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Experimental Determination of the P–T Melting Curves of Kr, Ne, and He*

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Pressure–temperature melting data have been obtained at pressures of 0–8 kbar for Kr, 0–10 kbar for Ne, and 1–10 kbar for He. The estimated accuracy of the data is ±1 bar and ±0.002 to ±0.011°K. Use of a modified Simon melting equation of the form $P=A(T+D)^c+B$ to represent the data removes nearly all of the systematic deviations which are observed when the usual Simon melting equation $P=AT^c+B$ is applied. The modified form of the equation also provides much better high pressure extrapolations from the melting curve data.

In an earlier paper[1] (subsequently referred to as I) apparatus and techniques for the precise measurement of the P–T melting curves of gases were described and the data for argon were presented. The same apparatus and techniques have now been applied to the measurement of the P–T melting curves of krypton, neon, and helium at pressures up to 10 kbar and the results are reported below. The degree to which the data are fit by the semiempirical Simon equation

$$P=AT^c+B \tag{1}$$

and by the modified form of this equation, introduced in I,

$$P=A(T+D)^c+B \tag{2}$$

is also discussed. [In Eqs. (1) and (2), A, B, c, and D are empirically determined constants.]

EXPERIMENTAL

In the experimental method used, a pressure vessel was held at a selected temperature and filled with the gas being studied. The vessel was connected to the external pressure generating and measuring system with a length of small diameter high pressure tubing (0.79 mm o.d., 0.15 mm i.d.) which was kept open during the experiment. The temperature of the vessel was measured with a platinum resistance thermometer, while the pressure in the system was measured using a precision manganin resistance manometer calibrated against the mercury melting curve as described in I. The presence of coexisting solid and fluid phases in the vessel was verified by slightly increasing or decreasing the pressure in the external system to change the amount of material in the vessel. When two phases were present the pressure would return to its initial value when equilibrium was again attained after such an operation. Further details of the experimental apparatus and procedures can be found in I.

The data for krypton, neon, and helium are presented in Table I. (Triple point data[2,3] for krypton and neon are included.) The data shown are from one run each for krypton and neon and from two different runs for helium. An additional short run was made for neon to check the reproducibility of the results. The pressure measurements have an estimated accuracy of ±1.0 bar, based on the provisional "mercury melting line" pressure scale discussed in I. The temperature measurements are based on the "1968 International Practical Temperature Scale" and are estimated to be accurate to within ±0.002°K at temperatures above 25°K. At lower temperatures the sensitivity of the platinum thermometer decreases so the temperature measurements decrease in accuracy, reaching an estimated maximum uncertainty of about ±0.011°K at 13.4°K which was the lowest temperature measured.

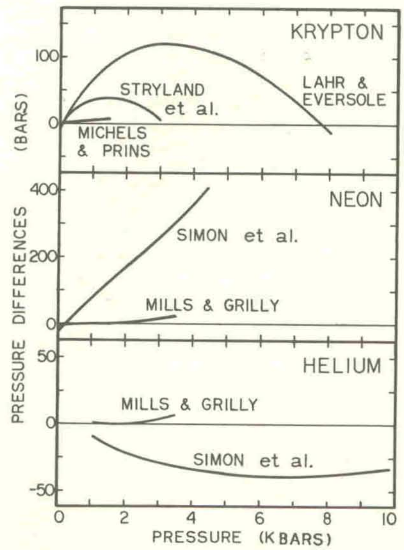

FIG. 1. Comparison of previously published P–T melting curve data with those presented here. The differences shown are the other data (represented by the Simon equations published in Refs. 6–12) minus the present data. The data of Holland, Huggill, and Jones (Ref. 13), Dugdale and Simon (Ref. 6), and Langer (Ref. 14) are represented within their experimental uncertainty by the curve for helium labeled Simon *et al.*

After completion of each data run a sample of gas was collected from the system and a mass-spectroscopic analysis was performed.[4] The results of these analyses are shown in Table II along with the estimated maximum effects of the impurities on the respective

TABLE I. Experimental P–T melting data. The column labeled "Dev." gives the deviation of the experimental data point from Eq. (2) with constants given in Table III.

Temperature (°K)	Pressure (bar)	Dev. (bar)	Temperature (°K)	Pressure (bar)	Dev. (bar)
		Krypton			
115.773[a]	0.73[a]	0.03	215.873	4 087.30	−0.46
138.270	788.25	−0.08	215.874	4 087.42	−0.38
138.284	788.87	0.02	228.296	4 687.23	−0.20
138.286	788.79	−0.13	228.302	4 687.63	−0.08
152.379	1324.95	−0.12	240.685	5 302.93	0.04
165.790	1863.60	0.49	253.143	5 939.51	0.75
165.790	1863.18	0.03	253.150	5 939.79	0.71
178.297	2388.24	0.26	265.674	6 594.43	−0.47
178.303	2388.12	−0.11	279.160	7 318.88	−0.24
190.430	2917.30	0.03	279.161	7 319.00	−0.15
190.431	2917.24	−0.10	291.695	8 008.52	0.06
202.696	3471.70	0.06	291.695	8 008.51	0.04
		Neon			
24.555[b]	0.43[b]	−0.85	78.900	5 555.66	−0.13
33.144	629.03	0.41	82.311	6 002.54	−0.15
33.146	629.24	0.44	82.312	6 003.62	0.81
41.530	1355.20	0.90	87.519	6 702.30	−0.25
41.530	1355.19	0.88	87.520	6 702.55	−0.15
48.497	2027.63	0.10	93.615	7 548.49	0.93
48.498	2027.81	0.15	93.615	7 548.04	0.47
54.513	2653.57	−0.30	96.716	7 988.15	0.36
54.513	2653.64	−0.25	96.716	7 989.44	1.61
59.873	3243.72	−0.38	99.962	8 456.69	0.76
59.874	3243.80	−0.45	100.023	8 465.09	0.42
64.665	3794.87	−0.80	105.253	9 234.66	0.34
64.665	3794.96	−0.74	105.253	9 234.65	0.31
69.476	4370.20	−0.62	109.870	9 928.11	−0.69
69.477	4370.26	−0.64	109.876	9 929.21	−0.53
74.168	4951.52	0.06	110.040	9 953.55	−1.15
74.170	4951.34	−0.30	110.041	9 953.58	−1.21
78.896	5555.34	0.07			
		Helium			
13.417	944.17	−1.17	31.140	3 544.98	−0.13
13.975	1008.96	0.40	31.236	3 561.51	−0.67
14.459	1065.41	0.87	37.092	4 653.24	0.65
15.060	1134.88	−0.63	37.095	4 653.39	0.19
16.536	1317.19	0.98	42.385	5 722.97	0.71
16.541	1317.19	0.28	42 386	5 722.72	0.20
16.541	1317.00	0.07	47.105	6 739.59	0.10
21.365	1967.90	−1.04	47.106	6 739.81	0.12
21.366	1968.75	−0.45	51.511	7 739.51	−0.70
26.361	2734.49	−0.21	51.514	7 740.17	−0.67
26.362	2734.76	−0.13	56.004	8 809.02	−0.47
26.447	2748.89	0.25	58.429	9 406.51	0.04
26.450	2749.40	0.25	60.863	10 019.53	0.46
31.139	3545.16	0.20	60.864	10 019.19	−0.18

[a] Triple point values taken from Ref. 2.

[b] Triple point values taken from Ref. 3.