kr	0.57482	−137.25	5671.9	−2.8643	250.8
Xe	0.52061	−235.12	14620.0	−2.3308	228.4
H_2	0.68720	−0.61732	−111.49	−3.9001	88.0
O_2	0.52662	−97.589	2650.7	−2.6892	203.2
CO_2	0.44037	−288.40	19312.0	−1.7418	146.7
CH_4	0.54188	−127.57	4700.8	−2.6952	109.3
Air	0.63404	−45.638	380.87	−3.4505	182.0

Table III. Least-Squares Analysis

Gas	N[a]	σ, %[b]	Estimated accuracy of recommended η, ± %	Temp range, K
N_2	75	0.59	1.0	100–200
			0.5	200–300
			1.5	300–2200
He	88	0.77	1.5	80–2200
Ne	83	0.74	1.5	80–2200
Ar	107	0.55	1.0	80–600
			1.5	600–2200
Kr	60	0.57	1.0	140–2000
Xe	31	0.42	1.0	180–1600
H_2	52	0.74	5.0	20–80
			1.5	80–2200
O_2	26	0.15	1.0	80–300
CO_2	76	0.46	1.0	180–1500
CH_4	63	0.51	1.5	100–400
			1.0	400–1100
Air	37	0.18	1.0	80–800

[a] N = total number of smoothed data points used for each gas in the least-squares analysis. [b] σ = standard deviation of the data from the fitted curves of Table II.

DISCUSSION

The deviations of measured viscosities from the curves defined in Table II are given in Figures 1-11. Many of the gases have been investigated by a series of workers in different laboratories and the results as exhibited on the deviation plots have many common features. Thus the work of Trautz et al. (*64–76*) and Vasilesco (*80*), neglected in establishing the rec-

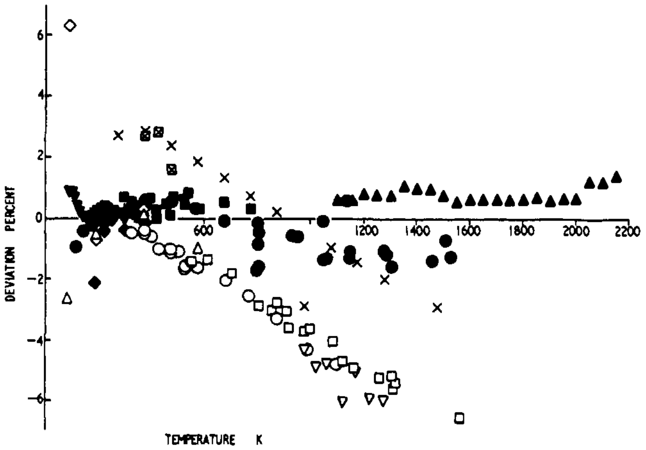

Figure 1. Deviations of nitrogen viscosities from the smooth curve of Table II

△ Bestelmeyer (*6*); ● Smith et al. (*8, 9, 13*); ■ Kestin et al. (*15–17, 35, 37*); ◆ Flynn et al. (*20, 24*); ◊ Fortier (*21*); ▲ Guevara et al. (*26*); ▼ Johnston and McCloskey (*32*); × Rammler and Breitling (*51*); ▽ Raw and Ellis (*55*); ☒ Reynes and Thodos (*56*); ○ Trautz et al. (*64, 66, 70, 76*); □ Vasilesco (*80*); + Wobser and Muller (*81*)

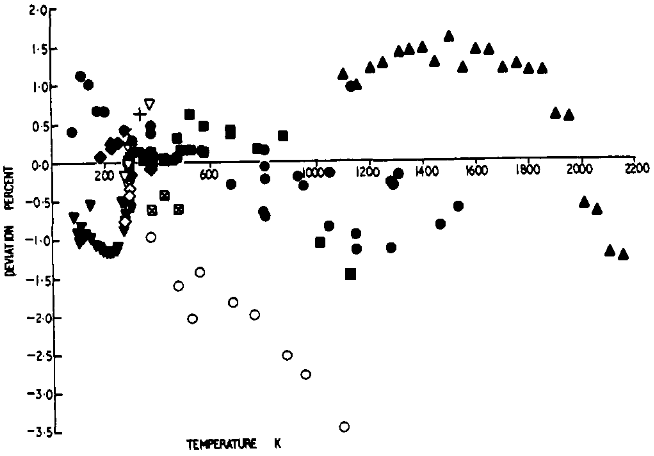

Figure 2. Deviations of helium viscosities from the smooth curve of Table II

● Smith et al. (*9, 13*); ■ Kestin et al. (*15, 33, 39*); ◆ Flynn et al. (*20, 24*); ▲ Guevara et al. (*26*); ▼ Johnston and Grilly (*31*); ◊ Michels et al. (*47*); ▽ Nasini and Rossi (*48*); × Rankine (*52*); ☒ Reynes and Thodos (*56*); ◭ Thornton (*59–61*); ○ Trautz et al. (*65, 76*); + Wobser and Muller (*81*)

Table IV. Recommended Smoothed Values for Viscosities, μP

T, K	N_2	He	Ne	Ar	Kr	Xe	H_2	O_2	CO_2	CH_4	Air
20							10.2				
40							20.7				
60				56.7			28.5				
80		82.7	120.3	68.7			35.3	62.0			55.8
100	69.2	95.7	144.4	83.5			41.4	76.7		40.0	70.5
120	82.3	107.8	166.3	99.0			47.2	91.6		47.3	84.4
140	94.8	119.3	186.5	114.6	122.7		52.6	106.2		54.8	97.5
160	106.8	130.4	205.4	130.0	140.0		57.8	120.5		62.5	110.1
180	118.2	141.0	223.4	145.0	157.3	141.0	62.8	134.2	92.5	70.1	122.0
200	129.2	151.3	240.6	159.6	174.4	155.8	67.5	147.5	101.6	77.4	133.5
220	139.8	161.4	257.1	173.8	191.3	171.0	72.1	160.2	111.0	84.7	144.6
240	150.0	171.2	273.1	187.7	208.0	186.4	76.7	172.5	120.7	91.7	155.2
260	159.9	180.7	288.5	201.1	224.3	201.8	81.1	184.4	130.6	98.5	165.6
280	169.4	190.1	303.5	214.3	240.2	217.2	85.3	195.9	140.4	105.3	175.6
300	178.7	199.3	318.1	227.0	255.8	232.4	89.5	(208.0)[a]	150.1	111.8	185.3
400	221.7	242.9	386.1	286.5	329.2	305.8	109.2	(260.0)	197.3	142.0	230.6
500	260.2	283.6	448.1	340.0	395.8	373.9	127.2	(308.3)	240.8	169.0	271.5
600	295.5	322.1	505.7	389.1	456.9	436.7	144.3	(350.0)	280.5	193.6	309.3
700	328.4	358.9	559.9	434.8	513.7	495.1	160.5	(389.8)	317.0	216.2	344.7
800	359.3	394.3	611.5	477.6	566.9	549.7	175.9	(427.0)	350.7	237.2	
900	388.6	428.5	660.8	518.1	617.1	600.9	190.8	(462.4)	382.1	257.0	
1000	416.5	461.6	708.1	556.7	664.8	649.4	205.1	(496.2)	411.4	275.6	
1100	443.3	493.8	753.8	593.6	710.4	695.4	219.0	(528.7)	438.9		
1200	469.1	525.2	798.1	629.1	754.0	739.3	232.5	(550.1)	464.9		
1300	493.9	555.9	841.1	663.3	796.1	781.3	245.6	(593.3)	489.6		
1400	518.0	586.0	882.9	696.3	836.6	821.6	258.6		513.2		
1500	541.3	615.5	923.7	728.4	875.8	860.4	271.1				
1600	564.1	644.4	963.5	759.5	913.9		283.4				
1700	586.2	672.8	1002.5	789.8	950.8		295.5				
1800	607.8	700.8	1040.6	819.3	986.8		307.3				
1900	628.9	728.3	1078.1	848.1	1021.8		318.9				
2000	649.5	755.4	1114.8	876.2	1056.1		330.4				

[a] Viscosities in parentheses are estimated. See text.

ommended values, is in substantial agreement with other investigators at room temperature. However, their results deviate to an increasing extent at high temperatures and are too low by about 3-4% at 1000K and by about 6-7% at 1500K. The more recent results of Guevara et al. (*22, 26, 27*) tend to lie above the recommended curve by up to approximately 1.5% in the temperature range 1000-2200K, and those of Smith et al. (*12, 13*) deviate in the opposite direction in the range 600-1600K. It is not possible to give an authoritative assessment of the relative accuracy of these two sets of determinations which provide the major body of data on high-temperature viscosities. Both groups of workers used capillary flow methods, Guevara (*26*) favoring a short tube (~8 cm) and the other workers (*12, 13*) longer capillary tubes (~100 cm). The data of Kestin et al. (*15-17, 33-40*), which have recently been extended to 1100K (*33, 38*), are usually within 0.5% of the smooth

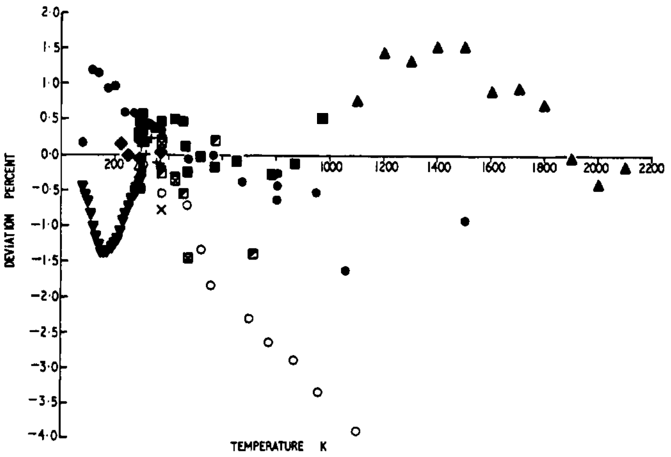

Figure 3. Deviations of neon viscosities from the smooth curves of Table II

● Smith et al. (*9, 13*); ■ Kestin et al. (*15, 38, 39*); ◩ Edwards (*18*); ◆ Flynn et al. (*20*); ▲ Guevara et al. (*27*); ▼ Johnston and Grilly (*31*); × Rankine (*52*); ⊠ Reynes and Thodos (*56*); ◬ Thornton (*59–61*); ○ Trautz et al. (*65, 76*); + Wobser and Muller (*81*)

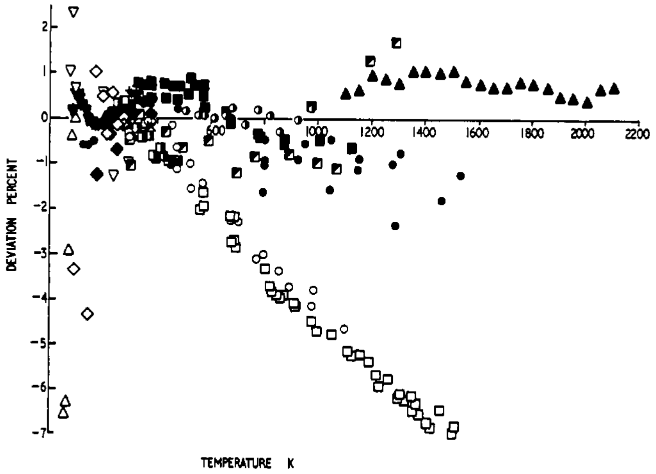

Figure 4. Deviations of argon viscosities from the smooth curves of Table II

◩ Anfilogoff (*1*); ● Smith et al. (*8, 13*); ◨ De Rocco and Halford (*14*); ■ Kestin et al. (*15, 33, 38, 39*); ◆ Flynn et al. (*20, 24*); ▲ Guevara et al. (*26*); ▼ Johnston and Grilly (*31*); ◇ Kopsch (*41*); × Rankine (*52*); ▽ Rietveld et al. (*57*); ◑ Rigby and Smith (*58*); ◬ Thornton (*59–61*); ○ Trautz et al. (*65, 69, 76*); △ Van Itterbeck and Van Paemel (*78*); □ Vasilesco (*80*); + Wobser and Muller (*81*) curves. The most recent work by Kestin (*33, 38*) on the viscosity of argon and helium has tended to lend some support to the lower values of Dawe and Smith (*13*). However, at the present time, it seemed proper to regard both these sets of data as of equal merit.

Again, at lower temperatures, no attempt was made to resolve the smaller discrepancy between the work of Johnston et al. (*31, 32*) and Clarke and Smith (*8, 9*). Both workers usually lie within ±1% of the smooth curves except for neon where the discrepancy rises to ±1.5%. The lower values of the latter workers are similar to those reported by Fortier (*21*) in the case of air. The results of Van Itterbeck et al. (*77–79*) at low temperatures (55–70K for argon, 70–90K for hydrogen, 70–90K for oxygen) have not been used in establishing the recommended values. The temperature dependence of their data in this region is difficult to reconcile with that of other low-temperature workers. In view of this, any extrapolation of the recommended viscosity values below the lowest temperatures of Johnston and Clarke (usually 80K) should be made with caution.

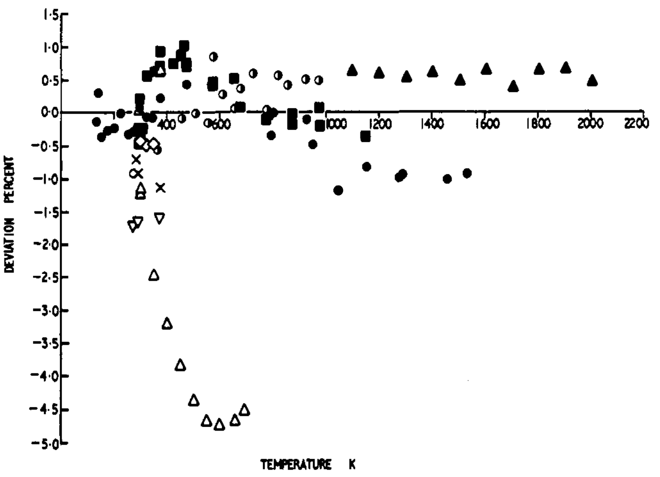

Figure 5. Deviations of krypton viscosities from the smooth curve of Table II

● Smith et al. (*8, 13*); △ Clifton (*10*); ■ Kestin et al. (*15, 33, 38*); ▲ Guevara et al. (*22*); ▽ Nasini and Rossi (*48*); × Rankine (*52*); ◐ Rigby and Smith (*58*); ◭ Thornton (*59–61*); ○ Trautz and Zimmerman (*75*); ◇ Trappeniers et al. (*63*)

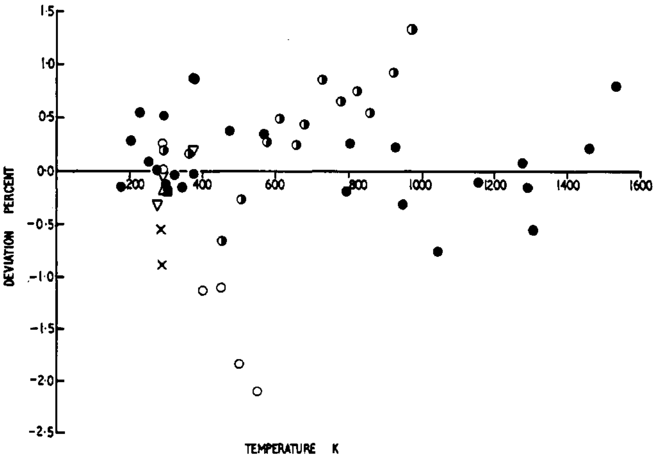

Figure 6. Deviations of xenon viscosities from the smooth curve of Table II

● Smith et al. (*8, 13*); ■ Kestin and Leidenfrost (*35*); ▽ Nasini and Rossi (*48*); × Rankine (*52*); ◐ Rigby and Smith (*58*); ◭ Thornton (*59*) ○ Trautz and Heberling (*66, 67*)

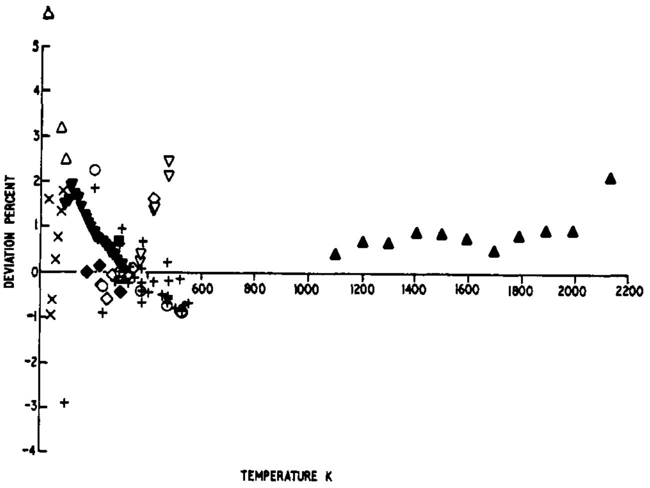

Figure 7. Deviations of hydrogen viscosities from the smooth curve of Table II

◇ Barua et al. (*4*); × Coremans et al. (*11*); ● Gracki et al. (*24*); ▲ Guevara et al. (*26*); ▼ Johnston and McCloskey (*32*); ■ Kestin and Leidenfront (*35*); ▽ Pal and Barua (*49*); ○, + Trautz et al. (*64, 65, 68, 70–75*); △ Van Itterbeck and Van Paemel (*79*)

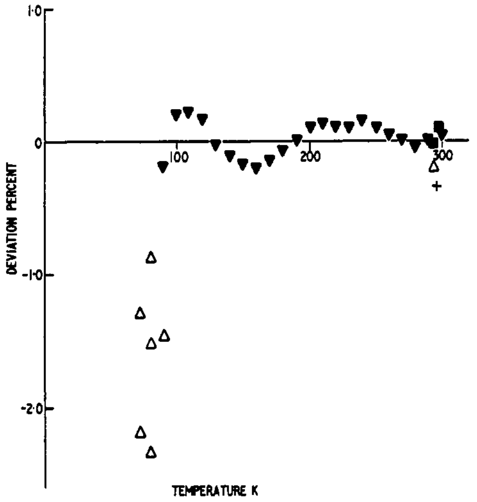

Figure 8. Deviations of oxygen viscosities from the smooth curve of Table II

▼ Johnston and McCloskey (*32*); ■ Kestin and Leidenfrost (*35*); △ Van Itterbeck and Claes (*77*); + Yen (*82*)

The majority of data points obtained by other workers, often over more limited temperature ranges, lie within 1.5% of our recommended values.

Figure 1 shows that the good agreement between different workers for nitrogen lends support to the selection of nitrogen as a standard gas in viscosity measurements (*34*). For krypton, the good agreement of most workers in the temperature range 293–700K (Figure 5) would suggest that the results of Clifton (*10*) and Nasini and Rossi (*48*) are in error. In the case of hydrogen, there is a larger scatter in the experimental determinations at low temperatures than is observed for other gases. Because of this and the fact that there is a lack of data covering wide temperature ranges, it was necessary to assess the reliability of some of the results by consideration of the data of the same workers for other gases. For oxygen, it was only possible to give recommended values in the temperature range 80–300K. However, above these temperatures, some estimates of the viscosity of oxygen have been given (in parentheses in Table IV) based on the assumption that the results of Trautz et al.

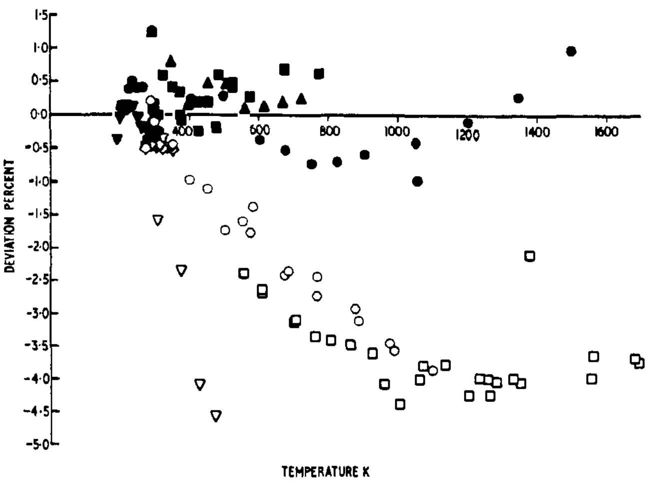

Figure 9. Deviations of carbon dioxide viscosities from the smooth curve of Table II

▲ Bailey (2); ■ Kestin et al. (*7, 15, 39*); ● Smith et al. (*23, 44*); ▼ Johnston and McCloskey (32); ◊ Michels et al. (*46*); ▽ Pal and Barua (*50*); ○ Trautz et al. (*68, 76*); □ Vasilesco (*80*)

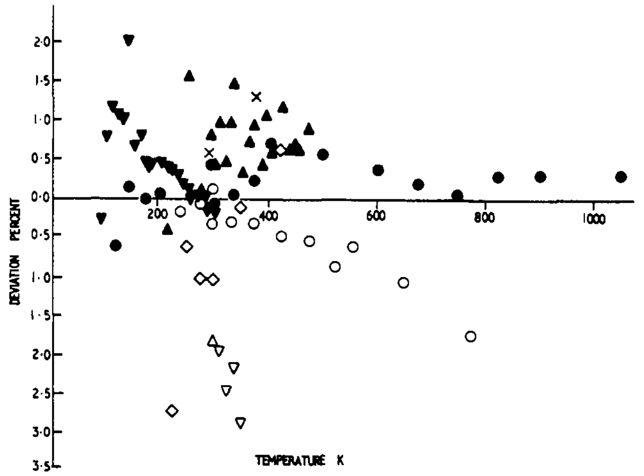

Figure 10. Deviations of methane viscosities from the smooth curve of Table II

◊ Barua et al (4); ● Smith et al. (*9, 12*); ▲ De Rocco and Halford (*14*); ▼ Johnston and McCloskey (*32*); ▽ Lambert et al. (*42*); × Rankine (*54*); ○ Trautz et al. (*72, 76*)

(*70, 75*) are in error to the same extent as for other gases. The good agreement of all other data for carbon dioxide (Figure 9) suggests that the data of Pal and Barua (*49, 50*) are in error. Likewise the data of Lambert et al. (*42*) and Barua et al. (*4*) for methane may be too low (Figure 10).

CONCLUSION

The recent extensive measurements of gas viscosities by several independent groups of workers, together with the substantial body of earlier data, have now made it possible to define the viscosities of most simple gases within fairly narrow limits. It is hoped that the results of this survey for the 11 gases concerned will be of considerable use both from a practical standpoint and in improving our knowledge of the forces between molecules. Nevertheless, there is no reason to suppose that existing techniques are not capable of giving an accuracy of 0.5% and it is reasonable to expect that the results of workers in different laboratories, using a variety of techniques, should agree to within this limit. Hopefully, the results of further experiments will enable us to define gas viscosities within even narrower limits than those given here.

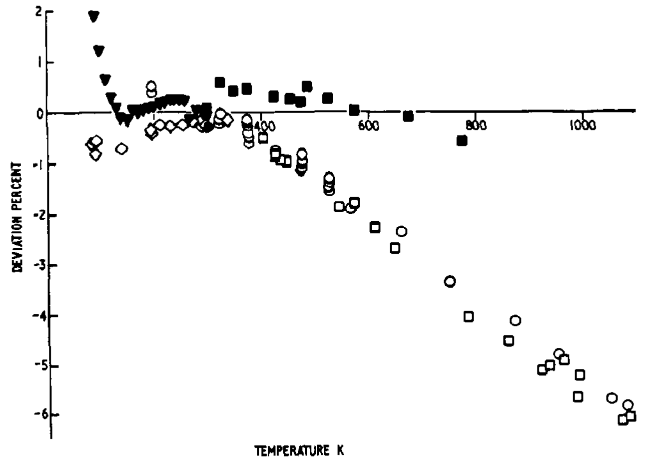

Figure 11. Deviations of air viscosities from the smooth curve of Table II

● Bearden (5); ■ Kestin et al. (*15, 35*); ▼ Johnston and McCloskey (*32*); ○ Trautz et al. (*64, 65, 71–74, 76*); □ Vasilesco (*80*); ◊ Fortier (*21*)

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Some Solubility Data for Ethane in *n*-Hexane

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The solubility of ethane in *n*-hexane is reported for temperatures of 0–30°C. The data contradict some rather old existing literature reports for hexane but fall in line with other data for C_9–C_6 hydrocarbons.

We wish to report some solubility data for ethane in *n*-hexane at 0–30°C. The results contradict existing literature values for this system (*3*, *4*) but fall in line with results for *n*-nonane, *n*-octane, and *n*-heptane (*5*).

The solubility measurements were carried out in duplicate according to a recently described technique (*6*). In this method the amount of gas required to saturate a known volume of liquid at a known temperature and partial pressure of gas was determined. Determination was made by measuring the change of pressure of the gas in the reservoir (a 286.4-ml bomb) after the previously evacuated absorption vessel had been filled and the liquid in it had been saturated by the gas. The gas flow to the liquid was controlled by two diaphragm-type regulators (Fisher-Governor Co., Marshalltown, Iowa) set to give the desired final pressure above the liquid. The solvent (300 ml at 23°C) was degassed by pumping out at 10^{-4} mm Hg at liquid nitrogen temperature in a 500-ml flask before being saturated with ethane while being stirred by a magnetic stirring bar and held at the desired temperature. The pressure in the reservoir was measured by a Heise gage calibrated with a Model 145 Digital Pressure Gage from Texas Instruments Co. (Houston, Tex.). This gage in turn had been calibrated against NBS standards to ±0.002 psia. Solvent vapor pressure and gas partial pressure were measured with a mercury manometer, and solvent temperature was controlled by a 1-gal Cellosolve bath maintained to within ±0.1°C of the desired temperature.

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