

A Re-assessment of the Thermodynamic Properties of Palladium

Improved values for the enthalpy of fusion

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The thermodynamic properties were reviewed by the author in 1995. A new assessment of the enthalpy of fusion has led to a revision of the thermodynamic properties of the liquid phase and although the enthalpy of sublimation at 298.15 K is retained as $377 \pm 4 \text{ kJ mol}^{-1}$ the normal boiling point is revised to 3272 K at one atmosphere pressure.

Introduction

The thermodynamic properties of palladium were reviewed by the author in 1995 (1). At that time the value for the enthalpy of fusion was considered to be tentative since it differed significantly from the only known experimental value. Newly considered enthalpy of fusion values now indicate that the original selected value was almost certainly incorrect and a more likely value has been suggested which leads to a major alteration to the selected values for the liquid phase. Additional measurements of the vapour pressure do not alter the selected enthalpy of sublimation value of 377 kJ mol^{-1} but the accuracy can now be refined to give a 95% confidence value of $\pm 4 \text{ kJ mol}^{-1}$.

Solid

Selected values in the low-temperature region as given in the previous review (1) were based mainly on the specific heat values of Boerstoe

et al. (2), Clusius and Schachinger (3) and Mitacek and Aston (4) and continue to be considered satisfactory. However only limited information was given in the original review which above 50 K consisted of specific heat values at 10 K intervals from 50 to 100 K and at 20 K intervals from 100 to 280 K and with the value at 298.15 K also included. This is now considered to be far too little information and instead a comprehensive review of the low-temperature thermodynamic properties is given in **Table I**.

In the high-temperature solid region closely agreeing specific heat values derived from the enthalpy measurements of Cordfunke and Konings (5) (528 to 848 K) and the direct specific heat measurements of Miiller and Cezairliyan (6) (1400 to 1800 K) were selected since they were in excellent agreement with an extrapolation of the selected low-temperature values and allowed a single smooth specific heat curve to represent both the low- and high-temperature regions. More recent high-temperature specific heat values by Milošević and Babić (7) (248 to 1773 K) differ significantly from the selected values showing a trend from 1.3% lower at 323 K to 3.9% lower at 723 K to 2.3% lower at 1223 K to 5.9% lower at 1773 K. However, at the low-temperature change over point at 270 K the measurements of Milošević and Babić show a sharp change in the slope of the specific heat curve compared to the selected low-temperature values, indicating that these high-temperature measurements are incompatible with those obtained at low temperatures. On these grounds the original high-temperature values were retained and can be represented by Equation (i) to cover the range from 298.15 K to the accepted melting point at 1828.0 K:

Table I Low Temperature Thermodynamic Data

T, K	$C_p^\circ, J mol^{-1} K^{-1}$	$H^\circ_T - H^\circ_{0K}, J mol^{-1}$	$S^\circ_T, J mol^{-1} K^{-1}$	$-G^\circ_T - H^\circ_{0K}, J mol^{-1}$	$-(G^\circ_T - H^\circ_{0K})/T, J mol^{-1} K^{-1}$
5	0.0594	0.133	0.0512	0.123	0.0246
10	0.196	0.722	0.128	0.554	0.0554
15	0.490	2.355	0.256	1.485	0.0990
20	0.999	5.978	0.461	3.241	0.162
25	1.768	12.78	0.761	6.253	0.250
30	2.794	24.13	1.172	11.04	0.368
35	3.998	40.97	1.689	18.15	0.519
40	5.388	64.40	2.313	28.11	0.703
45	6.809	94.90	3.030	41.43	0.921
50	8.190	132.4	3.819	58.53	1.171
60	10.724	227.3	5.541	105.2	1.753
70	12.921	345.8	7.364	169.7	2.424
80	14.803	484.6	9.215	252.6	3.157
90	16.411	640.9	11.054	353.9	3.933
100	17.784	812.1	12.856	473.5	4.735
110	18.949	995.9	14.607	610.9	5.554
120	19.926	1190	16.299	765.5	6.379
130	20.746	1394	17.927	936.7	7.205
140	21.443	1605	19.491	1124	8.027
150	22.043	1822	20.991	1326	8.842
160	22.561	2046	22.431	1543	9.646
170	23.012	2273	23.813	1775	10.439
180	23.406	2506	25.139	2020	11.219
190	23.752	2741	26.414	2277	11.986
200	24.059	2980	27.641	2548	12.738
210	24.334	3222	28.821	2830	13.476
220	24.582	3467	29.959	3124	14.200
230	24.806	3714	31.057	3429	14.909
240	25.007	3963	32.117	3745	15.604
250	25.189	4214	33.141	4071	16.285
260	25.352	4467	34.133	4408	16.952
270	25.499	4721	35.092	4754	17.607
280	25.629	4977	36.022	5109	18.248
290	25.751	5234	36.923	5474	18.876
298.15	25.845	5444	37.638	5778	19.379

Notes to Table I

C_p° is specific heat

$H^\circ_T - H^\circ_{0K}$ is enthalpy

S°_T is entropy

$-G^\circ_T - H^\circ_{0K}$ and $-(G^\circ_T - H^\circ_{0K})/T$ are free energy functions

$$C_p^\circ (\text{J mol}^{-1} \text{K}^{-1}) = 24.0658 + 9.54408 \times 10^{-3} T - 5.31329 \times 10^{-6} T^2 + 2.02516 \times 10^{-9} T^3 - 57,835.6/T^2 \quad (\text{i})$$

Equivalent enthalpy and entropy equations are given in **Table II** and derived thermodynamic values are given in **Table III**.

In comparison with the selected equations the specific heat values of Vollmer and Kohlhaas (8)

(300 to 1825 K) trend from 2.6% lower at 300 K to 5.3% lower at 800 K to an average of 1.5% higher above 1600 K (**Figure 1**). Enthalpy measurements of Holzmann (9) (575 to 1177 K) trend from 0.4% higher to 1.7% higher whilst those of Jaeger and Veenstra (10) (573 to 1772 K) scatter from 0.7% lower to 1.4% lower with an average of 1.1% lower (**Figure 2**). More recent enthalpy measurements of Cagran and Pottlacher (11) (1550 to 1828 K)

Table II Thermodynamic Equations Above 298.15 K

Solid: 298.15 to 1828.0 K

$$C_p^\circ (\text{J mol}^{-1} \text{K}^{-1}) = 24.0658 + 9.55408 \times 10^{-3} T - 5.31329 \times 10^{-6} T^2 + 2.02516 \times 10^{-9} T^3 - 57,835.6/T^2$$

$$H_T^\circ - H_{298.15 \text{ K}}^\circ (\text{J mol}^{-1}) = 24.0658 T + 4.77704 \times 10^{-3} T^2 - 1.77109667 \times 10^{-6} T^3 + 5.06290 \times 10^{-10} T^4 + 57,835.6/T - 7750.91$$

$$S_T^\circ (\text{J mol}^{-1} \text{K}^{-1}) = 24.0658 \ln(T) + 9.55408 \times 10^{-3} T - 2.656645 \times 10^{-6} T^2 + 6.75053333 \times 10^{-10} T^3 + 28,917.8/T^2 - 102.4348$$

Liquid: 1828.0 to 3300 K

$$C_p^\circ (\text{J mol}^{-1} \text{K}^{-1}) = 41.2000$$

$$H_T^\circ - H_{298.15 \text{ K}}^\circ (\text{J mol}^{-1}) = 41.2000 T - 10,903.0$$

$$S_T^\circ (\text{J mol}^{-1} \text{K}^{-1}) = 41.2000 \ln(T) - 208.9240$$

Notes to Table II

C_p° is specific heat

$H_T^\circ - H_{298.15 \text{ K}}^\circ$ is enthalpy

S_T° is entropy

Table III High Temperature Thermodynamic Data

$T, \text{ K}$	$C_p^\circ, \text{ J mol}^{-1} \text{K}^{-1}$	$H_T^\circ - H_{298.15 \text{ K}}^\circ, \text{ J mol}^{-1}$	$S_T^\circ, \text{ J mol}^{-1} \text{K}^{-1}$	$-(G_T^\circ - H_{298.15 \text{ K}}^\circ)/T, \text{ J mol}^{-1} \text{K}^{-1}$
298.15	25.845	0	37.638	37.638
300	25.866	48	37.798	37.639
400	26.805	2684	45.375	38.665
500	27.536	5402	51.438	40.633
600	28.162	8188	56.515	42.868
700	28.727	11,033	60.899	45.138
800	29.255	13,932	64.770	47.355
900	29.766	16,883	68.245	49.486
1000	30.274	19,885	71.407	51.522
1100	30.794	22,938	74.317	53.464
1200	31.339	26,045	77.019	55.316
1300	31.922	29,207	79.551	57.084
1400	32.555	32,431	81.939	58.774

(Continued)

T, K	$C_p^\circ, J mol^{-1} K^{-1}$	$H_T^\circ - H_{298.15 K}^\circ, J mol^{-1}$	$S_T^\circ, J mol^{-1} K^{-1}$	$-(G_T^\circ - H_{298.15 K}^\circ)/T, J mol^{-1} K^{-1}$
1500	33.251	35,720	84.209	60.395
1600	34.023	39,083	86.379	61.952
1700	34.882	42,528	88.467	63.450
1800	35.841	46,063	90.487	64.896
1828 (s)	36.129	47,071	91.043	65.293
1828 (l)	41.200	64,411	100.528	65.293
1900	41.200	67,377	102.120	66.658
2000	41.200	71,497	104.232	68.485
2100	41.200	75,617	106.243	70.235
2200	41.200	79,737	108.160	71.916
2300	41.200	83,857	109.991	73.532
2400	41.200	87,977	111.745	75.088
2500	41.200	92,097	113.427	76.588
2600	41.200	96,217	115.043	78.036
2700	41.200	100,337	116.597	79.436
2800	41.200	104,457	118.096	80.790
2900	41.200	108,577	119.542	82.101
3000	41.200	112,697	120.938	83.373
3100	41.200	116,817	122.289	84.606
3200	41.200	120,937	123.597	85.805
3300	41.200	125,057	124.865	86.969

Notes to Table III

C_p° is specific heat

$H_T^\circ - H_{298.15 K}^\circ$ is enthalpy

S_T° is entropy

$-(G_T^\circ - H_{298.15 K}^\circ)/T$ is the free energy function

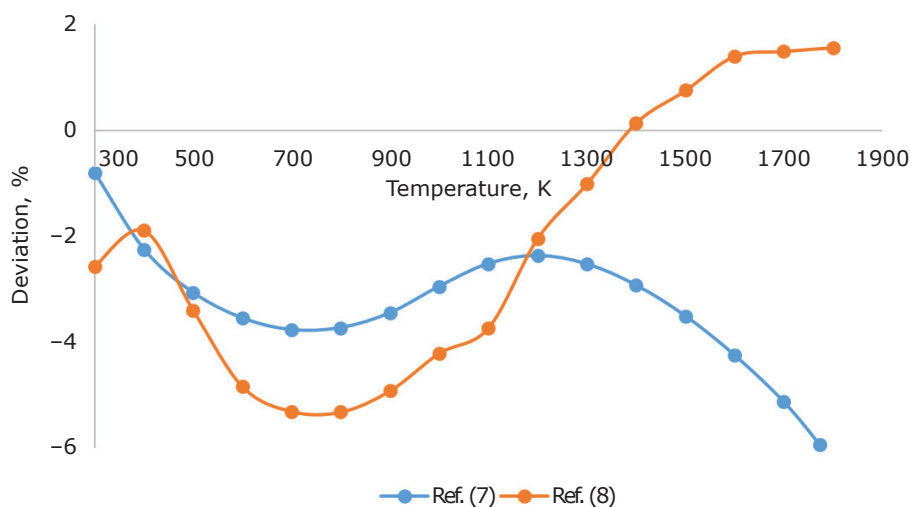


Fig. 1. Percentage deviations of specific heat in the high-temperature region

determined using the rapid pulse heating technique trend from 1.4% to 3.7% lower in the solid range (Figure 3).

Liquid

Drop calorimetry enthalpy measurements by Treverton and Margrave (12) were initially determined over the range 1846 to 2334 K on the International Practical Temperature Scale of 1948 (IPTS-48) but a short note added in the proof indicated further corrections for radiation losses and a conversion to the temperature scale IPTS-68. However only the amended liquid specific heat value and the liquid enthalpy at the melting point (given as 1827 K) were given. After correction

for atomic weight, to the melting point of 1828.0 K and to the International Temperature Scale of 1990 (ITS-90), the liquid enthalpy at the melting point is $H^{\circ}_T - H^{\circ}_{298.15\text{ K}} = 63,151\text{ J mol}^{-1}$ which in combination with the enthalpy of the solid at the melting point leads to an enthalpy of fusion of $16.08 \pm 0.74\text{ kJ mol}^{-1}$. This is notably lower than actual experimental values of 17.64 kJ mol^{-1} determined by Nedumov (13) using differential thermal analysis and rapid pulse heating values of $17.4 \pm 2.0\text{ kJ mol}^{-1}$ determined by Seydel *et al.* (14, 15) and 16.98 kJ mol^{-1} determined by Cagran and Pottlacher (11). The reason why the indirect determination of the enthalpy of fusion was low is not known but may be due to either an overestimation of the enthalpy values for the solid or, more likely,

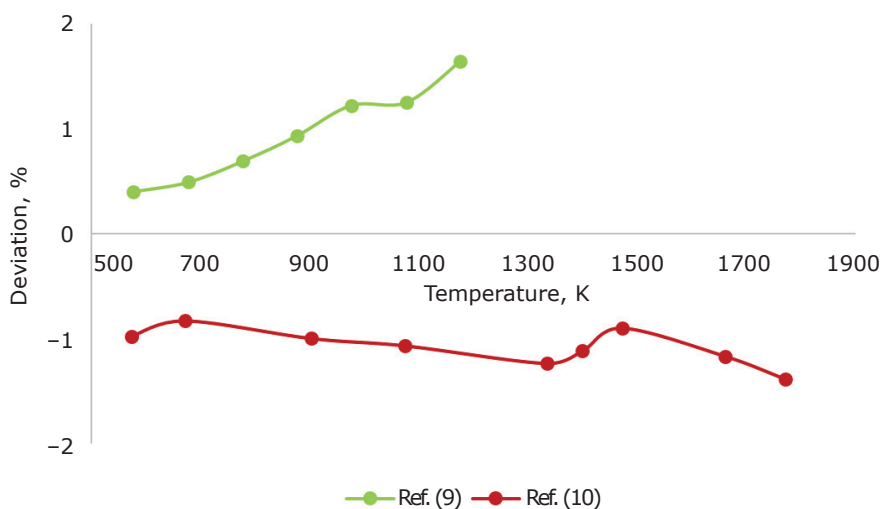


Fig. 2. Percentage deviations of enthalpy in the high-temperature region

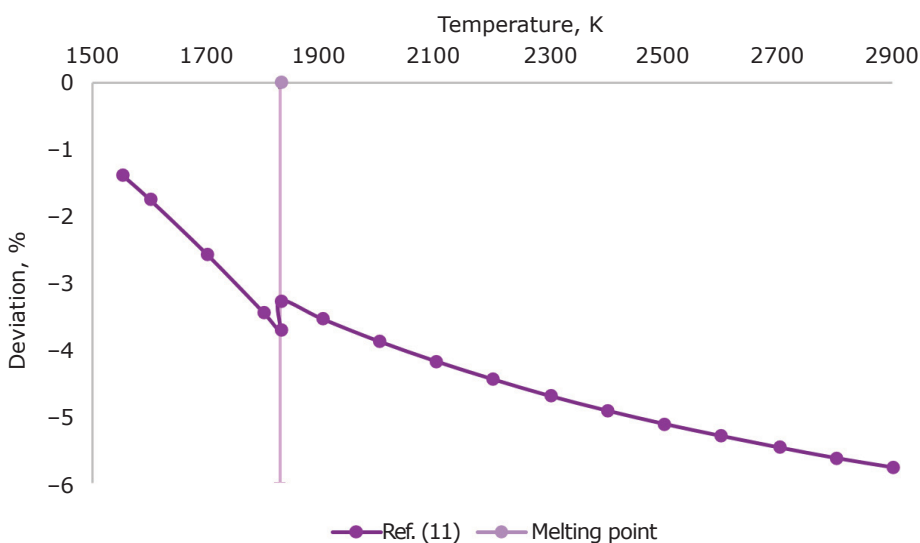


Fig. 3. Percentage deviations of enthalpy in the high-temperature region

to the fact that even the revised values of Treverton and Margrave had still not accounted for all of the systematic errors that may have been present in their measurements. Not including the measurement of Seydel *et al.* because of the large uncertainty, the two other enthalpy values were equivalent to entropy of fusion values of $9.65 \text{ J mol}^{-1} \text{ K}^{-1}$ and $9.29 \text{ J mol}^{-1} \text{ K}^{-1}$ respectively. Kats and Chekhovskoi (16) noted that for a particular structure type the entropies of fusion (ΔS_M) could be linearly related to the melting points (T_m) by means of the equation $\Delta S_M = a T_m + b$ where a and b are constants. For the face-centred cubic platinum group metals rhodium, iridium and platinum selected entropy of fusion values of $12.21 \pm 0.38 \text{ J mol}^{-1} \text{ K}^{-1}$ at a melting point of 2236 K for rhodium (17), $15.20 \pm 0.41 \text{ J mol}^{-1} \text{ K}^{-1}$ at a melting point of 2719 K for iridium (18) and $10.83 \pm 0.46 \text{ J mol}^{-1} \text{ K}^{-1}$ at a melting point of 2041.3 K for platinum (19) when fitted to the above equation extrapolated to $9.52 \text{ J mol}^{-1} \text{ K}^{-1}$ for palladium, in excellent agreement with the above experimental entropy values. The two experimental entropy values for palladium were therefore combined with the values for rhodium, iridium and platinum and were fitted to the equation: $\Delta S_M = 6.4574 \times 10^{-3} T_m - 2.3211$ with the derived value for palladium as $9.483 \pm 0.40 \text{ J mol}^{-1} \text{ K}^{-1}$ where the error is assigned to match those obtained for the other elements. The derived enthalpy of fusion value is rounded to $17.34 \pm 0.73 \text{ kJ mol}^{-1}$ and leads to an enthalpy for the liquid at the melting point of $64,411 \text{ J mol}^{-1}$, suggesting that even with corrections applied the enthalpy measurements of Treverton and Margrave were 2.0% too low. This confirms the suggestion that other liquid enthalpy measurements obtained by Treverton and Margrave also appear to be systematically low with, for example, the values obtained for vanadium (20) being on average 2.4% lower than the preferred values of Berezin *et al.* (21) and Lin and Froberg (22).

The liquid specific heat determined by Treverton and Margrave (12) on IPTS-68 corrected to the value $41.20 \pm 1.38 \text{ J mol}^{-1} \text{ K}^{-1}$ on ITS-90 which is notably higher than the value for the liquid of $37.3 \text{ J mol}^{-1} \text{ K}^{-1}$ determined by Cagran and Pottlacher (11) (1828 to 2900 K) using rapid pulse heating. However, it is noted that Cagran and Pottlacher obtained a specific heat value for the solid which is some 10% to 16% lower than the selected values. Therefore, the value of Treverton and Margrave was selected on the assumption that the apparently lower enthalpy values obtained

are due to a constant systematic error. Over the range 1828 to 3300 K the actual enthalpy can be expressed as (Equation (ii)):

$$H^\circ_T - H^\circ_{298.15 \text{ K}} (\text{J mol}^{-1}) = 41.2000 T - 10,903.0 \quad (\text{ii})$$

Equivalent specific heat and entropy equations are also given in **Table II** whilst derived thermodynamic properties are given in **Table III**. The more recent liquid enthalpy measurements of Cagran and Pottlacher (11) trend from 3.3% lower at 1828 K to 5.8% lower at 2900 K.

Gas

Selected values are based on the 143 energy levels selected by Engleman *et al.* (23). The thermodynamic properties were calculated using the method of Kolsky *et al.* (24) and the 2014 Fundamental Constants selected by Mohr *et al.* (25, 26). Derived thermodynamic values based on a one bar standard state pressure are given in **Table IV**.

Enthalpy of Sublimation at 298.15 K

Because of a general lack of detail as to what temperature scales were used and problems associated with the exact measurement of temperature, no attempt was made to correct vapour pressure measurements to ITS-90 from what would have been contemporary scales. For results given in the form of the Clausius-Clapeyron equation, $\log(p) = A + B/T$ (where p is pressure and T is temperature), the enthalpy of sublimation was calculated at the two temperature extremes and averaged. For the measurements of Walker *et al.* (27), Lindscheid and Lange (28) and Chegodaev *et al.* (29) no temperature ranges were given and therefore these measurements were not included. From **Table V**, in view of possible systematic errors in the earlier measurements, only the twelve determinations from Taberko *et al.* (42, 43) to Ferguson *et al.* (51) were considered. The unweighted average value of 377 kJ mol^{-1} is assigned an accuracy of $\pm 4 \text{ kJ mol}^{-1}$ which is equivalent to a 95% confidence level (two standard deviations).

Vapour Pressure Equations

The vapour pressure equations as given in **Table VI** were evaluated for the solid from free energy

Table IV Thermodynamic Properties of the Gaseous Phase

T, K	$C_p^\circ, J mol^{-1} K^{-1}$	$H_T^\circ - H_{298.15 K}^\circ, J mol^{-1}$	$S_T^\circ, J mol^{-1} K^{-1}$	$-(G_T^\circ - H_{298.15 K}^\circ)/T, J mol^{-1} K^{-1}$
298.15	20.786	0	167.066	167.066
300	20.786	38	167.194	167.066
400	20.786	2117	173.174	167.881
500	20.786	4196	177.812	169.421
600	20.788	6274	181.602	171.145
700	20.802	8354	184.807	172.874
800	20.854	10,436	187.588	174.543
900	20.991	12,527	190.051	176.132
1000	21.273	14,639	192.276	177.637
1100	21.763	16,789	194.324	179.062
1200	22.508	19,000	196.248	180.414
1300	23.537	21,300	198.088	181.704
1400	24.850	23,717	199.878	182.938
1500	26.424	26,279	201.646	184.126
1600	28.213	29,009	203.407	185.276
1700	30.152	31,926	205.175	186.395
1800	32.167	35,042	206.955	187.488
1828	32.734	35,951	207.456	187.790
1900	34.179	38,360	208.749	188.559
2000	36.115	41,875	210.551	189.614
2100	37.908	45,578	212.358	190.654
2200	39.505	49,450	214.159	191.681
2300	40.869	53,471	215.946	192.698
2400	41.977	57,615	217.709	193.703
2500	42.823	61,858	219.441	194.698
2600	43.411	66,171	221.133	195.682
2700	43.757	70,532	222.779	196.656
2800	43.883	74,916	224.373	197.617
2900	43.815	79,302	225.912	198.567
3000	43.582	83,673	227.394	199.503
3100	43.213	88,014	228.817	200.426
3200	42.734	92,312	230.182	201.334
3300	42.172	96,558	231.489	202.229

Notes to Table IV

C_p° is specific heat

$H_T^\circ - H_{298.15 K}^\circ$ is enthalpy

S_T° is entropy

$-(G_T^\circ - H_{298.15 K}^\circ)/T$ is the free energy function

$H_{298.15 K}^\circ - H_{0 K}^\circ = 6197.4 J mol^{-1}$

Table V Enthalpies of Sublimation at 298.15 K

Authors	Ref.	Method	Temperature range, K	$\Delta H^{\circ}_{298.15\text{ K}}$ (II), kJ mol^{-1}	$\Delta H^{\circ}_{298.15\text{ K}}$ (III), kJ mol^{-1}	Notes
Babeliowsky	(30)	MS	1250–1730	385 ± 4	–	(a)
Trulson and Schissel	(31)	MS	1370–1785	382 ± 5	–	
Haefling and Daane	(32)	KE	1388–1675	332 ± 7	352.9 ± 0.5	
Alcock and Hooper	(33)	Trans	1673–1773	459	376.1 ± 2.4	
Zanitsanov	(34)	KE	1537–1841	368 ± 22	375.9 ± 1.2	(b)
Dreger and Margrave	(35)	L	1220–1640	362 ± 11	380.6 ± 1.0	
Hampson and Walker	(36)	L	1294–1488	365 ± 4	373.4 ± 0.2	
Norman <i>et al.</i>	(37)	KEMS	1485–1710	381	380.5 ± 0.1	(c)
Strassmair and Stark	(38)	L	1361–1603	372 ± 14	373.3 ± 0.6	
Myles	(39)	TE	1515–1605	372	372.0 ± 0.1	(c)
Darby and Myles	(40)	TE	1517–1608	372	371.8 ± 0.1	(c)
Novosolov <i>et al.</i>	(41)	TE	1730–1938	363	370.0 ± 0.4	(c)
Taberko <i>et al.</i>	(42, 43)	Evap	1828–2023	381 ± 10	376.9 ± 0.3	
Zaitsev <i>et al.</i>	(44)	KE	1267–1598	377 ± 1	377.3 ± 0.1	
Bodrov <i>et al.</i>	(45)	AA	1511–1678 (s) 1842–2046 (l)	389 ± 4 394 ± 12	376.6 ± 0.2 373.1 ± 0.5	
Naito <i>et al.</i>	(46)	KEMS	1567–1758	386	375.5 ± 0.5	(c)
Chandrasekharaiah <i>et al.</i>	(47)	KEMS	1439–1724	373 ± 5	377.9 ± 0.2	(d)
Stølen <i>et al.</i>	(48)	KEMS	1523–1743	389	375.5 ± 0.5	(c)
Bharadwaj <i>et al.</i>	(49)	KEMS	1627–1818 (s) 1833–2041 (l)	378 ± 7 380 ± 8	377.7 ± 0.2 376.7 ± 0.2	(d) (d)
Kulkarni <i>et al.</i>	(50)	KEMS	1237–1826	375 ± 2	381.7 ± 0.3	(e)
Ferguson <i>et al.</i>	(51)	KE	1473–1825 (s) 1840–1973 (l)	373 ± 7 385 ± 7	377.8 ± 0.4 377.4 ± 0.2	
				Selected	377 ± 4	

Notes to Table V

 $\Delta H^{\circ}_{298.15\text{ K}}$ (II) and $\Delta H^{\circ}_{298.15\text{ K}}$ (III) are the Second Law and Third Law enthalpies of sublimation at 298.15 K

(a) Value given only at 298.15 K

(b) Two runs combined since individual Second Law values were 433 kJ mol^{-1} and 312 kJ mol^{-1} respectively

(c) Values given only in terms of the Clausius-Clapeyron equation

(d) Average of two runs

(e) Average of five runs

Methods

AA: atomic absorption

Evap: evaporation

KE: Knudsen effusion

KEMS: Knudsen effusion mass spectrometry

L: Langmuir free evaporation

MS: mass spectrometry

TE: torsion effusion

Trans: transpiration

Table VI Vapour Pressure Equations

Phase	Temperature range, K	A	B	C	D	E
Solid	900–1828	14.71536	0.220029	-45,349.16	-1.26392×10^{-3}	2.03201×10^{-7}
Liquid	1828–3300	92.57304	-10.78530	-51,305.62	3.94374×10^{-3}	-2.33142×10^{-7}

Table VII Free Energy Equations Above 298.15 K

Solid: 298.15 to 1828.0 K

$$G^\circ_T - H^\circ_{298.15\text{ K}} (\text{J mol}^{-1}) = 126.5006 T - 4.77704 \times 10^{-3} T^2 + 8.85548333 \times 10^{-7} T^3 - 1.68763333 \times 10^{-10} T^4 + 28,917.8/T - 24.0658 T \ln(T) - 7750.91$$

Liquid: 1828.0 to 3300 K

$$G^\circ_T - H^\circ_{298.15\text{ K}} (\text{J mol}^{-1}) = 250.1240 T - 41.2000 T \ln(T) - 10,903.0$$

Note to Table VII

$G^\circ_T - H^\circ_{298.15\text{ K}}$ is the free energy function

Table VIII Transition Values Involved with the Free Energy Equations

Transition	Temperature, K	$\Delta H_M, \text{ J mol}^{-1}$	$\Delta S_M, \text{ J mol}^{-1} \text{ K}^{-1}$
Fusion	1828.0	17,340.00	9.4858

Table IX Vapour Pressure

T, K	$p, \text{ bar}$	$\Delta G^\circ_T, \text{ J mol}^{-1}$	$\Delta H^\circ_T, \text{ J mol}^{-1}$	$p, \text{ bar}$	T, K
298.15	5.16×10^{-60}	338,411	377,000	10^{-15}	911
300	1.32×10^{-59}	338,172	376,991	10^{-14}	956
400	3.31×10^{-43}	325,314	376,433	10^{-13}	1005
500	2.20×10^{-33}	312,606	375,794	10^{-12}	1060
600	7.59×10^{-27}	300,034	375,087	10^{-11}	1122
700	3.47×10^{-22}	287,585	374,321	10^{-10}	1191
800	1.07×10^{-18}	275,250	373,504	10^{-9}	1269
900	5.43×10^{-16}	263,019	372,644	10^{-8}	1359
1000	7.86×10^{-14}	250,886	371,754	10^{-7}	1462
1100	4.56×10^{-12}	238,843	370,851	10^{-6}	1582
1200	1.33×10^{-10}	226,882	369,956	10^{-5}	1725
1300	2.30×10^{-9}	214,994	369,093	10^{-4}	1899
1400	2.63×10^{-8}	203,171	368,286	10^{-3}	2121
1500	2.16×10^{-7}	191,403	367,558	10^{-2}	2403
1600	1.36×10^{-6}	179,680	366,926	10^{-1}	2770

(Continued)

T, K	p, bar	$\Delta G^\circ_T, \text{J mol}^{-1}$	$\Delta H^\circ_T, \text{J mol}^{-1}$	p, bar	T, K
1700	6.89×10^{-6}	167,994	366,399	1	3268.52
1800	2.91×10^{-5}	156,336	365,979	NBP	3271.88
1828 (s)	4.23×10^{-5}	153,076	365,880		
1828 (l)	4.23×10^{-5}	153,076	348,540		
1900	1.01×10^{-4}	145,388	347,983		
2000	3.03×10^{-4}	134,742	347,378		
2100	8.17×10^{-4}	124,121	346,961		
2200	2.02×10^{-3}	113,516	346,713		
2300	4.60×10^{-3}	102,919	346,614		
2400	9.79×10^{-3}	92,323	346,638		
2500	1.96×10^{-2}	81,725	346,761		
2600	3.73×10^{-2}	71,120	346,954		
2700	6.75×10^{-2}	60,506	347,195		
2800	0.117	49,883	347,459		
2900	0.196	39,251	347,745		
3000	0.318	28,609	347,976		
3100	0.498	17,960	348,197		
3200	0.760	7304	348,375		
3268.52	1.000	0	348,467		
3300	1.130	-3356	348,501		

Notes to Table IX

ΔG°_T is the free energy of formation at one bar standard state pressure and temperature T and ΔH°_T is the enthalpy of sublimation at temperature T

Enthalpy of sublimation at 0 K: $\Delta H^\circ_0 = 376.247 \pm 4.000 \text{ kJ mol}^{-1}$

NBP is the normal boiling point at one atmosphere pressure (1.01325 bar)

functions for the solid and the gas at 50 K intervals from 900 K to 1800 K and the melting point and for the liquid at the melting point and at 50 K intervals from 1850 to 3300 K and were fitted to the following equation (Equation (iii)):

$$\ln(p, \text{bar}) = A + B \ln(T) + C/T + D T + E T^2 \quad (\text{iii})$$

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