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		L·K-'mol-'			- Jour-		
7.K	ະ	S° -[G	$^{\circ}-H^{\circ}(T_{*})]T$	$H^{\bullet}-H^{\bullet}(T_{*})$	Δ,Η*	$\Delta_i G^{\bullet}$	log K
°8;	0.	0.	INFINITE -65.394	-5.842 -4.764	00	ರ ರ	00
298.15	25.687	33.561 43.560	-45.871 43.560	-2.462	o	o' c	o' o
300	25.708	43 719	43.560	0.048	်ဝံ	6 0	် ဝံ
8 8 8	26.751 27.692	51.261 57.332	44.581 46.543	2.672 5.394	o o	ဝ ဝ	00
88	28.583 29.445	62.460	48.780	8.208	00	o o	00
8	30.288	70.919	53.298	14.097	0	ö	Ö
88	31.943	71.856	55.459 57.535	20.320	င် ဝ	ರ ರ	o 0
200	32.759	80.938	59.524	23.556	o o	0 0	Ö
30	34.372	86.543	63.258	30.270	် ဝ	်ဝံ	o o
1500 1500	35.064	89 115 91 5 58	65 014 66.703	33.741 37.283	00	o o	o o
0091	36.466	63.889	68.330	40.894	0	Ö	0
881	37.167 37.868	96.121 98.265	71.416	44.576 48.328	ರ ರ	ರ ರ	o c
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	38.569	100.331	72.884	52.149 56.041	00	ဝင	00
2054.000		103.378	75.057	58 172	ALPH	A <> A	BETA
2100		10701	75.057	65 657	•	IKANSIIION	c
2200		108.632	77.207	69.136	000	; c) c	io
2400	37.154	111 784	79 957	76.383	000	ರ ರ ರ	000
2500 000		113.353	81.262	80.228	BET/	î;	ļ
2600		126 545	797-18	13.781		TRANSITION O	
2700	37.656	127 966	84.616	117.047	o o	်ဝံ	0
2800	37.656	130.657	80.189 87.699	124.578	ာဝံဝ	တ် ဝ	ಶರ
3100	37.656	133.169	90.553	132.109	i ဝ	ර	.
3300	37.656 37.656	134,364	91.903 93.208	135.875	ರ ರ	ರ ರ	00
3400 3500	37.656 37.656	136.647	94.469 95.690	143.406	00	00	00
3600		138.799	96.872	150.937	0	o'	Ö
3800	37.656 37.656	139,831	98.020 99.133	154.703	00	ರ ರ	o 0
96.4 00.00	37.656 37.656	141.814	100.215	162.234	o' c	o o	o c
4100	37.656	143,697	102.291	169.765	Ö	ó	· •
4.4 9.65 9.00 9.00	37.656	45.490	103.287	173531	ာဝ	ರ ರ	00
4400 5000	37.656	146.356	105.205	181.062	600	600	öc
4600	37.656	148.030	107.031	188.593	o o	; o;	; o
808	37.656	148.840	107.912	192.339	တ် တံ	တံ တံ	ರ ರ
4900	37.656	150.409	109.615	199.890	0.	o !	
4963 793	37.996	263.754	110.142	202.292 762.496		LIQUID <> IDEAL FUGACITY = 1 ba	AL GAS_
2000	38.154	264 031	111.256	763.875	o.	ó	Ö
2500 2400	39.04	265.544	117.161	771.594	00	o c	00
2005	40 910	268.505	127.866	787.581	600	. 0 0	တ် တ
200	47.870	771 304	0KE CE	80.434	j c	<i>i</i> e	5 6

 $A_r = 178.49$ Hafnium (Hf)

Hf₁(ref)

REFERENCE STATE

Refer to the individual tables for details.

0 to 2054 to 2500 to 4963.793 to

Hafnium (Hí)

J. Phys. Chem. Ref. Data, Monograph 9

Hf₁(cr)

Hafnium, Alpha (α⊣Hŋ

PREVIOUS

CURRENT March 1979

Standard State Pressure = $p^* = 0.1$ MPa -0.003 -0.009 -0.018 -0.018 ದರದರ ರ ಪರಕ್ಷಕ ಕ್ಷಣಕ್ಷ ರದಕ್ಕೆ ಕ್ಷಣಕ್ಕೆ 0.129 0.392 0.629 0.845 K-mod ರದರೆದೆ ರ ರದದೆದೆದೆ ದದ್ದಿದೆದೆ ದದ್ದಿದೆದೆ $H^{\bullet}-H^{\bullet}(T_{\bullet})$ 8.208 11.110 14.097 17.167 20.320 23.556 22.8872 39.270 39.270 39.270 39.270 39.270 44.894 44.894 44.894 44.894 44.894 44.894 44.894 44.894 44.894 44.894 86.941 58.172 Enthalpy Reference Temperature = T, = 298.15 K S -[C-H(L)]I 59.524 61.430 63.258 65.014 66.703 68.330 68.330 71.416 71.284 71.284 71.267 71.267 71.268 71 0. 17.753 33.561 39.086 80.938 83.824 86.543 89.115 91.558 93.889 96.121 98.265 100.331 102.327 103,378 104.260 106.136 107.959 109.734 111.466 43,560 54.439 74534 32.759 33.572 34.372 35.064 35.064 36.466 37.167 37.868 38.569 39.269 25.708 26.247 26.751 27.230 27.692 28.583 29.445 30.288 31.120 31.943 25 687 200 250 250 28.15 $\Delta_1 H^{\circ}(0 \text{ K}) = 0 \text{ kJ·mol}^{-1}$ $\Delta_1 H^{\circ}(298.15 \text{ K}) = 0 \text{ kJ·mol}^{-1}$ $\Delta_{-}H^{\circ} = 5.908 \pm 0.2 \text{ kJ mol}^{-1}$ The adopted thermal functions for α-Hf(cr) are derived from the studies of Collings and Ho, Westrum, Hawkins et al 3 and Cezairliyan in the calculated values for S(5 K) is 0 00004 cal K⁻¹ mol⁻¹ with the adopted value being S'(5 K) = 0 0038 cal·K⁻¹ mol⁻¹. Similarily for C'₀(5 K) the maximum difference is 0.00024 cal K⁻¹ mol⁻¹, with the adopted value being C'₀(5 K) = 0 00638 cal·K⁻¹ mol⁻¹ In the region above 5 K, and below 350 K, there are four heat capacity studied. ²²⁻¹ Cristescu and Simon's studies Hf from 13 to 210 K and temperature is so low, the effects of superconductivity on the thermal functions are not considered.

There are four studies 16-4 on the heat capaicty of hafmium in the region 1-5 K. Only Wolcott[®] reported the experimental data (56 data points). In the other three states, an equation (with two constants) was given to describe the entire set of experimental data. The second set the peak is completely absent. The heat capacity measurements of Burk et al. (10–200 K)," and Westrum (5 82–348.55 K) $^{1.2}$ support this latter conclusion, i.e., no peak. The values of Burk et al.," after correction for the ~2% Zr in this sample, agree with the data of Westrum^{2,12} Roberts* surveyed the superconductive properties of the elements and reported a critical temperature of 0.128 K for lpha-Hf(cr). Since this of constants given by Betterton and Scarbrough^a are stated to be an average of the two studies of Kneip et al. 7 and the more recent study by reported 15 heat capacity values with a peak near 75 K. Burk and Darnell¹⁰ made heat capacity measurements (40-190 K) and reported that between 10 and 40 K but deviate above 40 K, becoming \sim 5% higher at 100 K and decreasing to \sim 1% higher at 200 K. Above 350 K, there Betterton and Scarbrough.* However, the values appear suspect and may contain a typographical error. Nevertheless the maximum difference and McClure. The mathematical and graphical treatment of these four studies yields a continuous and smooth heat capacity curve.

Wt % Zr in Hf Sample 0.7 1.0 0.79 0.79 0.66 0.65 1500-2400 1200-2200 100-2050 551-1309 338-1346 595-137 16 (smoothed) 26 13 (smoothed) Data Points 282 Golutvin and Maslennikova (1970)15 Golutvin and Maslennikova (1970)15 Cezairliyand and McClure (1975)4 Fieldhouse and Lang (1961)14 Arutyunov et al (1972)17 Rumyantsev et al. (1979)¹¹ Peletskii *et al*. (1971)¹⁶ Hawkins et al. (1963) Adenstedt (1952)13 Source (Year) Heat Capacity Enthalpy

are four heat capacity studies and four enthalpy studies

The enthalpy studies show an unusually large scatter within each study as well as a lack of agreement between the studies. The heat capacity studies all have a similar temperature dependence in comparison with the adopted values. However, the studies of Arutyunov et al. 1719 and by Aruymov et al. 1719 and Rumyantsev et al. 18 suggest a sharp decrease in the heat capacity values within 50 K of the α-β transition Rumyantsev et al. is roughly 10% higher than the adopted values, whereas the study of Peletskii et al. is lies 5-24% below. The studies temperature. The experimental results were corrected for this zirconium content.

Transition Data

Refer to the \(\theta\)-crystal table for details.

Sublimation Data

There are no sublimation studies involving \(\alpha\)-Hf(cr) The enthalpy of sublimation is calculated as the difference between the enthalpy of formation of the ideal gas and the enthalpy of formation of α-Hf(cr)

References

E. W. Collins and J C. Ho, Phys Rev. 4B, 349 (1971).

P. F. Westrum, University of Michigan, personal communication, (1979).
³D. T. Hawkins, M. Onillon and R. L. Orr, J. Chem. Eng. Data 8, 628 (1963).

 (4) Cezairliyan and J. L. McClure, J. Res. Nat. Bur Stand. 79A, 431 (1975).
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Continued on page 137

feat Capacity and Entropy

S°(298.15 K) = 43.560 J·K⁻¹·mol⁻¹

 $r_{\rm rs} = 2054 \pm 50 \, \text{K} \, (\alpha - \beta) \, \text{K}$ Enthalpy of Formation Zero by definition.

Hafnium, Alpha (α–Ηf)

Hf₁(cr)

Hafnium, Beta (β⊣Hf)

Hafnium, Beta (B-Ht)

 $\Delta_{\rm fur}H^{\circ} = [29.288 \pm 4.2] \, \text{kJ·m}$

$S^{\circ}(298.15 \text{ K}) = [61.104] \text{ J·K}^{-1} \cdot \text{mol}^{-1}$ $T_{\text{m}} = 2054 \pm 50 \text{ K} (\alpha - \beta) \text{ J·K}^{-1}$ $T_{\text{m}} = 2500 \pm 20 \text{ K} (\beta - 1) \text{ J·K}^{-1}$

Enthalpy of Formation

The enthalpy of formation is calculated from that of the a-crystal by addition of A., H. and the difference in enthalpy, H'(2054 $H^{\circ}(298.15 \text{ K})$, between the α -crsytal and β -crystal

Heat Capacity and Entropy

capacity of a sample containing 3.12% (wt) Zr in the range 2054 to 2400 K. These results were corrected by Cezairityan and McClurr represent pure B-Hf and are extrapolated linearly to the melting point, 2500 K, and to 298.15 K. The entropy at 298.15 is calculated it The only heat capacity study for the β -crystal is that of Cezairityand McClure. Using a pulse heating technique, they studied the manner similar to that for the enthalpy of formation.

Phase Data

Hafnium, at ambient pressures, exists in two crystal modifications. The low temperature form, lpha—H4, is hexagonal close packed, an hcp(structure isotypic with Mg. The high temperature form, B-Hf, is body centered cubic, a boc(A2) structure isotypic with W. The wide variation in the observed transition temperature is undoubtedly due to the effects of various impurities, in particular, zirconium

Transition Data

given below. All temperatures were corrected to IPTS-68. The pure hafmium value reported by the cited author was corrected for the zirconi content of the alloy. Hultgren et al., 11 based on data available through 1965, recommended $T_{in} = 2013 \pm 20$ K. We adopt $T_{in} = 2054 \pm 50$ based on the study of Cezairliyan and McClure² since we have also adopted their measured heat capacity values. In addition there are ms studies of binary phase diagrams which lend support to this adopted value. Cezairlivan and McClure² have summarized the reported transition temperatures for the α to β transition of hafnium. Their summar

Source	Zirconium Content (W/%)	Transformation Hafnium Alloy	Temperature (K) Pure Hafnium
Duwez³ unknown	1586 ± 10		
Fast (1952)*	9	1960-2075	
Gibson et al. (1958) ⁵	0.01	2011	
Deardorff and Kato (1959)6	1.2-8.8		2026 ± 20
Peterson and Beemsten (1960)7	0.03	1966-2096	
Giessen et al. (1963)	2.3	1991 ± 15	2031 ± 20
Ross and Hume-Rothery (1963)8	1.6	2236-2266 50	2271 ± 70
Krikorian and Wallace (1964)10	0.02-3.45	20072100	2016 ± 14
Taylor and Doyle (1964)11	2.3	2226 ± 50	2270 ± 70
Romans et al. (1965)12	1.5	2028	2053
Bates and Barnes (1967)13	3.6	2033	
Peletskii and Druzhinin (1971)14	99.0	1970 ± 5	
Carlson et al. (1973)15	3.3	1990-2003	
Cezairlivan and McClure (1976) ²	3.12	2012 + 10	2054

respectively. Hoerster et al. 7 measured an enthalpy of transition of 0.52 keal mol-1 at 2090 K. We adopted Ap. 1 . 412 ± 0.05 keal m Cezairliyand and McClure, 2 using a millisecond-resolution pulse-heating technique, measured the transformation enthalpy to be 33.1 J. of Cezairliyan and McClure.² Martynyuk and Tsapkov, ¹⁶ using a continuous-pulse heating technique, measured a transformation enthalp $(1.412 \pm 0.05 \text{ kcal-mol}^{-1})$. Peletskii and Druzhinin¹⁴ measured 29 J g⁻¹ (1.237 kcal-mol⁻¹), a value which is roughly 12% lower than 1.24 kcal·mol⁻¹. The samples used in all three studies contained significant amounts of zirconium wt %, 20.66 wt %, ¹⁴ and 0.7 wt as derived from the study of Cezairliyan and McClure.

Fusion Data

Refer to the liquid table.

Sublimation Data

Continued on page 1371

The sublimation studies for β -Hf(α) are summarized on the Hf(β) table. The enthalpy of sublimation for Hf(β , α) is calculated as difference in the enthalpies of formation at 298.15 K of Hf(β) and Hf(β , α).

| 7. S [GIF(T)]/T HIF(T) Adf" Adf" Adf" Adf" Adf" Adf" Adf" Adf" | 7. | T/K C; S* -[G*-If(T,)]/T H*-If*Tf) A,H* A,G** k 0 100 | T/K C; S* -[G*-If(T,)]/T H*-If*Tf) A,H* A,G** k 0 100
 | T/K C; S* -[G*-IF(T)]IT H*-IP(T) A,H* A,G** k 100
 | T/K C; S* -[G*-IF(T)]IT H*-IP(T) A,H* A,G** k 0 100
 | T/K C; S* -[G*-IF(T)]IT H*-IP(T) A,H* A,G** k 0 100
 | T/K C; S* -[G*-If(T,)]/T H*-If*Tf) A,H* A,G** k 0 100
 | T/K C; S* -[G*-If(T,)]/T H*-If*Tf) A,H* A,G** k 0 100 | T/K C; S* -[G*-If(T,)]/T H*-If*Tf) A,H* A,G** k 0 100 | T/K C; S* -[G*-If(T,)]/T H*-If*Tf) A,H* A,G** k 0 100 |
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288.15 17.747 61.104 61.104 0. 18.686 13.30 17.747 61.104 61.104 0. 18.686 13.30 18.276 65.397 65.329 0.333 18.271 65.104 65.104 0. 18.686 13.30 18.276 65.397 65.393 18.271 17.869 19.611 70.720 65.180 3.770 17.869 17.869 19.611 70.720 65.180 3.770 17.869 17.869 19.611 70.720 65.180 3.770 17.869 19.611 70.720 65.180 3.770 17.869 19.611 70.720 65.180 3.770 17.870 17.871 18.271 19.272 17.871 18.272 19.272 19.273 19.273 19.273 19.273 19.273 19.273 19.273 19.273 19.273 19.273 19.273 19.274 17.199 17.279 19.273 19.274 17.199 17.279 19.274 19.274 17.279 19.274 19.274 17.279 19.274 17.279 19.274 17.279 19.274 19.274 17.279 19.274 19.274 17.279 19.274 19.274 19.274 17.279 19.274 19.274 17.279 19.274 19.274 17.279 19.274 19	288.15 17747 61.104 61.104 0 18.686 13.455 298.15 17747 61.104 61.104 0 0 18.686 13.455 300 17.764 61.214 61.105 0.033 18.671 13.759 450 18.627 66.397 64.105 0.033 18.671 13.759 450 19.611 70.720 66.182 2801 17.869 11.793 450 19.611 70.720 66.182 2801 17.869 11.793 450 19.611 70.720 66.182 2801 17.869 11.793 450 19.611 70.720 66.182 2801 17.869 11.793 450 12.331 80.538 67.951 10.009 450 22.331 80.538 67.951 10.009 440 22.331 80.538 67.951 10.009 1100 25.151 88.082 72.447 17.199 11.233 13.877 150 26.97 92.448 75.193 12.349 10.370 150 28.844 96.456 77.611 27.98 9.401 2.098 160 29.767 98.317 78.987 30.978 87.00 16.41 160 29.767 98.317 78.987 30.928 87.00 16.41 160 29.767 98.317 78.987 30.928 87.00 16.41 160 29.767 98.317 88.97 30.928 87.00 16.41 160 29.767 98.317 88.97 30.928 87.00 16.41 160 29.767 98.317 88.97 30.928 87.00 16.41 160 29.767 98.317 88.97 30.928 87.00 16.41 160 29.767 98.317 88.97 30.928 87.00 16.41 170 34.384 107.011 84.646 46.966 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
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| 700 21,457 7,612 66,359 7,877 15,453 800 23,248 80,338 67,951 10,069 14,638 900 23,248 82,739 7,1000 14,730 13,052 1100 25,151 88,082 72,447 17,199 12,329 1200 26,574 93,100 73,844 19,760 11,239 1500 27,921 24,48 75,193 22,444 10,139 12,119 1500 28,844 96,476 77,761 27,198 9,401 1500 28,844 96,476 77,761 27,198 9,401 1700 29,757 82,434 77,761 27,198 9,401 1800 11,614 10,193 81,338 37,067 6,810 1800 13,461 10,193 81,338 37,067 6,230 200 13,461 10,193 81,348 45,344 6,230 200 33,461 10,103 84,154 | 800 21.457 7.612 66.359 7.871 15.453 7.975 800 23.348 86.338 7.877 11.543 1.976 6.648 900 23.348 86.378 11.000 14.538 15.875 6.648 1100 23.151 88.277 71.000 14.373 13.795 6.521 1100 25.151 88.287 72.444 19.760 11.573 3.789 1200 26.074 90.310 73.193 22.444 10.629 3.171 1300 28.844 96.456 77.761 27.198 9.401 2.088 1600 29.844 96.477 77.61 27.998 9.401 2.089 1600 29.844 96.477 77.61 27.998 9.401 2.089 1700 20.69 10.0189 81.738 3.951 8.649 1.211 1800 23.444 10.566 40.244 40.744 0.693 1.211 1800 | 800 21.345 7.61 66.359 7.871 15.453 7.975 800 22.348 86.348 67.511 10.069 146.58 6.545 900 23.348 86.378 11.000 14.038 15.648 6.545 1100 25.151 86.379 71.000 11.373 13.795 6.521 1200 25.697 92.434 71.199 11.279 4.700 11.571 4.700 1200 25.697 92.434 75.193 22.444 10.629 3.178 1.701 1800 27.971 92.434 75.161 25.160 10.104 26.09 1800 27.977 92.448 76.477 75.193 9.401 20.08 1800 28.478 77.61 27.938 8.700 1.614 10.08 1800 28.4164 95.59 9.401 2.008 1.11 1.008 1.11 1800 28.4164 96.596 0.744 6.810 0.15 | 700 21,457 7,612 65,359 7,877 15,453 7,976 800 22,341 80,338 67,951 10,099 14,638 6,648 900 23,244 83,277 6,501 12,353 13,872 6,648 1000 24,277 83,790 10,009 14,638 6,648 6,648 1200 26,674 90,310 13,844 10,760 11,573 3,789 1500 28,844 96,416 77,761 27,169 12,09 1,711 1500 28,844 96,426 77,761 27,198 9,401 2,098 1500 28,844 96,426 77,761 27,198 9,401 2,098 1500 28,844 96,426 77,761 27,998 9,401 2,098 1500 28,844 96,431 78,897 30,938 8,701 1,644 1500 28,841 46,448 77,744 6,810 0,417 1,104 1500
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Standard State Pressure = p = 0.1 MPa

eference Temperature = T, = 298.15 K

J-K-'mol-'

K-mol- Δ_H

 $H^{\bullet}-H^{\bullet}(T_{\epsilon})$

 $S^{\bullet} - [G^{\bullet} - H^{\bullet}(T_{\bullet})]T$

log Kr

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-6.613 -6.563 -5.419 -4.568 -3.912 -3.393

71.938 72.157 72.157 72.646 73.288 74.014 75.582 77.193 78.785 80.335

88.211 88.446 91.372 94.061 96.564

98.916

20.534 21.457 22.381 23.304 24.227 25.151 26.074 26.997 27.921 28.844 29.767 30.691 31.614

71.938 72.048 74.821 77.285 79.513

-2.633 -1.686 -1.183 -1.144 -0.737 -0.737 -0.667 -0.558 -0.466 -0.317 -0.317

30.128 27.916 25.819 23.821 21.910 20.076 18.312 16.610 14.965 13.371 11.823 10.317 8.849

39.852 39.097 38.353 37.627 36.924

83.281 84.678 86.027 87.331 88.595 89.821 99.012

36.243 35.584 34.948

109.151 110.984 112.764 13.114

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-0.204 -0.156 -0.116 -0.083 -0.053 0.

7.406 5.969 4.669 3.513 2.346 1.173

34.773 34.646 28.802 29.083 29.271 29.368

92.400 92.400 93.306 94.426 95.529 96.614 97.678 99.746

114.734 116.666 118.503 120.255 121.929 123.531 125.068

37.656 37.656 37.656 37.656

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126.545 127.966 129.336 130.657 131.934

100.748 101.730 102.692 103.633 104.556 105.459 106.344 107.210 108.060

133.169 134.364 135.523 136.647 137.739

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CURRENT: March 1979

-0.157 -0.268 -0.374 -0.476 -0.575 -0.043

15 373 26.662 37 953 49.248 60.547

-560.290 -560.407 -560.568 -560.776 -561.030

119.680 120.305 120.920 121.525 122.121 122.709

142.384 146.150 149.916 153.681

117.077 117.744 118.400 119.045 119.452

148.030 148.840 149 632 150.409 150,896

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123.556 127.322 131.088 134.853 138.619

13.561 14.289 15.005 15.707

43.697 44.604 45.490 46.356 47.202

109.708 110.508 111.293 112.063

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Hf ₁ (I)
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Hafnium
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tafnium (Hf)

S°(298.15 K) = [71.938] J·K ⁻¹ ·mol ⁻¹	Futhslay Ref	16
$T_{\text{tot}} = 2500 \pm 20 \text{ K}$ $\Delta_{\text{tot}} H^{\circ} = [29.288 \pm 4.2] \text{ kJ·mol}^{-1}$. '
Enthalpy of Formation	¥.	_
The enthalpy of formation is calculated from that of the β -crystal by addition of $\Delta_{lm}H^n$ and the difference in enthalpy, H^n (2500 K)- H^n (298.15 K), between the β -crystal and liquid.	280 00 280 00 280 00	
Heat Capacity and Entropy There are no heat capacity or enthalpy studies covering the liquid region of hafmum. A constant value of $C_p^* = 90 \text{cal} \cdot \text{K}^{-1} \text{ mol}^{-1}$ is assumed for the region 1820-5500 K. A glass transition is assumed at 1820 K below which extrapolated β -Hf heat capacity values are used. The entropy is calculated in a manner similar to that used for the enthalpy of formation.	28.15 28.15 28.05	
Fusion Data Garg and Ackermann,¹ using pyrometric techniques, measured the melting point of hafnium as 2501 ± 3 K. Hultgren <i>et al.</i> ² reviewed nine studies available through 1955 and recommended T_{ku} = 2500 ± 20 K. We adopted T_{ku} = 2500 ± 20 K. The studies (and the reported melting temperatures in K) examined by Hultgren <i>et al.</i> ² are: DeBoer and Fast,² 2503 ± 50; Skinner <i>et al.</i> ² 498; Linon,² 2403; Adenstedt,² 2248; Spedding.² 2508 ± 5; Deardoff and Hayes,² (2495 ± 20; Gregorovitch,² 2116; Taylor <i>et al.</i> ¹ 5503 ± 70.		
Ackermann and Rauh!! measured a melting point of 2467 ± 4 K in a HfO ₂ container. However, they state that the melting point may be as high as 2495 K since their sample contained 0.7 wt % Zr.		
The cuthalpy melting for Hf has not been measured. Various estimates and calculations have been made. Martynyuk <i>et al</i> ¹² correlated graphically Δ _{ho} S ² versus T _{ho} for many metals and used the resulting linear relationship to estimate Δ _{ho} H° = 7.0 kcal·mol ⁻¹ . We adopt this value Ackermann and Rauh ¹³ measured vapor pressures over Hf(β,cr) and Hf(l), adjusted the vapor pressures for Hf(β,cr) to match those of Hf(l) at T _{ho} , and derived Δ _{ho} H° = 6.2 kcal·mol ⁻¹ .	1600 1700 1800 1820,000 1820,000	
Vaporization Data The vaporization studies are summarized on the ideal gas table. The boiling point is calculated as that temperature for which AG ^o = 0 for Hf(l)=Hf(g) A _{rry} H ^o is the corresponding enthalpy change. Trop is the temperature at which the fugacity is one bar. The normal boiling point (p=1 bar) would be a slightly lower temperature.	2000 2100 2200 2300 2400	
References 1S. P. Garg and R. J. Ackermann, Met. Trans 8A, 239 (1977). 2R. Hultgren, P. D. Desai, et al., "Selected Values of the Thermodynamic Properties of the Elements," American Society for Metals, Metals Park, Ohio, (1973).	2500 2500 0000 2600 2700 2800	(**) (**) (**)
 H. deBoer and J. D. Fast, Z. Anorg. Allgem. Chem. 187, 193 (1930). B. Skinner, C. W Beckett and H. L. Johnston, Ohio State University, Tech. Rept. No 102–AC49/1–100–3, (1950). B. Litton, J. Electrohem. Soc. 98, 488 (1951). H. K. Adenstedit, Trans. A. S. M. 44, 949 (1952). 	320000000000000000000000000000000000000	() () ()
 ¹F. H. Spedding, U. S. AEC Rept. ISC-531, (1955). ²D. K. Deardorff and E. T. Hayes, Trans. AIME 206, 509 (1956). ³V. K. Gregorovitch, Izvest. Akad. Nauk SSSR, Otdel. Tekhn. Nauk Met. 1 Toplivo (6), 93 (1960). ³D. Alaylov, B. J. Kagle and N. J. Doyle, J. Less-Common Metals 5, 26 (1963). ³C. Ackermann and E. G. Rauh, High Term. Sci. 4, 272 (1972). 	3500 3500 3700 3800 3900	مارسة ليبارس ليبارس
¹² M. M. Martynyuk, Zh. Fiz. Khim. 51 , 1199 (1977). ¹³ R. J. Ackermann and E. G. Rauh, J. Chem. Thermodyn. 4, 521 (1972).	24 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	յ այտոտոյա ա
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Vaporization Data

Hafnium (Hf)

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0	0.	0	INFINITE	-5.842	ó	Ö	Ö
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ଧ	25.110	39,086	-43.979	-1.223	ó	ó	Ö
298.15	25.687	43.560	43,560	o i	o ·	ď	Ó
38	26247	43.719	43.560 43.875	1347	ರರ	ರ ರ	o o
8 8	26.751	54.439	44.581	2.672	o o	o o	o c
808	27.692	57.332	46.543	5.394	ó	ာ်ဝံ	Ö
88	28.583 29.445	62.460 66.932	48.780 51.060	8208	0 0	o' c	o c
8	30.288	70.919	53.298	14097	id	Ö	Ö
88	31.943	77.856	55.439 57.535	20,320	ာ် ဝေ	ರ ರ	ာ် တံ
86	32.759	80.938	59.524	23.556	oʻ c	Ö	Ö
300	34.372	86.543	63.258	30.270	ó	ာ်ဝံ	0
80 <u>8</u>	35.064 35.765	89.115 91.558	65.014 66.703	33.741 37.283	ರ ರ	ರ ರ	00
000	36,466	93.889	68,330	40.894	Ö	ó	Ö
88	37.868	98.265	71.416	48.328	ರ ರ	o o	್ ರ
1900	38.569	100,331	72.884	52.149	oʻ c	o o	Ö
2054.000	39.648	103.378	75 057	58.172		о. ЭНА <> ВЕТА	
2054.000	33.959	106.255	75.057	64.080]	TRANSITION	<u> </u>
2100 2200	35,307	107 011	75.749	65.652	o c	00	000
2300	36.231	110.222	78.608	27.73	60	o	ó
288	38.077	113.353	81.262	76.283 80.228	ರ ರ	ဝဝ	o o
2500.000	38.077	113,353	81.262	80.228	BETA	A <> LIQUID	Q
2600	37.656	126.545	82.976	113.281		0	ď
202	37.656	127.966	84.616	117.047	i oʻ c	i oʻ	io
2800	37.656	130.657	87.699	124.578	ာ်ဝ	óó	jĢ
900	37.656	131.934	89.153	128.344	oʻ	o ·	0
3200	37.656 37.656	134,364	90.553	132.109	ರ ರ	ợ ơ	00
3300	37.656	135.523	93.208	139.641	ó	ó	00
3200	37.656	137.739	95.690	143.400	ာ် ဝ	ာ်ဝံ	o o
3600	37.656	138.799	96.872	150.937	o c	Ö	0,0
888	37.656	140.835	99.133	158.469	ó	ೆರ	ö
3300 4000 0000	37.656 37.656	141.814	100.215	162 234	ဝံင	o' c	o c
4100	37.656	143.697	102.291	169.765	ó	i o	Ö
88	37.656	45.490	104.258	173.531	o o	o c	o
95	37.656	146356	105.205	181,062	io	io	io
960	37.656	148,030	107.031	188.593	င်င	o c	o c
4700	37.656	148.840	107.912	192.359	ioi	ó	0
864 9064	37.656	150 409	108.773	198.125	ರ ರ	00	00
4963.793	37.656	150.896	110,142	202.292	. 1	FUGACITY - 1 bar	İ
2000	37 656	151.170	110,438	203.656	-560.219	4.086	-0.043
2100	37 656	151 915	111 244	207.421	-560.290	15.373	-0.157
2300	37.656	153,364	112.807	214.953	-560.568	37.953	-0.268
5400	37.656	154 068	113.564	218 718	-560.776	49.248	-0.476
200	7376						•

Refer to the individual tables for details.

crystal, alpha crystal, beta liquid

0 to 2054 to above

Ar = 178.49 Hafnium (Hf)

Hf (cr,l)

CRYSTAL(α—β)-LIQUID

Hafnium (Hf)

$\Delta_t H^0(0 \text{ K}) = 618.0 \pm 6.3 \text{ kJ} \cdot \text{mol}^{-1}$ E. $\Delta_t H^0 = (298.15 \text{ K}) = 618.4 \pm 6.3 \text{ kJ} \cdot \text{mol}^{-1}$
₹8

A_r = 178.49 Hafnium (Hf)

IDEAL GAS

K ⁻¹ ·mol ⁻¹			$\Delta_i H^\circ = (298.$	$\Delta_t H^{\circ}(0 \text{ K}) = 618.0 \pm 6.3 \text{ K}$ $\Delta_t H^{\circ} = (298.15 \text{ K}) = 618.4 \pm 6.3 \text{ K}$
	Electronic State	Electronic Levels and Quantum Weights State e., cm ⁻¹ 8,	eights 8,	
	F2	000	S	
	ች	2356.68	7	
	řτ	4567.64	6	
		53853.61		
	2	\$4700		

Enthalpy of Formation

There are six sublimation studies and two vaporization studies from which an enthalpy of formation for Hf(g) could be derived. A plot of these vapor pressure data, log p vs 1/7, reveals considerable discrepancy between the various studies. In the liquid region, the vapor pressure values of Koch et al 1 and Ackermann and Rauh? are in close agreement. The pressures of the former study are 5% higher at 2500 K but so that at the observed melting point the temperature would be 2500 K. The sample purity was not stated. In the latter study² the reported become 10% lower at 2800 K. The measured temperatures in the former study' were adjusted (i.e., the pyrometer reading) by Koch et al. vapor pressures were corrected pressures (assuming ideal solution) from a eutectic of Hf and W. The Hf sample had a measured melting point of 2464 K; the purity was not reported.

agreement. The pressures of Panish and Reif are 60% above these three studies, 245 there is considerable scatter with one distinctly low The sublimation studies of Golubtsov and Mikul'skaya3 and Ackermann and Rauh2 spanned a temperature range which involved the aand B-phases of hafmium, yet neither study mentioned the characterization of the condensed phase. The study of Golubssov and Mitul'skaya3 is not considered further since their reported vapor pressure equation is ambiguous and cannot be easily modified to yield reasonable vapor pressures. In general terms, the sublimation pressures of Ackermann and Rauh, 2 Kibler et al. 4 and McClaine and Blackburn 4 are in reasonable pressure point at 2113 K. On the other hand, the results of Trulson et al. 7 are substantially lower by 50% than the three studies 444 with two

on the reasonable consistency of the two vapor pressure studies²⁴ with each other and with our adopted thermodynamic functions as evidenced by the small values of the drift. Hultgren et al., I using different thermodynamic functions and data available through 1966, recommended an enthalpy of formation of 148.0 \pm 1.0 kcal·mol⁻¹ based heavily on the study by Kibler et al. Other values for $\Delta_t H^0$ (298.15 K), also derived from vapor pressure studies, have been reported by Krupka, Krikorian and Kibler et al. 11 A 2nd and 3rd law analysis is given in the following table We adopt D.H" (Hf. g. 298.15 K) = 147.8 ± 1.5 kcal·mol-1. This result is based

			i		Δ,H°(298.15 K	1,H°(298.15 K), kcal·mol-1	Drift A	Drift A.H" (298.15 K)
Source (Year)	Reaction* Pts	F.	7.K	Method	2nd law	3rd law	cal·K-1·mol-1 kcal·mol-	kcal·mol-1
Kibler et al. (1963)11	Y	8	2035-2325	Langmuir	141.5 ± 2.4	143.4 ± 0.5	0.9 ± 1.1	147.8
Panish and Reif (1963)6	∢	9	2066-2274	Langmuir	160.3 ± 15.5	140.9 ± 2.7	-9.0 ± 7.2	145.4
McClaine (1964)6	∢	2	2200-2363	Langmuir 1	124.3 ± 5.7	144.5 ± 1.3	8.8 ± 2.5	149.0
Trulson et al. (1965)7	∢	12	2075-2273	Knudsen	145.1 ± 4.2	145.9 ± 0.7	0.4 ± 1.9	150.4
Ackermann and Rauh (1972) ²)² A	EG EG	1950-2464	mass eff.	145.4	143.6	-0.8	148.0
Koch et al. (1968)	B	17	2500-2810	Langmuir	131.6 ± 3.4	136.9 ± 1.2	2.0 ± 1.3	147.9
Ackermann and Rauh (1972)2)² B	EG.	1464-2800	mass eff.	140.1	136.7	-13	147.8
*Reaction. A) Hf(\(\beta\),cr) = Hf(\(\beta\))	f(β,cr) = Hi	(8)	B) Hf(l) = Hf(g)		Two points d.	iscarded due to	Two points discarded due to a statistical test.	

Heat Capacity and Entropy

added near the ionization limit. The calculations indicate that for Hf(g) the thermodynamic functions up to at least 3000 K are independent of the estimated missing levels (for n = 6 and 7), the cut-off procedure, and the inclusion of n = 7 levels. At this temperature there are no The electronic energy levels are given in the compilation by Meggers and Moore. 12 Although we have listed only the ground state, the lowest two excited states, the highest observed excited state (below the ionization potential), and the ionization potential for Hf(g), all levels listed by Meggers and Moore, ¹³ as well as estimated levels (for n = 5,6,7), are used in the calculation. The 233 observed levels, two of which lie above the ionization potential, are too numerous to list completely. In our calculations, the missing levels for n = 6 and 7 have been arbitrarily experimental heat capacity enthalpy, or vapor pressure data. The Gibbs energy function is essentially unaffected up to 5500 K.

¹R. K. Koch, W. E. Anable and R. A. Beall, U. S. Bur. Mines RI-7125, 24 pp. (1968).
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Hf₁(g)

Hafnium (Hf)

Continued on page 1371

	Enthalpy Reference		Temperature	- T, - 298.15 K		Standard State Pressure		p° = 0.1 MPa
	тÆ	ย		-H'(T,)]/T	$H^{\bullet}-H^{\bullet}(T_t)$	Librard'	Δ,G•	log Kr
	٥٥	0,		INFINITE	-6.198	618.040	618.040	INFINITE
	88	20.786	178.596	188.799	-2.041	618.816	589.809 587.809	-154.042
	298.15	20.803		186.897	0	618.395	575.659	-100.853
	88	20 804 20.854	187.026	186.898	0.038	618.386	575.394	-100.185
	\$ \$	20.960	193.027	187.715	2125	617.848	561.142	-73.278
	8	21.397	197.745	189,265	4.240	617.241	547.034	-57.148
	88	22 113 23.012	201.706	191.017 192.797	6.414 8.669	616,600 615,954	533.053	-46.406 -38.742
	88	23.991 24.978	208.317	194.544	11.019	615.317	505.398	-32.999
	000	25.925	213.881	197.868	16.013	614.088	478.062	-24.971
	28	26.806	216.394	199.439	18.650	613.490	464.489	-22.057
	8	28.305	220.999	202.409	24.167	612.293	437.500	- 17.579
	8 <u>8</u> 8	28.912 29.424	225.132	203.813	27.029 29.947	611.683	424.077	-15.823
-	009	29.847	227.045	206.476	32,911	610.412	397.362	-12.973
	88	30.465	230.599	208.962	38.947	609.014	370.813	-11.801
	0 2 2 2 3 3 3 3	30.681 30.852	232.252	210.144	42.004 45.081	608.250	357.600	-9.831
_	2100	30.986	235,339	212.399	48.174	600.917	331.429	-8.244
_	2002	31.095	236.783	213.475	51.278	600537	318.605	-7.565
	2400	31.270	239.496	215.532	57.515 60.646	599.528	293.017	637
	2600	31.436	242.006	217.473	63.785	568.899	268.702	-5.398
	2700	31.528	243.194	218.404	66.933	568.282	257.168	-4.975
	888	31.750	245.454	220.192	73.260	267.077	234.166	-4218
	3100	32.037	247.581	221.891	79 638	\$65.00	211 246	-3.50
	3300	32.208	248.601	222.710	82.850	565.370	199 814	-3.262
	3400	32.610 32.841	250.565	224.291	89 330	564319	176.999	-2719
	3600	33.090	252.442	225.803	95.899	563.357	154.243	-2.238
	3,00	33,359	253.352	226.536	922	562.914	142.885	-2017
	0 0 0 0	33.948	255.124	227.957	105.951	562.112	120.203	01971
	4100	34.602	256.837	229.324	112.805	561.435	97.559	-1.243
	2 2 2 2 3 3 3 3 3	35,313	258.502	230.642	116.282	561.147	86.248	-1.073
	4400 4500	35.688	259.318	231.285	123.345	560.678 560.503	63.645	-0.756
	000 000 000 000	36.471	260.921	232.539	130.561	560.362	41.061	-0.466
	88 80 80 80 80	37.294	262.491	233.754	137.936	560 207	18.486	505
	4963.793	37.996	263.754	234.723	144.102	FUG	FUGACITY = 1 bar	100
	2000	38.154	264.031	234,934	145.481	o	ö	0
	\$200 \$200	38.595 39.044	265.544	235.512	149.318	o c	o c	o c
_	2300	39.501	266.292	236.646	157.127	ö	်ဝ	ó
	2800	40.434 40.434	267.035 267.773	237.202 237.751	161.100 165.120	တံ တံ	o o	ರ ರ
	2600	40.910	268.505	238.293	169.187	o'	ó	Ö
	2800	41.879	269.234 269.958	238.830 239.360	173,302	0 0	ರ ರ	ರ ರ
	0000	42.372 42.870	270.678 271.394	239.885 240.404	181.678 185.940	o o	ರ ರ	ರರ
	PREVIOUS N	March 1979	(1 atm)			5	CURRENT March 1979	h 1979 (1 bar)

 $S^{(298.15 \text{ K})} = 186.897 \pm 0.2 \text{ J}$

 $IP(Hf, g) = 54700 \pm 600 \text{ cm}^{-1}$

Hafnium (Hf)

CURRENT: March 1984 (1 bar)

-5.374 -5.061 -4.471 -4.236

-4.083 -3.935 -3.792 -3.654 -3.520

(Hff)	
<u></u>	
Hafnium,	

PREVIOUS: March 1979 (1 atm)

Hafnium, Ion (Hf*)		IDEAL GAS	M _r = 178.48945 Hafnium, Ion (Hf [*])	Hafnium,	lon (Hf ⁺)	_					Hf;(g)	=
IP(Hf', g) = $120000 \pm 1000 \text{ cm}^{-1}$ $S^{\circ}(298.15 \text{ K}) = 185.040 \pm 0.01 \text{ J·K}^{-1} \cdot \text{mol}^{-1}$			$\Delta_t H^{\circ}(0 \text{ K}) = 1272.4 \pm 4.0 \text{ kJ} \cdot \text{mol}^{-1}$ $\Delta_t H^{\circ}(298.15 \text{ K}) = [1278.950] \text{ kJ} \cdot \text{mol}^{-1}$	Enthalpy R	eference Te	mperature	Enthalpy Reference Temperature = T, = 298.15 K		tandard Stat	e Pressure -	Standard State Pressure = p° = 0.1 MPa k1·mol ⁻¹	F
	Electronic I	Moister Weight		7,8	ដ	S -[G	$S^{\bullet} - [G^{\bullet} - H^{\bullet}(T_{\bullet})]T$	$H^{\bullet}-H^{\bullet}(T_t)$ $\Delta_t H^{\bullet}$	Δ _r H•	ΦC_{\bullet}	log Kr	
	State	State		٥	ó		INFINITE	-6.197	1272.397			
		4,		8	20.786	162,333	203.521	-4.119				
	ָבָ בַּ	0.00		500	20.786	176.741	186.942	-2.040				_
	, c	00000		ន្ត	20.786	181.379	185.382	1001-				
	C.	3030.88		298.15	20.786	185.040	185.040	ó	1278.950	1230.512	-215.581	
				300	20.786	185.169	185.041	0.038	1278.979	1230.212	-214.199	
	•			350	20.786	188.373	185.294	1.078	1279.758	1222 022	-182.377	
		•		400	20.786	191.149	185.856	2.117	1280.512	1213.722	-158.496	
		83170 8		420	20.786	193.597	186.583	3.156	1281.241	1205,329	-139.911	
		0.67100		Š	20.786	195.787	187.396	4 195	1281 946	1106.857	-125.035	_

Enthalpy of Formation

ΔH°(HΓ', g 0 K) is calculated from ΔμP°(Hf, g, 0 K)¹ using the spectroscopic value of IP(Hf) = 54700 ± 600 cm⁻¹ (654.358 ± 1.18 kJ·mol⁻¹) from Meggers and Moore.² The ionization limit is converted from cm⁻¹ to kJ·mol⁻¹ using the factor, 1 cm⁻¹ = 0.01196266 kJ·cm⁻¹, which is derived from the 1973 CODATA fundamental constants.³ Rosenstock et al.⁴ and Levin and Lias⁵ have summarized additional

-102.703 -86.735 -74.748 -65.417 -51.828 -46.777 -42.408 -38.703

-32.680 -30.198 -27.991 -26.015

ionization and appearance potential data. $\Delta H'(Hf, g, 0 \text{ K})$ by using IP (Hf) with JANAF¹ enthalpies, H'(0 K)-H'(298.15 K), for Hf(g), $\Delta H'(Hf, g, 298.15 \text{ K})$ at each a room temperature threshold energy due to inclusion of these enthalpies and to threshold effects discussed by Rosenstock *et al.* $^4\Delta_H''(298.15 \text{ K})$ should be changed by $-6.197 \text{ kJ-mol}^{-1}$ if it is to be used in the ion convention that excludes the enthalpy of the electron.

Heat Capacity and Entropy

The electronic energy levels are given in the compilation by Moore. Although we have listed only the ground state, the first excited state, the highest observed excited state, and the ionization potential for Hf'(g), all levels listed by Moore, as well as estimated levels (for n = 6and 7), are used in the calculation. The 121 observed levels are too numerous to list completely. In our calculations the missing levels for n=6 and 7 have been arbitrarily added near the ionization limit. The calculations indicate that for Hf'(g) the thermodyanmic functions up energy function is unaffected up to 10000 K. The reported uncertainty in 5°28 is due to uncertainties in the gram formula weight and the fundamental constants. Extension of these calculations above 6000 K may require consideration of the higher excited states (n-7), more precise estimation of the missing levels (for all n), and utilization of proper fill and cut-off procedures. to 5000 K are independent of the estimated missing levels (for n = 6 and 7), the cut-off procedure, and the inclusion of n=7 levels. The free

JANAF Thermochemical Tables: Hf(g), 3-31-84, e-(g), 3-31-82.

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R. Downey, Jr., The Dow Chemical Company, Thermal Research, AFOSR-TR-78-0960, (March 1978).

1179.711 1162.347 1144.810 1127.130 1091.442 1073.469 1055.429 1037.334 1019.192 982.797 982.797 984.254 994.234 994.234 998.830 891.808 873.733 8875.273 8875.273 8875.273 877.573 769.429 735.219 7018.054 683.645 666.376 649.066 641.712 614.312 596.863 561.816 544.214 526.558 508.846 491.077 473.250 455.365 437.420 419.416 405.438 398.601 391.704 384.751 377.740 370.675 363.555 356.382 349.157 341.882 334.558 1201.745
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CURRENT: March 1984 (1 bar)

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PREVIOUS: March 1979 (1 atm)

$\Delta_t H'(0 \text{ K}) = 618.040 \pm 6.3 \text{ kJ·mol}^{-1}$ $\Delta_t H''(298.15 \text{ K}) = [612.1971 \text{ kJ·mol}^{-1}]$	Enthalpy R	eference To	I-K-'mol-'	Enthalpy Reference Temperature = $T_r = 298.15 \text{ K}$ $1.\text{K}^{-1} \text{mol}^{-1}$		Standard State Pressure = $p^* = 0.1 \text{ MPa}$ k1·mol ⁻¹	Pressure = 1	p° = 0.1 MPa
	7,8	ប	S - [G	-[G*-H*(T,)]/T	$H^{\bullet}-H^{\bullet}(T_{\tau})$	Δ,Η*	Φ_G	log K,
	° 22 23	0. 20.786 20.786 20.786	0. 162.333 176.741 181.379	INFINITE 203.521 186.942 185.383	-6.197 -4.119 -2.040 -1.001	618.040		
	298.15	20.786		185.040	ó	612.197	576.270	-100.960
	330	20.786 20.786	185.169	185.041	0.038	612.150	576.047	-100.299
= ~0 0 eV. This value, recommended	\$ \$ \$	20.786 20.786	193.597	185.856 186.583	3.156	609.526 608.176	558.846	-73.704
(A) and (A) and (A) and (A) and (A)	88	20.786	199.577	189.120	6274	603.989	543.028	-47.275
the form of these entralies	88	20.786	205.781	192.517	8.333 10.431	598.101	533.096 523.586	-39.780
kJ·mol ⁻¹ if it is to be used in the ion	88	20.786 20.786	208.005 210.195	194.105 195.606	12.510 14.589	595.030 591.877	514.455 505.671	-29.858
	1100	20.786 20.786	212.176 213.984	197.024 198.363	16.667	588.642 585.325	497.206	-23.610
tock et al. ³ Lacking any experimental	1400	20.786 20.786	215.648 217.189	199.629 200.829 201.968	20.824 22.903	581.928 578.456 574.015	481.153	-19.333
3. (-0	091	20.786	219.964	203.052	27.060	571.303	459.026	-14.986
	886	20.786	222.412	205.069	31.217	563.870 863.870	445.435	-13.892 -12.926 -12.068
	2000	20.786	224 602	206.915	35.375	526.156	432.687	-11301
	2200	20.786	225.617 226.584	207.782 208.615	37.453 39.532	546.546 543 061	426.740 421.116	-10.615
	7,400 7,400 7,400	20.786 20.786	227.508	209 416 210.188	41.610	539 484	415.653	-9.440 -8.931
	000	20.786	230.056	210.934	45.768	076.166	405.198	-8.466 -8.064
	2700	20.786	230.840	212.350	\$5.55	495.150	397.693	-7.694
	3000	20.786	232,326	213.677	\$4.082 \$6.161	487 619	390.747	-7.038
	3100	20 786	233.712	214.925	58.239	480.088	384.320	-6.476
	3300	20.786	234,372	215.523	60.318 62.397	476.322 472.557	381.290 378.379	-6.224 -5.989
	3400 3500	20.786 20.786	235.632 236.235	216.669 217.219	64.475 66.554	468.791 465.026	375.581 372.895	-5.770 -5.565
	3600	20.786	236.820	217.756	68.632	461.260	370.316	-5.373
	3800	20 786	237.944	218.789	22.79	453.729	365.469	-5.024
	4000	20.786	239.010	219 774	76.947	446.198	361 018	-4.714
	4100 4200	20.786 20.786	239.524 240.024	220.249 220.714	79.025 81.104	442.432 438.666	358.936 356.945	-4 <i>5</i> 73 -4 439
	4400	20.786 20.786	240.514	221.169	83.183	434.901	355.043	-4.313 -4.193
	4600	20.786	241.915	222.477	89.418	423.604	349.857	-4.080
	4700	20.786	242.362	222.895	91.497	419 838	348.294	-3.871
	\$000 \$000	20.786	243.229	223.707	95.654	412.307 -151.677	345.408	-3.682 -3.637
	5200	20.786	244 060 244 464	224.489	99,811	-155.514	358.202	-3.669
	5300 5400	20.786	244.860 245.248	225.243 225.610	103.969	-163,324 -167,297	378.499	-3.760
	2800	20.786	245.630	225.970	108.126	-171317	399.093	-3 790
	5700 8700 8700 8700 8700	20.786	246.372	226 673	112.283	-173.84	419.982	-3.849 -3.849
	28009	20 786 20 786	247.089 247.438	227.353 227.353 227.685	116.440	-183.802 -187.874 -192.136	450.333 441.161 451.858	-3.877 -3.906 -3.934

EA(Hf, g) = 0.0 eV S°(298.15 K) = $185.040 \pm 0.002 \text{ J·K}^{-1} \cdot \text{mol}^{-1}$

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Electonic Level and Quantum Weight State

80

F.

M; = 178.49055 Hafnium, Ion (Hf⁻)

IDEAL GAS

Hafnium, Ion (Hf⁻)

 $\Delta H^{\circ}(H\Gamma, g, 0 \text{ K})$ is calculated from $\Delta H^{\circ}(Hf, g, 0 \text{ K})^{1}$ using the adopted electron affinity of EA(Hf) = by Hotop and Lineberger, 2 is based on a semiempirical extrapolation. 3 Additional information on HΓ(g) discussions of Hotop and Lineberger, 2 Rosenstock et al. 3 and Massey. 6 $\Delta H^{\circ}(H\Gamma$, g, 298.15 K) is obtained from $\Delta_{i}H^{\circ}(Hf$, g, 0 K) by using EA(Hf) with JANAF' enthalpies, Hf(g), and e (ref). $\Delta_{i}H^{\circ}(H\Gamma \to Hf + e^{-}$, 298.15 K) differs from a room–temperature threshold energy and to threshold effects discussed by Rosenstock *et al.* $^{3}\Delta_{i}H^{\circ}(298.15 \text{ K})$ should be changed by +6 197 k

Heat Capacity and Entropy

convention that excludes the enthalpy of the electron.

The ground state electronic configuration for HF(g) is given by Hotop and Lineberger^{2,4} and Rosensto evidence as to the stability of any excited states, we assume that no stable excited states exist.

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Refer to the individual tables for details.

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