IV. PROPERTIES OF DEUTERIUM

CONTENTS

NORMAL DEUTERIUM - LIQUID VAPOR PRESSURE

Sources of Data:

Friedman, A. S., White, D., and Johnston, H. L., "The Direct Determination of the Critical Temperature and Critical Pressure of Normal Deuterium. Vapor Pressures between the Boiling and Critical Points", J. Am. Chem. Soc. 73, 1310-11 (1951), C.A. 45, 5992 i.

Grilly, E. R., "The Vapor Pressure of Hydrogen, Deuterium and Tritium up to Three Atmospheres", J. Am. Chem. Soc. 73, 843 (1951).

Hoge, H. J., and Arnold, R. D., "Vapor Pressures of Hydrogen, Deuterium, and Hydrogen Deuteride and Dew Point Pressures of their Mixtures", J. Res. Natl. Bur. Std. 47, 63-74 (1951).

Other References:

Brickwedde, F. G., Scott, R. B., and Taylor, H. S., "The Difference in Vapor Pressures of Ortho and Para Deuterium", J. Chem. Phys. 3, 653-60 (1935).

Newman, R. B., and Jackson, L. C., "The P, T, x Relationships of Hydrogen plus Hydrogen Deuteride and Hydrogen plus Deuterium Mixtures between 18° and 28°K", Trans. Faraday Soc. 54, 1481-91 (1958).

Comments:

The table was obtained by a least squares fit to (1) of the experimental data with a weight proportional to pressure.

$$\ln P = \frac{A_1}{T'} + A_2 + A_3 T' + A_4 (T')^2 + A_5 (T')^3 + A_6 (T')^4 \qquad (1)$$

The uncertainty of the smoothed value is estimated to be ± 0.01°K.

TABLE 1. Vapor Pressure of Liquid n-D_2 (for interpolation)

200/T 1/°K	Temp °K	mm Hg	$\log_{10}$ P atm	psia	Δ	Temp °R	360/T 1/°R
10.8	18.519	2.0700	-0.8108	0.3564		33.333	10.8
10.7	18.692	2.1038	-0.7771	0.3901	337	33.645	10.7
10.6	18.868	2.1376	-0.7433	0.4239	338	33.962	10.6
10.5	19.048	2.1714	-0.7094	0.4578	339	34.286	10.5
10.4	19.231	2.2054	-0.6754	0.4918	339	34.615	10.4
10.3	19.417	2.2394	-0.6414	0.5258	340	34.951	10.3
10.2	19.608	2.2735	-0.6073	0.5599	341	35.294	10.2
10.1	19.802	2.3077	-0.5731	0.5941	342	35.644	10.1
10.0	20.000	2.3419	-0.5389	0.6283	342	36.000	10.0
9.9	20.202	2.3762	-0.5046	0.6626	343	36.364	9.9
9.8	20.408	2.4106	-0.4702	0.6970	344	36.735	9.8
9.7	20.619	2.4451	-0.4357	0.7315	345	37.113	9.7
9.6	20.833	2.4796	-0.4012	0.7660	345	37.500	9.6
9.5	21.053	2.5142	-0.3666	0.8006	346	37.895	9.5
9.4	21.277	2.5488	-0.3320	0.8352	347	38.298	9.4
9.3	21.505	2.5836	-0.2972	0.8700	347	38.710	9.3
9.2	21.739	2.6184	-0.2624	0.9048	348	39.130	9.2
9.1	21.978	2.6532	-0.2276	0.9396	349	39.560	9.1
9.0	22.222	2.6882	-0.1927	0.9745	349	40.000	9.0
8.9	22.472	2.7232	-0.1577	1.0095	350	40.449	8.9
8.8	22.727	2.7582	-0.1226	1.0446	351	40.909	8.8
8.7	22.989	2.7933	-0.0875	1.0797	351	41.379	8.7
8.6	23.256	2.8285	-0.0523	1.1149	352	41.860	8.6
8.5	23.529	2.8638	-0.0170	1.1502	353	42.353	8.5
8.4	23.810	2.8991	0.0183	1.1855	353	42.857	8.4
8.3	24.096	2.9345	0.0537	1.2209	354	43.373	8.3
8.2	24.390	2.9699	0.0891	1.2563	355	43.902	8.2
8.1	24.691	3.0055	0.1247	1.2919	355	44.444	8.1
8.0	25.000	3.0411	0.1603	1.3275	356	45.000	8.0

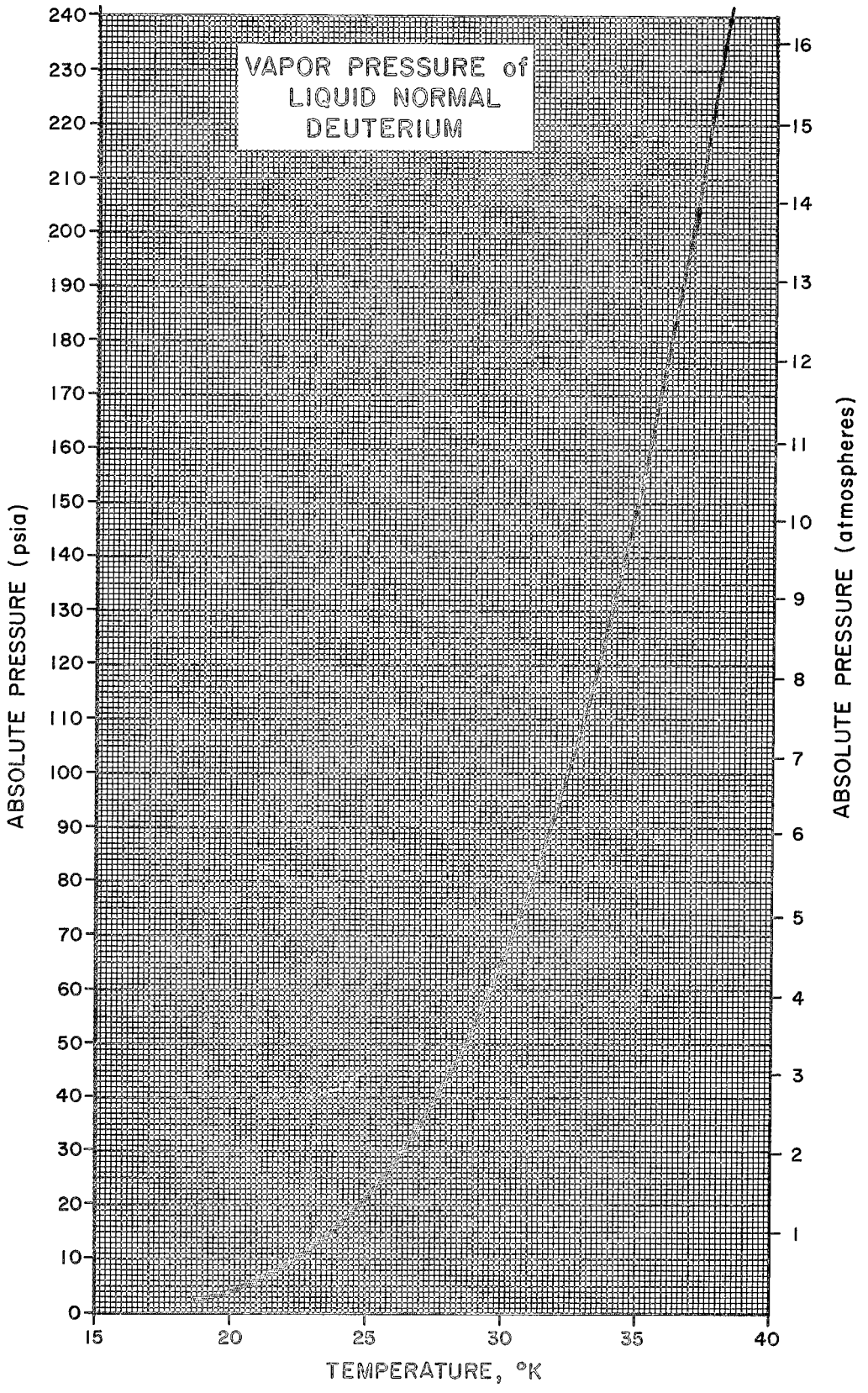
TABLE 1. (Continued)

200/T 1/°K	Temp °K	mm Hg	$\log_{10}$ P atm	psia	Δ	Temp °R	360/T 1/°R
7.9	25.316	3.0768	0.1960	1.3632	357	45.570	7.9
7.8	25.641	3.1125	0.2317	1.3989	358	46.154	7.8
7.7	25.974	3.1484	0.2676	1.4348	359	46.753	7.7
7.6	26.316	3.1843	0.3035	1.4707	359	47.368	7.6
7.5	26.667	3.2204	0.3395	1.5067	360	48.000	7.5
7.4	27.027	3.2565	0.3757	1.5429	361	48.649	7.4
7.3	27.397	3.2927	0.4119	1.5791	362	49.315	7.3
7.2	27.778	3.3291	0.4483	1.6155	364	50.000	7.2
7.1	28.169	3.3656	0.4848	1.6520	365	50.704	7.1
7.0	28.571	3.4022	0.5214	1.6886	366	51.429	7.0
6.9	28.986	3.4390	0.5582	1.7254	368	52.174	6.9
6.8	29.412	3.4759	0.5951	1.7623	369	52.941	6.8
6.7	29.851	3.5131	0.6322	1.7994	371	53.731	6.7
6.6	30.303	3.5504	0.6695	1.8367	373	54.545	6.6
6.5	30.769	3.5879	0.7071	1.8743	375	55.385	6.5
6.4	31.250	3.6256	0.7448	1.9120	377	56.250	6.4
6.3	31.746	3.6636	0.7828	1.9500	380	57.143	6.3
6.2	32.258	3.7018	0.8210	1.9882	382	58.065	6.2
6.1	32.787	3.7404	0.8596	2.0268	385	59.016	6.1
6.0	33.333	3.7792	0.8984	2.0656	388	60.000	6.0
5.9	33.898	3.8184	0.9376	2.1048	392	61.017	5.9
5.8	34.483	3.8579	0.9771	2.1443	395	62.069	5.8
5.7	35.088	3.8978	1.0170	2.1842	399	63.158	5.7
5.6	35.714	3.9381	1.0573	2.2245	403	64.286	5.6
5.5	36.364	3.9788	1.0980	2.2652	407	65.455	5.5
5.4	37.037	4.0199	1.1391	2.3063	411	66.667	5.4
5.3	37.736	4.0614	1.1806	2.3478	415	67.925	5.3
5.2	38.462	4.1033	1.2225	2.3897	419	69.231	5.2
5.1	39.216	4.1456	1.2648	2.4320	423	70.588	5.1

TABLE 2. Vapor Pressure of Liquid n-D_2 at Integral Temperatures

Temp °K	Pressure atm	Pressure mm Hg	Pressure psia	Temp °R
18.720	0.1692	128.6	2.487	33.696
19.000	0.1913	145.4	2.811	34.200
20.000	0.2891	219.7	4.249	36.000
21.000	0.4218	320.6	6.199	37.800
22.000	0.5965	453.3	8.766	39.600
23.000	0.8204	623.5	12.057	41.400
24.000	1.1012	836.9	16.183	43.200
25.000	1.4463	1099.2	21.256	45.000
26.000	1.8635	1416.3	27.386	46.800
27.000	2.3605	1794.0	34.690	48.600
28.000	2.9453	2238.4	43.284	50.400
29.000	3.6263	2756.0	53.292	52.200
30.000	4.4121	3353.2	64.841	54.000
31.000	5.3123	4037.3	78.070	55.800
32.000	6.3367	4815.9	93.124	57.600
33.000	7.4959	5696.8	110.159	59.400
34.000	8.8009	6688.7	129.338	61.200
35.000	10.2632	7800.1	150.829	63.000
36.000	11.8942	9039.6	174.798	64.800
37.000	13.7046	10415.5	201.403	66.600
38.000	15.7038	11934.9	230.783	68.400
38.350	16.4495	12501.7	241.742	69.030

Taken from Cryogenic Data Center Memorandum M 1, Cryogenic Division of National Bureau of Standards, Boulder, Colorado.


VAPOR PRESSURE of
LIQUID NORMAL
DEUTERIUM
ABSOLUTE PRESSURE (psia)
ABSOLUTE PRESSURE (atmospheres)
TEMPERATURE, °K
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
15
20
25
30
35
40

NORMAL DEUTERIUM - SATURATION DENSITY OF LIQUID

Sources of Data:

Clusius, K., and Bartholome, E., "Calorische und Thermische Eigenschaften des Kondensierten Schweren Wasserstoffs" (Calorimetric and Thermal Properties of Condensed Heavy Hydrogen), Z. physik. Chem. B30, 237-57 (1935).

Kerr, E. C., "Molar Volumes of Liquid Deuterium and of a 1 to 1 Mixture of Tritium, Deuterium, 19.5 to 24.5°K", J. Am. Chem. Soc. 74, 824-25 (1952).

Friedman, A. S., Trzeciak, M., and Johnston, H. L., "Pressure-Volume-Temperature Relationships of Liquid Normal Deuterium", J. Am. Chem. Soc. 76, 1552-53 (1954).

Comments:

Clusius and Bartholome (1935) represent their experimental data by

$$v = 22.9758 + 0.2472\ (T - 18) + 0.0137\ (T - 18)^2.$$

They found the molar volume at the triple point (18.65°K) to be 23.14 cm^3.

Kerr (1952) combined his experimental values with those of Clusius and Bartholome by the least squares method to obtain the equation

$$V_m\ (cm^3/mole) = 18.555 + 0.1294\ T + 0.004203\ T^2$$

which has a standard deviation from experimental points of 0.04%. [The deuterium was 99.6% pure, with 0.4% hydrogen as the impurity].

Friedman, et al. (1954) made P-V-T measurements with liquid normal deuterium between the triple and critical points. The isotherms were extrapolated to the saturation line to obtain the values of density listed in the tables of experimental values.

Tables of Experimental Values

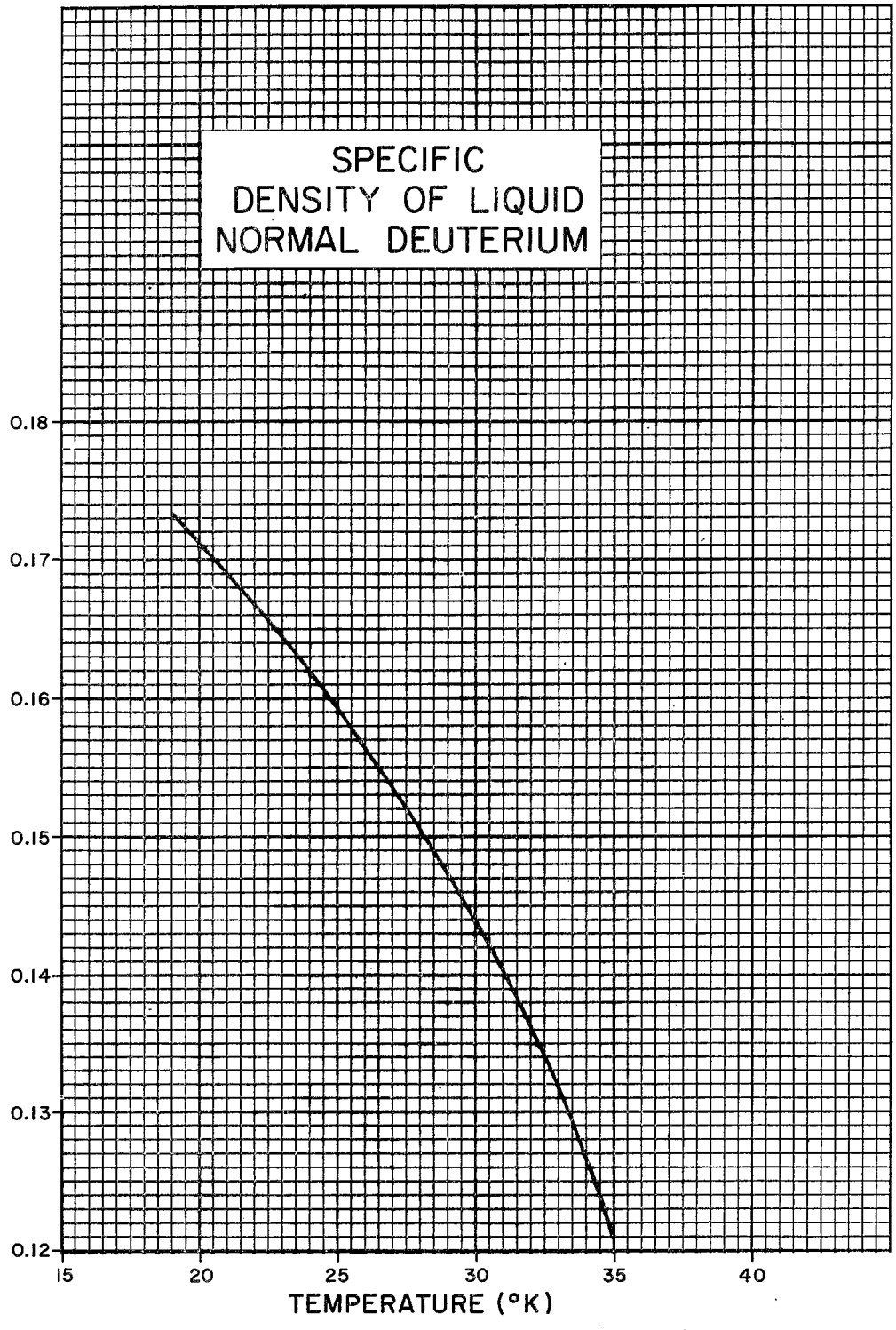
Clusius & Bartholome (1935)			Kerr (1952)			Friedman, Trzeciak, Johnston (1954)		
T,°K	v,cm^3/mole	ρ,g/cm^3	T,°K	v,cm^3/mole	ρ,g/cm^3	T,°K	v,cm^3/mole	ρ,g/cm^3
18.80	23.179	0.17374	19.51	23.411	.1721	35.17	33.52	.1202
18.97	23.235	0.17332	21.14	23.889	.1687	30.52	28.43	.1418
19.24	23.298	0.17285	22.375	24.281	.1660	27.21	26.32	.1531
19.64	23.427	0.17190	23.41	24.620	.1637	23.52	24.66	.1634
20.05	23.541	0.17107	24.205	24.905	.1618	20.33	23.57	.1710
20.07	23.535	0.17111						
20.41	23.657	0.17023						
20.53	23.687	0.17001						

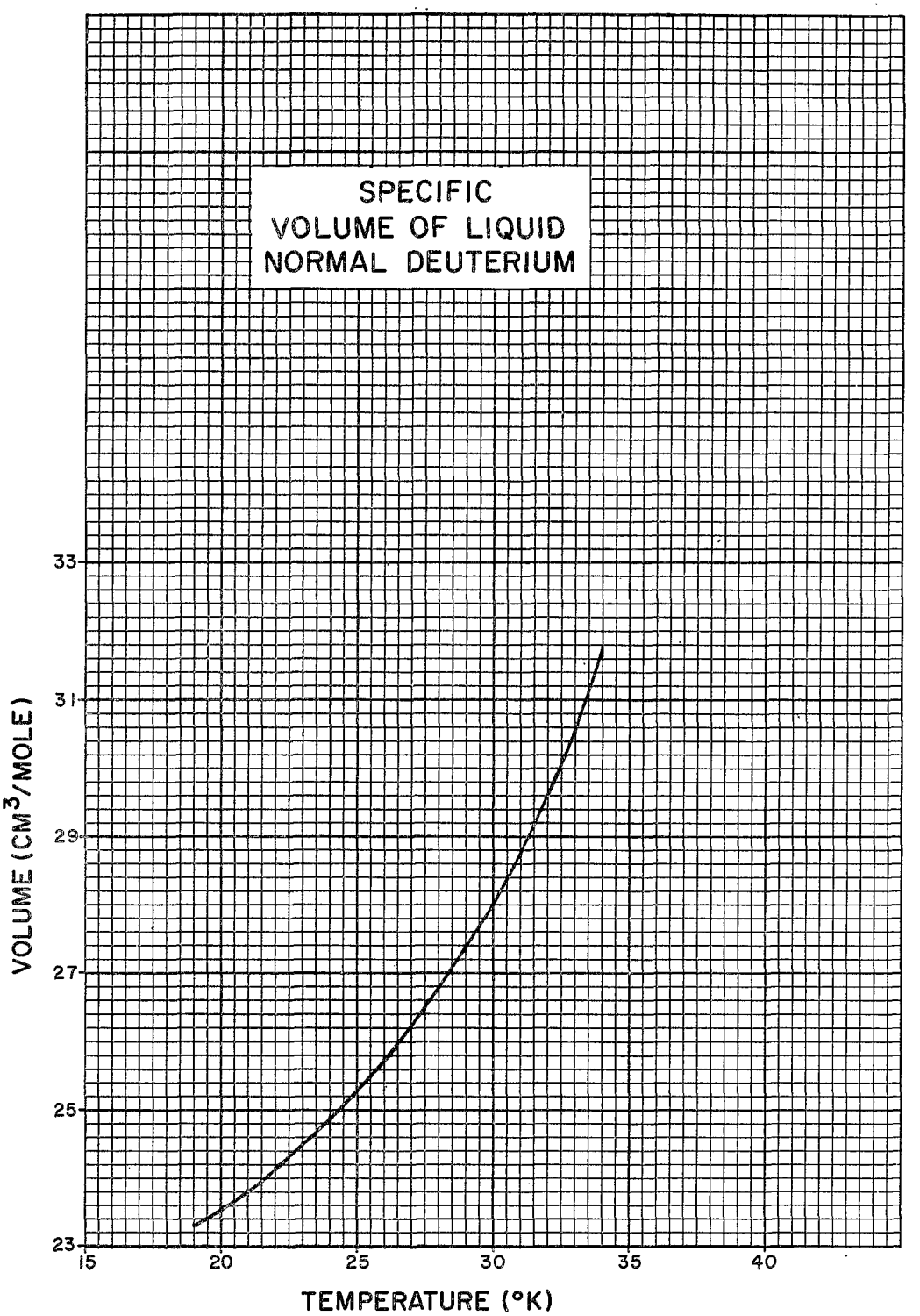
The following table of selected values for saturation density of liquid n-deuterium have been determined graphically from the experimental data. Uncertainty for the temperature range 19° to 35°K, the range of the data, is 0.6% in molar volume. Above 35°K, large changes in volume occur for small differences in temperature and the uncertainty in volume or density becomes larger.

Table of Selected Values

T,°K	v,cm^3/mole	ρ,g/cm^3	T,°K	v,cm^3/mole	ρ,g/cm^3
19	23.25	.1733	29	27.38	.1472
20	23.54	.1712	30	28.02	.1438
21	23.85	.1690	31	28.76	.1401
22	24.17	.1667	32	29.61	.1361
23	24.52	.1644	33	30.61	.1317
24	24.90	.1618	34	31.75	.1269
25	25.32	.1591	35	33.25	.1212
26	25.78	.1563			
27	26.28	.1533			
28	26.80	.1504			

Taken from Cryogenic Data Center Memorandum M4, Cryogenic Division of National Bureau of Standards, Boulder, Colorado


SPECIFIC
DENSITY OF LIQUID
NORMAL DEUTERIUM
0.18
0.17
0.16
0.15
0.14
0.13
0.12
15
20
25
30
35
40
TEMPERATURE (°K)


SPECIFIC
VOLUME OF LIQUID
NORMAL DEUTERIUM
VOLUME (CM3/MOLE)
33
31
29
27
25
23
15
20
25
30
35
40
TEMPERATURE (°K)

EQUILIBRIUM DEUTERIUM - HEAT OF VAPORIZATION

Sources of Data:

Kerr, E.C., Rifkin, E.B., Johnston, H.L., and Clarke, J.T., "Condensed Gas Calorimetry. II. Heat Capacity of Ortho-Deuterium between 13.1 and 23.6°K, Melting and Boiling Points, Heats of Fusion and Vaporization. Vapor Pressure of Liquid Ortho-Deuterium", J.Am.Chem.Soc. 73, 282-89 (1951).

White, D., Hu, J.H., and Johnston, H.L., "The Heats of Vaporization of Para-Hydrogen and Ortho-Deuterium from their Boiling Points to their Critical Temperature", J.Phys. Chem. 63, 1181-83 (1959).

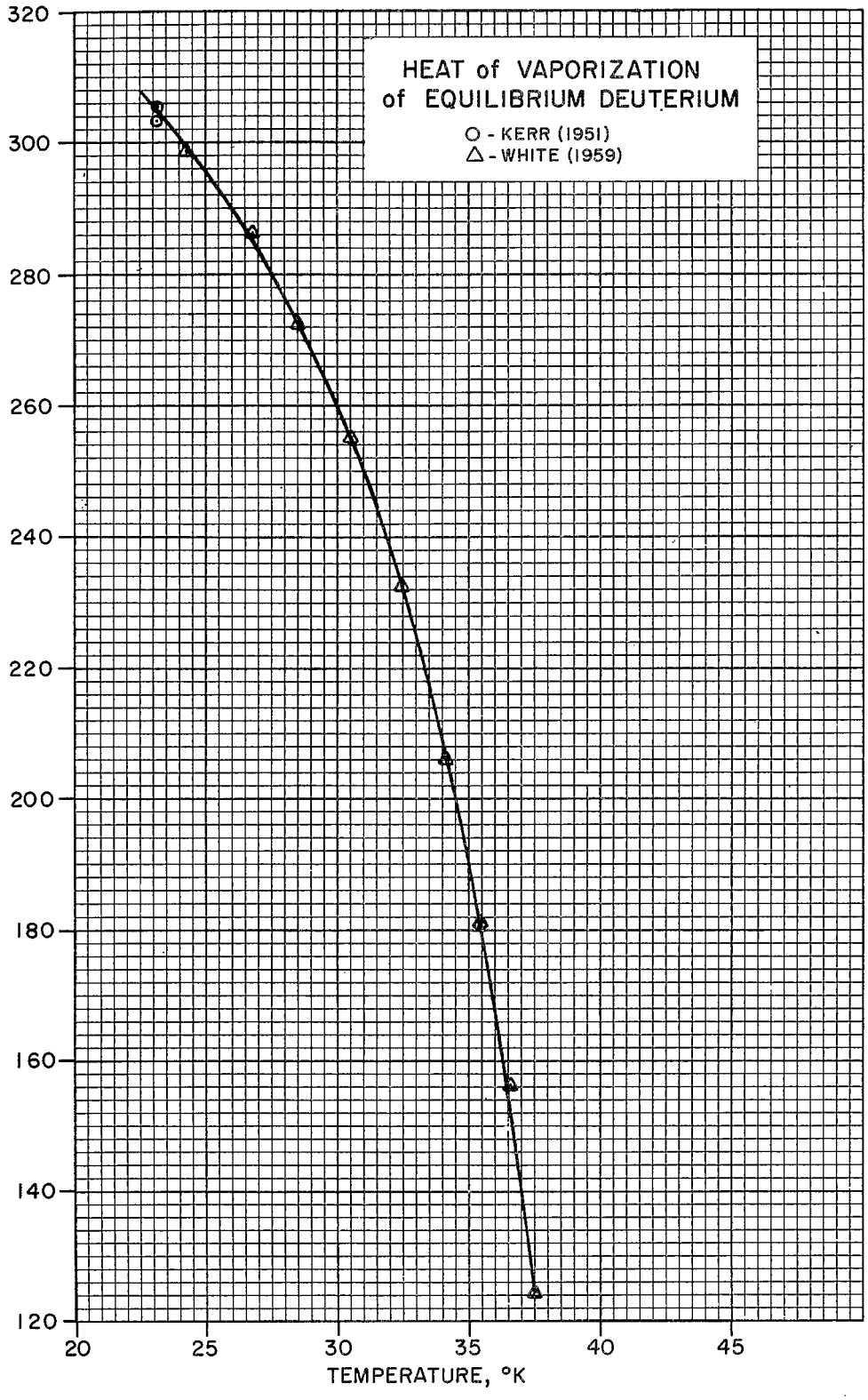
Comments:

Kerr, et al. (1951) determined the heat of vaporization for 20.4°K equilibrium deuterium (97.8% o-deuterium) with a sample containing 0.6% HD. This value of the heat of vaporization at the boiling point (23.59°K) is 292.3 ± 1.5 cal/mole. Another determination with a sample containing 1.1 mole percent HD gave a value for heat of vaporization of the boiling point of 293.93 ± 0.5 cal/mole. Corrections were made for the amount of HD in each case.

White, et al. (1959) used deuterium containing 0.99% HD impurity which was catalyzed to 20.4 °K equilibrium (97.8% o-deuterium and 2.2% p-deuterium). A correction was made for the impurity. Uncertainties in the heat of vaporization may be as much as 5% at temperatures approaching critical due to uncertainties in density obtained by extrapolating P-V-T data of Friedman* to the saturation line.

Experimental Values					
Kerr, et al.(1951)			White, et al.(1959)		
Temp. °K	Heat of Vaporization		Temp. °K	Heat of Vaporization	
	cal/mole	joules/gm		cal/mole	joules/gm
23.59	292.3	303.5	24.25	287.7	298.7
23.59	293.9	305.2	26.83	275.7	286.3
			28.58	262.5	272.6
			30.53	245.9	255.3
			32.48	224.1	232.7
			34.10	198.4	206.0
			35.43	173.5	180.2
			36.57	150.3	156.1
			37.52	120.0	124.6

*Friedman, A.S., Trzeciak, M., and Johnston, H.L., J. Am.Chem. Soc. 76, 1552 (1954)


HEAT of VAPORIZATION
of EQUILIBRIUM DEUTERIUM
O - KERR (1951)
△ - WHITE (1959)
320
300
280
260
240
220
200
180
160
140
120
20
25
30
35
40
45
TEMPERATURE, °K