Argonne National Laboratory

A SURVEY OF THE FREE ENERGIES OF
FORMATION OF THE FLUORIDES, CHLORIDES,
AND OXIDES OF THE ELEMENTS TO 2500°K.

by
Alvin Glassner

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ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

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CHEMICAL ENGINEERING DIVISION

August 1953

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A renewed interest in pyrometallurgical methods for separations processes has prompted a survey of the free energies of formation of oxides, fluorides, and chlorides in the range from 298°K. to 2500°K. With the aid of free energy tables it is possible to make estimates of the values of the equilibrium constants for various reactions which may be under consideration.

The free energies of formation presented here have been calculated with the aid of the free energy functions

$$(F - H_{298})/T$$

for the compound and its constituent elements, together with a knowledge of ΔH_{298} , to give

$$(\Delta F - \Delta H_{298})/T$$

Here

T = the absolute temperature

F = the free energy at temperature T

H_{298} = the heat content at 298.16°K.

ΔH_{298} = the heat of formation at 298.16°K.

The free energy functions themselves have been calculated from values of the heat capacities at constant pressure, the entropies at 298.16°K., and latent heats of transformation. Thus

$$(1) \quad \frac{F - H_{298}}{T} = \frac{1}{T} \left(\int_{298}^T C_p dT + \sum \Delta H_{tr} \right) - \left(\int_{298}^T \frac{C_p}{T} dT + S_{298} + \sum \frac{\Delta H_{tr}}{T_{tr}} \right)$$

where C_p = the heat capacity at constant pressure
 S_{298} = the entropy at 298.16°K.
 ΔH_{tr} = the latent heat of transformation
 T_{tr} = the absolute temperature of transformation.

When available, the heat capacities used have been obtained from experimental data reported in the literature up to May, 1953. The heat capacities at temperatures beyond the range of experimental determination were estimated by extrapolation and analogy with similar compounds whose heat capacities are known. Where this was not possible, approximations were made by rules summarized by Kubaschewski and Evans.¹ Similarly, when not given values of the entropy at 298°K. were estimated by empirical rules.¹⁻³

The results of the survey have been summarized in Table 1. Superscript letters indicate the references from which the particular values were taken. The data have been arranged alphabetically in Table 1 in accordance with the symbols for the various elements. Values are given first for chlorides, then fluorides, and finally oxides.

The data have also been presented in terms of free energy versus temperature diagrams for the various groups of the Periodic Table in Figure 1 for chlorides, in Figure 2 for fluorides, and in Figure 3 for oxides. The free energy has been plotted on the basis of kcal. per gram-atom of non-metal, rather than on the usual basis of kcal. per mole, so that a visual comparison makes immediately evident the order of stability of the various compounds at a given temperature. The advantages of this type of plot have been discussed by Kellogg.⁴ In these graphs the symbols M for melting point, B for boiling point, and S for sublimation point of the compound have been employed. At these and other transformation points, changes in slope occur in the generally linear curves. Solid lines represent free energies based on experimental heat capacities, whereas the dotted lines represent the regions where approximations have been made.

¹O. Kubaschewski and E. Evans, Metallurgical Thermochemistry, Academic Press, New York, N. Y., 1951, Chapter III.

²R. R. Wenner, Thermochemical Calculations, McGraw-Hill, New York, N. Y., 1941, Chapter VIII.

³W. M. Latimer, "Methods of Estimating the Entropies of Solid Compounds," J. Am. Chem. Soc., 73, 1480 (1951)

⁴H. H. Kellogg, "Thermodynamic Relationships in Chlorine Metallurgy," J. of Metals, 188, 862 (1950).

In general, the agreement with previously published compilations⁴⁻⁸ is good. In those cases at higher temperatures where divergences do occur, the differences result from alternate choices for estimated heat capacities or other thermal data.

⁵H. H. Kellogg, Ibid, 191, 137 (1951).

⁶L. Brewer, et al, "The Thermodynamic Properties of the Halides," The Chemistry and Metallurgy of Miscellaneous Materials, L. L. Quill, ed., McGraw-Hill, New York, N. Y., 1950.

⁷M. de Kay Thompson, The Total and Free Energies of Formation of the Oxides of Thirty-Two Metals, Electrochemical Soc., New York, N. Y., 1942.

⁸F. D. Richardson, "Thermodynamics of Substances of Interest in Iron and Steel Making from 0°C. to 2400°C," J. Iron and Steel. Ind., 160, 261 (1948).

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal./mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal./mole	Heat of Evaporation at B. Pt., kcal./mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal./mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Ag	----	----	10.206 ^a	2.70 ^a	60.72 ^a	1234 ^a	2485 ^b	c	1600	----	----	----	----	----	----
	AgCl	- 30.362 ^a	22.97 ^a	3.16 ^a	42.5 ^d	728 ^a	1837 ^d	c	900	- 26.2	- 23.6	- 19.4	- 17.0	- 18.0	- 26.0
	AgF	- 48.7 ^e	20.5	1.4	32.7	708 ^a	1420 ^f	-	----	- 44.2	- 41.8	- 37.6	- 36.3	- 44.6	- 50.8
		(est.)	(est.)	(est.)											
	AgF ₂	- 50.3 ^e	25 ^e	----	----	>963 ^f	----	----	----	- 40	- 33	- 18	----	----	----
Al	----	----	6.769 ^a	2.6 ^a	67.9 ^a	931.7 ^c	2600 ^a	d	1000	- 2.6	+ 2.4	+ 17.1	----	----	----
	AlCl(g)	- 11.6 ^d	54.2 ^d	----	----	----	----	d	2000	- 17.8	- 21.9	- 31.1	- 38.6	- 45.6	- 52.6
	AlCl ₃	-166.2 ^a	36.9 ^d	----	13.4	----	453.3 ^a	d	1800	-151.4	-142.9	-133.5	-122.7	-111.4	-101
			(subl.)	(subl.)	(subl.)	(subl.)	(subl.)								
	AlF	-102 ^e	15.5	7.0	36.5	1100 ^f	1650 ^f	-	----	- 97	- 94	- 87	- 81	- 84	- 90
As	----	----	8.4 ^a	----	7.75 ^a	----	883 ^a	d	1090	----	----	----	----	----	----
	AsCl ₃ (1)	- 72.0 ^d	55.8 ^a	2.42 ^a	7.5 ^a	257 ^a	395 ^d	d	371	- 61.8	----	----	----	----	----
	AsF ₃ (1)	-198.3 ^d	50.1 ^d	2.486 ^a	8.6 ^d	267.21 ^a	336 ^d	d	336	-191.1	-188	----	----	----	----
	AsF ₅ (g)	----	----	2.75 ^d	4.98 ^f	193 ^d	220 ^f	-	----	----	----	----	----	----	----
	As ₂ O ₃	-156 ^g	25.6 ^d	4.0 ^d	7.15 ^d	586 ^d	730 ^d	d	548	-137.7	-124.7	----	----	----	----
Au	----	----	11.4 ^a	3.03 ^a	74.21 ^a	1336.16 ^a	2933 ^a	c	1600	----	----	----	----	----	----
	AuCl	- 8.4 ^a	24 ^e	----	----	----	1600 ^f	-	----	- 4.2 ^e	- 1.4 ^e	+ 3 ^e	----	----	----
	AuCl ₂	- 18.1 ^a	36 ^e	----	----	----	1200 ^f	-	----	- 9.5 ^e	- 4 ^e	----	----	----	----
	AuCl ₃	- 28.3 ^a	44.5	1.5	----	561 ^f	700 ^f	-	----	- 14.3	- 5.1	+ 3 at 700°K.	----	----	----
		(est.)	(est.)	(est.)											
	AuF	- 18 ^e	23 ^e	----	----	----	----	-	----	- 14 ^e	- 12 ^e	- 9 ^e	----	----	----
	AuF ₂	- 57 ^e	32 ^e	----	----	----	----	-	----	- 47 ^e	- 41 ^e	----	----	----	----
	Au ₂ O ₃	- 11 ^d	30 ^a	----	----	----	----	-	----	----	----	----	----	----	----

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TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
B	----	----	1. 7 ^d	----	----	2573 ^d	2800 ^f	c	1200	----	----	----	----	----	----
	BCl ₃ (g)	- 94. 5 ^a	69. 29 ^a	0. 5 ^f	5. 682 ^f	166 ^f	285. 6 ^f	d	1000	- 90. 8	- 88. 4	- 82. 4	- 76. 3	- 69. 9	- 63. 7
	BF ₃ (g)	-273. 5 ^e	60. 70 ^a	1. 0 ^a	4. 3 ^a	144. 5 ^a	174 ^a	d	1000	-269	-266	-259	-251	-245	-237
	B ₂ O ₃	-305. 4 ^g	13. 0 ^d	5. 50 ^c	40 (est.)	723 ^a	1773 ^d	c	1800	-286	-274	-244	-219	-197	-182
Ba	----	----	16 ^a	1. 83 ^d	35. 7 ^a	983 ^d	1911 ^a	c	1000	----	----	----	----	----	----
	BaCl ₂	-205. 3 ^e	30 ^a	5. 37 ^f	50 ^f	1233 ^f	2100 ^a	d	1198	-193	-186	-168	-149	-133	-120
	BaF ₂	-286. 9 ^a	23. 0 ^a	3. 0 ^a	70 ^d	1593 ^a	2473 ^d	c	1300	-274	-266	-248	-229	-211	-189
	Ba ₂ O	-147 ^a	----	----	----	----	----	-	----	----	----	----	----	----	----
	BaO	-133 ^g	16. 8 ^a	13. 8 ^d	----	2196 ^g	3000 ^g	d	1500	-126	-121	-111	- 95	- 80	- 63
	BaO ₂	-150. 5 ^a	----	----	----	dec. 1110°K. ^g	----	-	----	-140 ^g	----	----	----	----	----
Be	----	----	2. 28 ^a	2. 3 ^a	53. 49 ^h	1556 ^a	3243 ^h	h	2000	----	----	----	----	----	----
	BeCl ₂	-112. 6 ^d	25. 6 (est.)	3 ^f	25 ^a	678 ^f	820 ^a	-	----	-104	- 98	- 92	- 98	-100	-105
	BeF ₂	-227 ^e	18 (est.)	6 ^f	40 ^f	1070 ^f	1600 ^f	-	----	-217	-211	-196	-185	-183	-183
	BeO	-147. 3 ⁱ	3. 37 ⁱ	17. 0 ⁱ	117. 0 ⁱ	2823 ⁱ	4533 ⁱ	i	1200	-140. 32 ⁱ	-135. 37 ⁱ	-123. 26 ⁱ	-111. 59 ⁱ	- 99. 46 ⁱ	----
Bi	----	----	13. 6 ^a	2. 63 ^a	41. 1 ^d	544. 2 ^a	1833 ^d	c	1300	----	----	----	----	----	----
	BiCl(g)	+ 10. 7 ^a	58. 9 ^a	----	----	----	----	-	----	5. 2 ^a	----	----	----	----	----
	BiCl ₃	- 90. 61 ^a	45. 8 ^d	2. 6 ^f	17. 35 ^a	502 ^f	714 ^a	-	----	- 76. 3	- 67. 1	- 54. 1	- 47. 6	- 32. 6	- 15. 4
	BiCl ₄	----	53 ^e	----	----	449 ^f	----	-	----	----	----	----	----	----	----
	BiF(g)	+ 7 ^a	----	----	----	----	----	-	----	----	----	----	----	----	----
	BiF ₂	----	31 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	BiF ₃	-212. 0 ^d	37. 0 (est.)	9. 1 (est.)	26. 5 (est.)	1000 ^a	1200 (est.)	-	----	-197	-188	-163	-166	-157	-140
	BiF ₄	----	44 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	BiO	-50 ^g	----	----	----	----	----	-	----	- 43. 5 ^g	----	----	----	----	----
	Bi ₂ O ₃	-138. 0 ^d	36. 2 ^a	6. 8 ^a	49. 7 (est.)	1090 ^a	1090 ^a	c	800	-119	-100	- 71	- 40	- 2	+ 10
C (graphite)	----	----	1. 3609 ^a	----	----	----	----	c	2300	----	----	----	----	----	----
	CCl ₄ (g)	- 25. 5 ^e	74. 2 ^e	0. 644 ^e	7. 283 ^e	249. 1 ^e	350 ^e	c	1000	- 15. 4 ^e	- 8. 7 ^e	----	----	----	----
	CF ₄ (g)	-164 ^e	62. 7 ^a	0. 167 ^a	3. 01 ^a	89. 47 ^a	145. 14 ^a	c	1200	-153	-146	-128	-109	- 89	- 77
	CO	- 26. 4157 ^a	47. 3 ^a	0. 2 ^a	1. 444 ^a	68. 10 ^a	81. 66 ^a	a	----	- 32. 8 ^a	- 37. 2 ^a	- 47. 9 ^a	- 58. 4 ^a	- 68. 5 ^a	- 78. 4 ^a
	CO ₂	- 94. 0518 ^a	51. 06 ^a	----	6. 031 ^a (subl.)	----	194. 68 ^a (subl.)	a	----	- 94. 3 ^a	- 94. 4 ^a	- 94. 6 ^a	- 94. 7 ^a	- 94. 7 ^a	- 94. 7 ^a

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Element	Compound	Heat of Formation at 298°K., kcal./mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal./mole	Heat of Evaporation at B. Pt., kcal./mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal./mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Ca	----	-----	9.95 ^a	2.2 ^a	38.6 ^d	1123 ^a	1963 ^d	d	1123	----	----	----	----	----	----
	CaCl ₂	-190.4 ^d	27.2 ^a	6.78 ^a	55 ^f	1055 ^a	2300 ^f	d	1700	-180	-173	-156	-140	-128	-115
	CaF ₂	-290.2 ^d	16.46 ^a	7.1 ^a	80 ^d	1691 ^a	2773 ^d	d	1800	-278	-269	-250	-230	-212	-190
	CaO	-151.9 ^a	9.5 ^a	12 ^a	-----	2873 ^a	3800 ^g	c	1800	-144	-140	-131	-114	-99.3	-79.4
	CaO ₂	-156.7 ^a	-----	-----	-----	dec.	548°K. ^g	-	-----	-72 ^g	-----	-----	-----	-----	-----
Cd	----	-----	12.3 ^a	1.45 ^c	23.87 ^f	594 ^c	1038 ^f	c	1100	----	----	-----	-----	-----	-----
	CdCl ₂	-93.00 ^a	31.2 ^e	5.3 ^a	29.4 ^a	841 ^a	1240 ^f	d	841	-82.7	-76.0	-60.7	-42.9	-35	-21
	CdF ₂	-164.9 ^a	27 ^a	5.4 ^a	53.8 ^d	1383 ^a	2023 ^d	-	-----	-155	-148	-132	-106	-85	-77
	CdO	-62.2 ^d	13.1 ^a	-----	53.8 ^a	-----	1832 ^a	d	2086	-55.1	-50.4	-37.6	-11.8	+2.0	+14.3
					(subl.)		(subl.)								
Ce	----	-----	13.8 ^b	2.1 ^a	73 ^b	1048 ^a	2800 ^b	c	800	-----	-----	-----	-----	-----	-----
	CeCl ₃	-260.0 ^d	43.0 ^d	8.0 ^f	46 ^f	1075 ^f	2000 ^f	-	-----	-245	-235	-211	-190	-182	-178
	CeF ₃	-416 ^e	29.0	9 ^f	62 ^f	1733 ^f	2600 ^f	-	-----	-399	-387	-360	-334	-313	-295
	CeF ₄	-442 ^e	41.0	10 ^f	44	1250 ^f	2000	-	-----	-421	-407	-374	-346	-324	-313
			(est.)		(est.)		(est.)								
	Ce ₂ O ₃	-435 ^g	30.7	22.5	-----	1960 ^a	-----	-	-----	-414	-400	-361	-321	-282	-249
			(est.)	(est.)											
	CeO ₂	-245.0 ^g	17.7 ^d	-----	-----	3000 ^g	-----	d	2500	-232	-223	-199	-175	-154	-129
Cl ₂	----	-----	53.286 ^a	1.531 ^a	4.878 ^a	172.16 ^a	239.10 ^a	a	----	-----	-----	-----	-----	-----	-----
Co	----	-----	6.8 ^a	3.66 ^f	93 ^f	1768 ^f	3370 ^f	c	1900	-----	-----	-----	-----	-----	-----
	CoCl ₂	-76.9 ^d	25.4 ^a	7.39 ^f	27.17 ^f	1000 ^f	1323 ^f	c	1000	-66.5	-59.9	-45.3	-39.7	-39.7	-38.4
	CoF ₂	-158 ^e	21.5	9 ^f	48 ^f	1475 ^f	2000 ^f	-	-----	-148	-141	-126	-113	-104	-106
			(est.)												
	CoF ₃	-190 ^e	29.5	12 ^f	40 ^f	1300 ^f	1600 ^f	-	-----	-175	-165	-142	-122	-116	-111
			(est.)												
	CoO	-57 ^g	10.5 ^a	9.6	-----	2078 ^a	-----	-	-----	-51	-47	-37	-27	-18	-11
			(est.)	(est.)											
	Co ₃ O ₄	-204 ^g	-----	-----	-----	dec.	1240°K. ^g	-	-----	-176.8 ^j	-161.8 ^j	-124.1 ^j	-84.7 ^j	-43.1 ^j	-----
Cr	----	-----	5.68 ^a	3.5 ^a	71.5 ^d	2173 ^a	2703 ^d	c	1900	-----	-----	-----	-----	-----	-----
	CrCl ₂	-94.56 ^a	27.7 ^e	7.7 ^a	47.5 ^d	1088 ^a	1573 ^d	d	1088	-85.3	-79.2	-64.8	-54.2	-57.6	-64.6
	CrCl ₃	-132.5 ^d	30.0 ^a	-----	56.8 ^f	-----	1220 ^f	c	1220	-116	-105	-78.7	-66.5	-65.1	-52.0
					(subl.)		(subl.)								
	CrF ₂	-182 ^e	25.0	5.5 ^f	60 ^f	1375 ^f	2400 ^f	-	-----	-173	-167	-154	-143	-135	-114
			(est.)												

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Element	Compound	Heat of Formation at 298°K., kcal./mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal./mole	Heat of Evaporation at B. Pt., kcal./mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal./mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Cr	CrF ₃	-266 ^e	29.0 (est.)	11 ^f	48 ^f	1373 ^f	1700 ^f	-	----	-251	-241	-219	-199	-193	-178
	CrF ₄	-286.5 ^d	38 ^e	5.5 ^f	14 ^f	550 ^f	570 ^f	-	----	-267	-254	-241	-230	-229	-202
	CrF ₅	----	50 ^e	----	8.5 ^f	375 ^f	390 ^f	-	----	----	----	----	----	----	----
	Cr ₂ O ₃	-269.7 ^a	19.4 ^a	----	----	2553 ^d	3273 ^d	c	1800	-250	-237	-206	-176	-144	-87
	CrO ₂	-141 ^g	----	----	----	dec. 700°K. ^g	----	-	----	-129 ^g	----	----	----	----	----
	CrO ₃	-138 ^g	17.2 ^d	----	----	460 ^g	----	-	----	-120 ^g	----	----	----	----	----
Cs	----	----	19.8 ^a	0.50 ^a	16.32 ^a	301.9 ^a	963 ^a	c	500	----	----	----	----	----	----
	CsCl	-106.2 ^d	22.04 ^k	3.60 ^a	35.69 ^a	918 ^a	1573 ^a	d	918	-98.9	-93.8	-80.9	-63.0	-55.8	-50.0
	CsF	-131.7 ^e	19.8 ^d	2.45 ^a	34.332 ^f	955 ^a	1524 ^f	d	955	-124	-119	-106	-87.3	-80.1	-72.7
	Cs ₇ O	----	----	----	----	276 ^a	----	-	----	<-66 ^g	----	----	----	----	----
	Cs ₄ O	----	----	----	----	dec. 283°K. ^g	----	-	----	<-66 ^g	----	----	----	----	----
	Cs ₇ O ₂	----	----	----	----	dec. 323°K. ^g	----	-	----	<-132 ^g	----	----	----	----	----
	Cs ₃ O	----	----	----	----	dec. 443°K. ^g	----	-	----	<-66 ^g	----	----	----	----	----
	Cs ₂ O	-75.9 ^a	26.7 (est.)	7 (est.)	35 (est.)	763 ^a	1500 ^g	-	----	-64.7	-56.5	-35.1	-3.6	+15.7	+36
	Cs ₂ O ₂	-102.5 ^d	----	----	----	867 ^d	----	-	----	----	----	----	----	----	----
	Cs ₂ O ₃	-135 ^g	----	----	----	775 ^g	dec. 1125 ^g	-	----	-120 ^g	----	----	----	----	----
	CsO ₂	-76 ^g	----	----	----	705 ^g	dec. 1153 ^g	-	----	-66 ^g	----	----	----	----	----
	Cu	----	----	7.97 ^e	3.11 ^a	72.8 ^a	1356.2 ^a	2855 ^a	c	1600	----	----	----	----	----
CuCl		-32.6 ^e	20.8 ^e	2.445 ^f	39.6 ^f	703 ^f	1963 ^f	c	2000	-28.5	-26.1	-22.0	-20	-18	-25
CuCl ₂		-53.2 ^d	30.7 ^d	5.5 (est.)	23 (est.)	903 ^d	1100 ^f	d	903	-43.1	-38.2	-25.7	-24.2	-24.0	-24.0
CuF		-60 ^e	17.5 (est.)	4.5 (est.)	35 (est.)	1181 ^l	1600 (est.)	-	----	-56	-53	-46	-41	-46	-52
CuF ₂		-128 ^e	27.1 ^d	6 ^f	41.5 (est.)	1200 ^f	1800 ^f	-	----	-119	-114	-101	-91	-87	-90
Cu ₂ O		-39.84 ^a	21.7 ^d	13.4 ^a	----	1502 ^a	----	d	1500	-34.2	-30.5	-21.7	-12.0	-6.6	-1.3
CuO		-37.1 ^a	10.4 ^a	13.3 ^d	----	1609 ^d	----	c	1250	-30.7	-26.1	-15.9	-5.7	+1.3	+7
F ₂	----	----	48.58 ^e	0.372 ^a	1.51 ^a	55.20 ^a	85.24 ^a	c	2000	----	----	----	----	----	----
Fe	----	----	6.49 ^a	3.7 ^c	84.62 ^f	1803 ^c	3008 ^f	c	1900	----	----	----	----	----	----
	FeCl ₂	-81.9 ^e	28.7 ^e	10.28 ^c	30.21 ^a	950 ^c	1299 ^a	c	1110	-72.6	-66.6	-53.3	-50.1	-53.1	-55.1
	FeF ₂	-168 ^e	23.5 (est.)	8 ^f	50 ^f	1375 ^f	2100 ^f	-	----	-159	-152	-138	-126	-116	-112

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal./mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal./mole	Heat of Evaporation at B. Pt., kcal./mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal./mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Fe	FeF ₃	-232.0 ^d	30	12 ^f	40 ^f	1300 ^f	1400 ^f	-	----	-217	-208	-186	-167	-162	-158
	FeO	- 63.7 ^a	(est.) 12.8 ^d	0.75 ^a	----	1641 ^a	----	c	1200	- 58.5	- 55.1	- 47.2	- 39.3	- 32.5	- 25.7
	Fe ₃ O ₄	-267.0 ^a	35.0 ^a	33.0 ^d	----	1870 ^d	----	c	1100	-242	-226	-188	-153	-122	- 95
	Fe ₂ O ₃	-197.1 ^g	21.5 ^a	----	----	dec. 1730°K. ^g	----	c	1100	-178	-165	-135	-106	- 79	----
Ga	----	----	10.2 ^a	1.336 ^a	----	302.7 ^c	2500 ^m	c	400	----	----	----	----	----	----
	GaCl	- 35 ^e	22 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	GaCl ₂	- 88 ^e	31.3	4	19 ^f	444 ^f	870 ^f	-	----	- 78	- 72	- 64	- 64	- 63	- 62
			(est.)	(est.)											
	GaCl ₃	-125.0 ^d	41.1	5.2 ^d	10.8 ^d	351 ^d	473 ^d	-	----	-110	-102	- 96	- 89	- 81	- 75
			(est.)												
	GaF	- 56 ^e	17 ^e	----	----	----	----	-	----	- 51 ^e	- 47 ^e	----	----	----	----
	GaF ₂	-165 ^e	24 ^e	----	----	----	----	-	----	-155 ^e	-147 ^e	-130 ^e	----	----	----
	GaF ₃	-255 ^e	30	----	37	----	1225 ^f	-	----	-239	-228	-202	-187	-179	-170
			(est.)		(subl., est.)		(subl.)								
	Ga ₂ O	- 82 ^a	20.7	6.3	----	700	>2500	-	----	- 75	- 68	- 53	- 42	- 30	- 20
Ge			(est.)	(est.)		(est.)	(est.)								
	Ga ₂ O ₃	-258 ^a	21.7 ^d	30	----	2013 ^a	>2500	c	923	-236	-220	-179	-147	-107	- 86
			(est.)	(est.)			(est.)								
	----	----	10.1 ^d	8.3 ^f	68 ^f	1232 ^f	2980 ^f	c	1232	----	----	----	----	----	----
	GeCl ₂	- 90 ^e	31 ^e	----	----	----	975 ^f	-	----	- 80 ^e	- 74 ^e	----	----	----	----
	GeCl ₄	-155.0 ^d	59.5 ^d	2.05 ^d	7.1 ^d	223 ^d	358 ^d	-	----	-138	-130	-113	- 96	- 76	- 58
	GeF ₂	-170 ^e	28 ^e	----	----	----	> 700 ^f	-	----	-161 ^e	-154 ^e	----	----	----	----
	GeF ₄ (g)	----	75.0 ^d	----	7.8 ^a	258.2 ^a	236.4 ^a	-	----	----	----	----	----	----	----
					(subl.)		(subl.)								
	GeO	- 61 ^g	13.6	----	60	----	983 ^a	-	----	- 55	- 51	- 42	- 61	- 79	- 96
			(est.)		(subl., est.)		(subl.)								
H ₂	GeO ₂	-128.6 ^g	12.5 ^d	10.5 ^d	----	1388 ^d	>2500	c	1368	-115	-105	- 82.4	- 59.2	- 38.2	- 18
							(est.)								
	----	----	31.211 ^a	0.028 ^a	0.216 ^a	13.96 ^a	20.39 ^a	a	----	----	----	----	----	----	----
	HCl	- 22.063 ^a	44.617 ^a	0.476 ^a	3.86 ^a	158.94 ^a	188.11 ^a	n	2000	- 22.77 ^a	- 23.21 ^a	- 24.06 ^a	- 24.77 ^a	- 25.5	- 26.0
Hf	HF	- 64.2 ^a	41.47 ^a	1.094 ^a	1.8 ^a	190.09 ^a	293.1 ^a	c	2000	- 64.7	- 65.0	- 65.8	- 66.6	- 67.4	- 68.2
	H ₂ O	- 68.3174 ^a	16.716 ^a	1.4363 ^a	9.7171 ^a	273.16 ^a	373.16 ^a	a	----	- 54.62 ^a	- 52.36 ^a	- 46.03 ^a	- 39.26 ^a	- 32.31 ^a	- 25.25 ^a
Hf	----	----	13.1 ^a	----	----	2500 ^a	5500 ^b	c	2500	----	----	----	----	----	----

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal./mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal./mole	Heat of Evaporation at B. Pt., kcal./mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal./mole					
								Ref.	Max. Exptl. Temp. °K.						
										298°K	500°K	1000°K	1500°K	2000°K	2500°K
Hf	HfCl ₄	-255 ^e	53.7 (est.)	----	24 ^f (subl.)	----	590 ^f (subl.)	o	485	-235	-222	-209	-199	-189	-180
	HfF ₄	-435 ^e	35 ^e _d	18 ^e	45 ^e	1200 ^e	1200 ^e	-	----	-413 ^e	-399 ^e	-363 ^e	----	----	----
	HfO ₂	-266.0 ^g	16.0 _d	----	----	3063 ^g	----	o	1800	-252	-243	-221	-201	-181	-162
Hg	----	----	18.46 ^d	0.557 ^a	13.985 ^c	234.29 ^a	634 ^c	c	3000	----	----	----	----	----	----
	HgCl	-31.6 ^e	23.5 ^e	3.5	14.5 (est.)	575 ^d	657 ^d	d	575	-25.2	-20.9	-15.5	-9.7	-3.8	+1.6
	HgCl ₂	-53.4 ^e	34.6 ^e	4.15 ^a	14.1 ^d (est.)	550 ^a _f	573 ^d	c, d	1000	-42.3	-35.0	-23.8	-12.2	-0.4	+10.6
	HgF	-46 ^e	21.5 (est.)	3.5	33.0 (est.)	843 ^f	1500 (est.)	-	----	-40	-35	-18	-2	+3	+8
	HgF ₂	-95 ^e	29.5 (est.)	5.5 ^f (est.)	22 ^f (est.)	918 ^f	920 ^f	-	----	-84	-76	-55	-45	-34	-24
	HgO	-21.708 ^p	16.839 ^p	----	----	----	dec. 750 ^g	p	300	-13.965 ^p	-8.6 ^j	----	----	----	----
In	----	----	13.88 ^d	0.78 ^a	53.8 ^f	430 ^a	2440 ^f	c	500	----	----	----	----	----	----
	InCl	-44.6 ^d	23.5 (est.)	3 (est.)	21.2 ^f	498 ^d	881 ^f	-	----	-39.5	-36.6	-34.1	-40.2	-46.2	-49.6
	InCl ₂	-86.8 ^a	33.4 (est.)	4.5 (est.)	42.1 ^f	508 ^a	758 ^f	-	----	-76.7	-70.0	-71.9	-85	-107	-108
	InCl ₃	-128.4 ^a	43 (est.)	----	37.8 ^f (subl.)	----	771 ^f (subl.)	-	----	-113	-103	-90	-86	-91	-90
	InF	-70 ^e	21 ^e	3 (est.)	19.5 (est.)	500 (est.)	800 (est.)	-	----	-65	-61	-60	-66	-71	-74
	InF ₂	-165 ^e	29 ^e	9 (est.)	39.0 (est.)	1000 (est.)	1600 (est.)	-	----	-155	-148	-133	-122	-123	-123
	InF ₃	-250 ^e	33.5 (est.)	15 (est.)	35 (est.)	1443 ^f	1500 (est.)	-	----	-234	-224	-199	-178	-176	-170
	In ₂ O ₃	-222.5 ^a	27 ^d	----	----	>2500 (est.)	----	-	----	-200	-185	-147	-109	-63	-35
Ir	----	----	8.7 ^a	----	----	2727 ^b	4800 ^b	d	1873	----	----	----	----	----	----
	IrCl	-20.5 ^d	22 ^e	----	----	dec. 1072°K. _f	----	-	----	-17 ^e	-14 ^e	-6 ^e	----	----	----
	IrCl ₂	-40.6 ^d	31 ^e	----	----	dec. 1044°K. _f	----	-	----	-31 ^e	-25 ^e	-10 ^e	----	----	----
	IrCl ₃	-60.5 ^d	37 ^e	----	----	dec. 1038°K. _f	----	-	----	-44 ^e	-34 ^e	-12 ^e	----	----	----
	IrF ₂	----	25 ^e	----	----	>1000 ^f	>1500 ^f	-	----	----	----	----	----	----	----
	IrF ₃	-50 ^e	32 (est.)	----	34 (subl., est.)	----	1000 (subl., est.)	-	----	-35	-26	-5	-3	-2	-2

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Ir	IrF ₄	----	37 ^e	----	----	----	1030 ^f	-	----	----	----	----	----	----	----
	IrF ₆	-130 ^e	----	2 ^f	6.5 ^f	317 ^f	326	-	----	----	----	----	----	----	----
	IrO ₂	- 44 ^g	15.9 ^d	----	----	>1500 (est.)	----	c	1300	- 32	- 23	- 4	+15	----	----
K	----	----	15.2 ^a	0.574 ^c	18.88 ^f	337 ^c	1052 ^b	c	600	----	----	----	----	----	----
	KCl	-104.25 ^d	19.76 ^a	6.1 ^c	38.84 ^f	1043 ^c	1680 ^f	c	1200	- 97.6	- 92.9	- 81.5	- 65.6	- 57.2	- 53.0
	KF	-134.5 ^e	15.91 ^a	6.75 ^c	41.275 ^f	1130 ^c	1775 ^f	c	1200	-128	-122	-110	- 93.1	- 81.9	- 77.0
	K ₂ O	- 86.4 ^g	23.5 ^d	7.2 (est.)	----	800 (est.)	dec. 1750 ^g	-	----	- 77.0	- 70.0	- 54.1	- 40.8	+ 3.6	+ 32
	K ₂ O ₂	-123.0 ^d	----	----	----	763 ^a	----	-	----	----	----	----	----	----	----
	K ₂ O ₃	-134 ^a	----	----	----	703 ^a	----	-	----	----	----	----	----	----	----
	KO ₂	- 67.6 ^g	----	----	----	653 ^g	dec. 760 ^g	-	----	- 57.4 ^g	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
La	----	----	13.7 ^a	2.3 ^f	80 ^f	1160 ^f	3000 ^b	c	800	----	----	----	----	----	----
	LaCl ₃	-264 ^e	43 ^d	10.3 ^d	44 ^f	1145 ^d	2020 ^f	-	----	-249	-239	-216	-198	-182	-203
	LaF ₃	-421 ^e	28 (est.)	8 ^f	62 ^f	1700 ^f	2600 ^f	-	----	-404	-392	-366	-340	-319	-299
	La ₂ O ₃	-435 ^g	36 (est.)	----	----	2590 ^g	4470 ^g	-	----	-416	-403	-370	-336	-302	-269
Li	----	----	6.70 ^a	0.69 ^d	32.4 ^f	459 ^d	1640 ^b	d	550	----	----	----	----	----	----
	LiCl	- 97.70 ^a	13.9 ^q	3.2 ^f	36.0 ^a	887 ^f	1655 ^a	c	887	- 91.8	- 89.5	- 78.7	- 71.0	- 74.7	- 38.3
	LiF	-145.6 ^e	8.57 ^a	2.36 ^f	51.0 ^a	1120 ^f	1954 ^a	d	1120	-139	-134	-122	-112	- 95.4	- 88.4
	Li ₂ O	-142.6 ^g	10.0 ^d	18 (est.)	----	2000 ^g	2600 ^g	-	----	-134	-128	-112	- 96.1	- 66.0	- 37
	Li ₂ O ₂	-151.9 ^d	----	----	----	dec. 470°K. ^g	----	-	----	-136 ^g	----	----	----	----	----
Mg	----	----	7.75 ^f	1.13 ^f	31.5 ^f	924 ^f	1393 ^f	r	2400	----	----	----	----	----	----
	MgCl ₂	-153.2 ^e	21.4 ^a	10.3 ^a	32.7 ^a	987 ^a	1691 ^a	c	1500	-141	-134	-115	-100	- 83.0	- 69.7
	MgF ₂	-263.5 ^a	13.68 ^s	13.9 ^a	65 ^a	1536 ^a	2500 ^a	d	1800	-250	-242	-221	-199	-173	-149
	MgO	-143.7 ^a	6.80 ^r	18.5 ^a	----	3173 ^a	----	r	2400	-136 ^d	-131 ^d	-119 ^d	-103 ^d	- 78.9 ^d	- 54.9 ^d
	MgO ₂	-148.9 ^a	----	----	----	dec. 361°K. ^g	----	-	----	-136 ^g	----	----	----	----	----
Mn	----	----	7.59 ^a	3.5 ^c	53.7 ^c	1517 ^c	2368 ^c	c	5000	----	----	----	----	----	----
	MnCl ₂	-112.0 ^d	28.0 ^a	8.97 ^c	29.6 ^f	923 ^c	1463 ^f	c	1200	-102	- 95.8	- 81.4	- 72.7	- 71.6	- 67.5
	MnCl ₃	-110 ^e	39 ^e	----	21 ^f	----	900 ^f	-	----	- 95 ^e	- 86 ^e	----	----	----	----
	MnCl ₄ (1)	----	62 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	MnF ₂	-190 ^e	22.25 ^q	5.5 ^f	57 ^f	1129 ^f	2300 ^f	-	----	-180	-173	-158	-145	-133	-121

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole						
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K	
Mn	MnF ₃	- 238 ^e	31 (est.)	11 ^f	42 ^f	1350 ^f	1600 ^f	-	----	-223	-214	-192	-172	-166	-158	
	MnF ₄	- 230 ^e	38 ^e	----	----	----	----	-	----	-210 ^e	-196 ^e	----	----	----	----	
	MnO	- 92.0 ^a	14.4 ^a	13.0 ^d	----	2058 ^d	3400 ^g	c	1800	- 86.7	- 83.2	- 74.7	- 65.9	- 55.4	- 44.5	
	Mn ₃ O ₄	- 331.4 ^a	35.5 ^a	39 (est.)	----	1863 ^g	----	e	1800	-306	-289	-247	-205	-163	-120	
	Mn ₂ O ₃	- 232.1 ^a	24.0 ^d	----	----	dec. 1620°K. ^g	----	-	----	-213 ^j	-200 ^j	-168 ^j	----	----	----	
	MnO ₂	- 124.2 ^g	12.7 ^a	----	----	dec. 1120°K. ^g	----	c	800	-112	-103	- 81	----	----	----	
	----	----	6.83 ^a	----	----	2883 ^a	----	c	1800	----	----	----	----	----	----	
	MoCl ₂	- 44 ^a	32.3 (est.)	6 ^f	36 ^f	1000 ^f	1700 ^f	-	----	- 36	- 30	- 18	- 10	- 9	- 14	
	MoCl ₃	- 65 ^t	42 (est.)	----	52 ^t (subl.)	----	1300 ^t (subl.)	-	----	- 52	- 43	- 22	- 11	- 12	- 13	
	MoCl ₄	- 79 ^a	51.8 (est.)	----	25 ^t (subl.)	----	595 ^t (subl.)	-	----	- 61	- 48	- 36	- 28	- 21	- 12	
Mo	MoCl ₅	- 90.8 ^a	61.6 (est.)	4.4 ^d	12 ^t	467 ^d	541 ^t	-	----	- 67.4	- 52.4	- 29.2	- 5.1	+ 0.6	+ 46	
	MoCl ₆	- 90 ^a	72.3 (est.)	----	19 ^t (subl.)	----	630 ^t (subl.)	-	----	- 68	- 62	+ 12	+ 87	+166	+248	
	MoF ₄	----	33 ^e	----	----	----	----	-	----	----	----	----	----	----	----	
	MoF ₅	----	58 ^e	4.2 ^f	11.0 ^f	350 ^f	500 ^f	-	----	----	----	----	----	----	----	
	MoF ₆ (g)	- 405.0 ^d	79.0 ^d	2.5 ^d	6.0 ^d	290 ^d	309 ^d	-	----	-383	-368	-332	-297	-264	-230	
	MoO ₂	- 131 ^g	16.2 (est.)	----	----	>2500 (est.)	----	-	----	-119	-111	- 93	- 76	- 60	- 44	
	Mo ₄ O ₁₁	-671 ^g	----	----	----	disproportionates ^g	----	-	----	-616 ^g	----	----	----	----	----	
	Mo ₈ O ₂₃	-1392 ^g	----	----	----	disproportionates ^g	----	-	----	-1254 ^g	----	----	----	----	----	
	Mo ₉ O ₂₆	-1573 ^g	----	----	----	disproportionates ^g	----	-	----	-1417 ^g	----	----	----	----	----	
	MoO ₃	- 180.33 ^a	18.68 ^a	12.54 (est.)	33 ^a	1068 ^a	1428 ^a	c	1068	-162	-150	-121	-100	- 90	- 79	
	Na	----	----	12.31 ^d	0.63 ^a	23.4 ^d	371 ^a	1156 ^d	c	500	----	----	----	----	----	----
		NaCl	- 98.2 ^d	17.30 ^a	7.22 ^f	40.808 ^f	1073 ^f	1738 ^f	c	1300	- 91.8	- 87.1	- 76.1	- 61.9	- 60.4	- 58.4
		NaF	-136.0 ^a	13.1 ^f	7.78 ^c	50 ^a	1265 ^c	1977 ^a	c	1300	-129	-124	-112	- 94.6	- 77.8	- 73.5
		Na ₂ O	- 99.4 ^a	17.4 ^a	11.2 (est.)	----	1193 ^d	>2500 (est.)	c	1100	- 89.9	- 83.2	- 65.5	- 37.8	- 6.4	+ 25
Na ₂ O ₂		-122.2 ^g	----	----	----	dec. 919°K. ^g	----	-	----	-106 ^g	----	----	----	----	----	
NaO ₂		- 61.9 ^a	----	----	----	----	----	-	----	- 51.8 ^g	----	----	----	----	----	
Nb	----	----	8.3 ^a	----	----	2760 ^a	5400 ^b	c	1900	----	----	----	----	----	----	

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal./mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal./mole	Heat of Evaporation at B. Pt., kcal./mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal./mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Nb	NbCl ₅	----	60.0 ^d	8.5 ^a	11.8 ^a	483 ^a	519 ^a	-	----	----	----	----	----	----	----
	NbF ₅	-435.0 ^d	58 ^e	4.2 ^f	11.0 ^f	349 ^f	498 ^f	-	----	-414	-401	-386	-369	-353	-335
	NbO	-97 ^g	12.0 ^d	----	----	>2500 (est.)	----	-	----	-91	-86	-76	-66	-57	-47
	NbO ₂	-189 ^g	12.7 ^d	----	----	>2500 (est.)	----	-	----	-176	-167	-145	-125	-106	-87
	Nb ₂ O ₅	-455 ^g	32.5 ^d	36.5 (est.)	----	1733 ^a	>2500 (est.)	c	800	-423	-401	-344	-285	-230	-181
Nd	----	----	14 (est.)	2.2 (est.)	----	1113 ^a	>2500 (est.)	d	923	----	----	----	----	----	----
	NdCl ₃	-254.3 ^a	44.2 (est.)	8.0 ^f	46 ^f	1033 ^f	1960 ^f	-	----	-240	-230	-207	-186	-169	-163
	NdF ₃	-410 ^e	29 (est.)	8.0 ^f	62 ^f	1683 ^f	2600 ^f	-	----	-393	-381	-355	-327	-305	-284
	Nd ₂ O ₃	-426 ^g	36.3 (est.)	----	----	>2500 (est.)	----	-	----	-407	-393	-360	-320	-283	-246
Ni	----	----	7.12 ^b	4.21 ^c	91 ^a	1725 ^c	3073 ^a	c	1900	----	----	----	----	----	----
	NiCl ₂	-75.0 ^d	25.6 ^a	----	48.36 ^a (subl.)	----	1260 ^a (subl.)	c	800	-64.6	-57.8	-42.1	-37.6	-42.0	-44.5
	NiF ₂	-158 ^e	22 (est.)	8.0 ^f	48 ^f	1300 ^f	1900 ^f	-	----	-148	-141	-126	-114	-107	-106
	NiO	-58 ^g	9.22 ^a	12.1 ^d	----	2233 ^d	----	c	1400	-51.3	-46.8	-36.0	-25.9	-15.1	-14.2
O ₂	----	----	49.003 ^a	0.106 ^a	1.630 ^a	54.40 ^a	90.19 ^a	a	5000	----	----	----	----	----	----
Os	----	----	7.8 ^a	6.4 ^f	162 ^f	2970 ^f	4900 ^b	c	1900	----	----	----	----	----	----
	OsCl ₂	-24 ^e	34 (est.)	9.5 (est.)	31 (est.)	1050 ^f	1400 ^f	-	----	-16	-11	0	----	----	----
	OsCl ₃	----	40 ^e	----	----	disproportionates at 800°K. ^f		-	----	----	----	----	----	----	----
	OsCl ₄	----	50 ^e	----	----	600 ^f	600 ^f	-	----	----	----	----	----	----	----
	OsF ₂	-32 ^e	26.5 (est.)	5.5 (est.)	49.5 (est.)	1100 (est.)	1900 (est.)	-	----	-23	-17	-4	+5	+9	+4
	OsF ₃	----	28 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	OsF ₄	----	37 ^e	----	----	----	1050 ^f	-	----	----	----	----	----	----	----
	OsF ₆	----	68 ^e	----	----	>325 ^f	477 ^f	-	----	----	----	----	----	----	----
	OsF ₈	----	88 ^e	----	6.84 ^f	307.6 ^f	320 ^f	-	----	----	----	----	----	----	----

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.						
										298°K	500°K	1000°K	1500°K	2000°K	2500°K
Os	OsO ₂	- 62 ^g	----	----	----	disproportionates at 923°K. ^g		-	----	----	----	----	----	----	----
	OsO ₄	- 93.6 ^g	34.7 ^a	3.41 ^a	9.45 ^d	313.3 ^a	403 ^d	c	1000	- 72.4	- 62.8	- 45.4	- 28.5	- 12.2	+ 2.6
P	----	----	10.6 ^a	0.15 ^a	2.97 ^a	317.4 ^a	553 ^a	d	1500	----	----	----	----	----	----
	PCl ₃	- 76.9 ^e	52.2 ^e	1.08 ^d	7.278 ^f	182 ^f	348 ^f	d	1000	- 52.5	- 53.9	- 62.0	----	----	----
	PCl ₅	-107.5 ^d	40.8 ^d	----	16.1 ^a	----	432 ^a	-	----	- 75.8 ^e	- 60 ^e	----	----	----	----
					(subl.)		(subl.)								
	PF ₃ (g)	----	64.12 ^a	----	3.43 ^a	121.7 ^a	172 ^a	c	2000	----	----	----	----	----	----
	P ₂ O ₃	-270 ^g	----	----	4.5 ^a	297 ^a	448.5 ^a	-	----	-249 ^g	----	----	----	----	----
	PO ₂	-176 ^g	----	----	----	----	1700 ^g	-	----	-162 ^g	----	----	----	----	----
	P ₂ O ₅	-360 ^a	33.5 ^d	----	17.6 ^c	----	631 ^c	c	1400	-338 ^d	-310 ^d	-247 ^d	----	----	----
				(subl.)		(subl.)									
Pb	----	----	15.51 ^a	1.22 ^a	42.5 ^d	600.6 ^a	2023 ^d	c	1300	----	----	----	----	----	----
	PbCl ₂	- 85.7 ^e	32.6 ^a	5.80 ^c	29.6 ^a	771 ^c	1227 ^a	c	900	- 74.9	- 67.9	- 52.9	- 48.7	- 49.5	- 40.9
	PbCl ₄	----	64 ^e	----	----	258 ^f	410 ^f	-	----	----	----	----	----	----	----
	PbF ₂	-158.5 ^a	29 ^a	1.86 ^f	38.34 ^f	1097 ^f	1566 ^f	c	1091	-148	-141	-124	-110	-107	-105
	PbF ₄	-222 ^e	45 ^e	----	23	----	773	-	----	-202	-189	-165	-150	-137	-122
					(subl., est.)		(subl., est.)								
	PbO	- 52.40 ^a	16.2 ^a	2.8 ^a	51.3 ^d	1159 ^a	1743 ^d	c	1000	- 45.3	- 40.6	- 29.0	- 19.2	- 18.0	- 23.4
	Pb ₃ O ₄	-175.6 ^a	50.5 ^a	----	----	decomposes ^g		-	----	-148 ^g	----	----	----	----	----
PbO ₂	- 66.12 ^a	18.3 ^a	----	----	decomposes ^g		c	1000	- 52.3	- 43.1	- 20.2	----	----	----	
Pd	----	----	9.04 ^d	4.12 ^b	89 ^b	1828 ^b	3440 ^b	c	1828	----	----	----	----	----	----
	PdCl ₂	- 44 ^d	31	9.7 ^f	28.5	951 ^f	1300 ^f	-	----	- 35	- 28	- 15	- 13	- 17	- 20
			(est.)	(est.)	(est.)										
	PdF ₂	-112 ^e	27.5	9.0	48.0	1100	1900	-	----	-103	- 97	- 89	- 87	- 73	- 80
			(est.)	(est.)	(est.)	(est.)	(est.)								
	PdF ₃	-122 ^e	26 ^e	----	----	dec. 500°K. ^f		-	----	-105 ^e	- 94 ^e	----	----	----	----
PdO	- 21.0 ^d	9.1 ^d	----	----	dec. 1150°K. ^g		c	823	- 13.7	- 8.7	+ 4.0 at 823°K.	----	----	----	
Pt	----	----	10.0 ^a	5.2 ^a	122 ^b	2042.5 ^a	4100 ^b	c	1900	----	----	----	----	----	----
	PtCl	- 13 ^e	22 ^e	----	----	dec. 856°K. ^f		-	----	- 9 ^e	- 6 ^e	+ 3 ^e	----	----	----
	PtCl ₂	- 29 ^e	31 ^e	----	----	dec. 854°K. ^f		-	----	- 19 ^e	- 13 ^e	+ 6 ^e	----	----	----
	PtCl ₃	- 43 ^e	35 ^e	----	----	dec. 708°K. ^f		-	----	- 27 ^e	- 15 ^e	+ 9 ^e	----	----	----
	PtCl ₄	- 53 ^e	50 ^e	----	----	----	600°K. ^f	-	----	- 33 ^e	- 21 ^e	+10 ^e	----	----	----
						(subl.)									

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Pt	PtF ₂	----	25 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	PtF ₃	----	28 ^e	----	----	>1000 ^f	>1000 ^f	-	----	----	----	----	----	----	----
	PtF ₄	----	37 ^e	----	----	>900 ^f	1000 ^f	-	----	----	----	----	----	----	----
Rb	----	----	16.6 ^a	0.525 ^b	18.11 ^a	312 ^b	952 ^a	c	400	----	----	----	----	----	----
	RbCl	-105.1 ^e	22.0 ^d	4.40 ^a	36.92 ^a	990 ^a	1654 ^a	c	990	- 98.8	- 94.2	- 82.1	- 60.1	-55.5	-50.1
	RbF	-133.2 ^e	18.0 ^d	4.13 ^a	39.51 ^a	1048 ^a	1681 ^a	c	1106	-125	-121	-108	- 89.7	-79.6	-73.4
	Rb ₂ O	- 78.9 ^a	22.2	8.5	----	900	>2500	-	----	- 68.3	- 60.4	- 39.1	- 5.7	+26	+57
			(est.)	(est.)		(est.)	(est.)								
	Rb ₂ O ₂	-106 ^d	----	----	----	843 ^d	----	-	----	----	----	----	----	----	----
	Rb ₂ O ₃	-121.5 ^d	----	----	----	dec. 1043°K. ^g	----	-	----	-108 ^g	----	----	----	----	----
	RbO ₂	- 65.8 ^d	----	----	----	dec. 1033°K. ^g	----	-	----	- 58 ^g	----	----	----	----	----
Rh	----	----	7.6 ^a	5.2 ^b	127 ^b	2240 ^b	4150 ^b	d	2239	----	----	----	----	----	----
	RhCl	- 20 ^e	20 ^e	----	----	dec. 1238°K. ^f	----	-	----	- 16 ^e	- 14 ^e	- 5 ^e	----	----	----
	RhCl ₂	- 39 ^e	29 ^e	----	----	dec. 1231°K. ^f	----	-	----	- 29 ^e	- 23 ^e	- 7 ^e	----	----	----
	RhCl ₃	- 55 ^e	38 ^e	----	----	dec. 1221°K. ^f	----	-	----	- 40 ^e	- 30 ^e	- 9 ^e	----	----	----
	RhF ₂	-110 ^e	23 ^e	----	----	----	----	-	----	-100 ^e	- 93 ^e	- 77 ^e	----	----	----
	RhF ₃	-160 ^e	26 ^e	----	----	>1400 ^f	>1500 ^f	-	----	-144 ^e	-133 ^e	-108 ^e	----	----	----
	RhF ₄	----	37 ^e	----	----	----	1025 ^f	-	----	----	----	----	----	----	----
	Rh ₂ O	- 24.0 ^g	25	----	----	dec. 1400°K. ^g	----	c	1273	- 19.6	- 16.8	- 10.3	- 4.5	+0.6	+5.8
			(est.)												
	RhO	- 23.9 ^g	----	----	----	dec. 1394°K. ^g	----	c	1273	- 19 ^g	----	----	----	----	----
	Rh ₂ O ₃	- 71.1 ^g	----	----	----	dec. 1388°K. ^g	----	c	1273	- 52.5 ^g	----	----	----	----	----
Ru	----	----	6.9 ^a	6.1 ^b	148 ^b	2700 ^b	4500 ^b	c	1900	----	----	----	----	----	----
	RuCl ₃	- 46 ^e	38 ^e	----	----	dec. 900°K. ^f	----	-	----	- 31 ^e	- 21 ^e	- 1 ^e	----	----	----
	RuF ₃	----	29.5	11	39	1300	1600	-	----	----	----	----	----	----	----
			(est.)	(est.)	(est.)	(est.)	(est.)								
	RuF ₄	----	37 ^e	----	----	----	1050 ^f	-	----	----	----	----	----	----	----
	RuF ₅	----	58 ^e	4.5 ^f	12 ^f	374 ^f	545 ^f	-	----	----	----	----	----	----	----
	RuO ₂	- 52.5 ^a	13.5 ^d	----	----	dec. 1400°K. ^g	----	-	----	- 39.9	- 31.5	- 12.0	+5.3	+19.9	----
RuO ₄	- 52 ^g	----	----	----	300 ^g	----	-	----	- 32 ^g	----	----	----	----	----	
S	----	----	7.62 ^a	0.293 ^a	2.5 ^a	392 ^a	717.76 ^a	d	718	----	----	----	----	----	----
	SCl	- 22.7 ^e	27 ^e	----	8.716 ^f	197 ^f	411 ^f	-	----	- 20.6 ^e	- 19.7 ^e	----	----	----	----
	SCl ₂	- 28 ^e	----	----	----	195 ^f	332 ^f	-	----	- 21 ^e	----	----	----	----	----
	SCl ₄	- 29.2 ^e	----	----	----	243 ^f	----	-	----	- 14.3 ^e	----	----	----	----	----
	SF ₆	-262 ^a	69.5 ^a	----	5.46 ^a	----	209.5 ^a	v	5000	-236 ^v	-218 ^v	-176 ^v	-134 ^v	-93.8 ^v	-53.8 ^v
					(subl.)		(subl.)								

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal./mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
S	SO	+ 19.02 ^a	53.04 ^a	----	----	----	----	c	2000	+ 12.78 ^a	----	----	----	----	----
	SO ₂	- 70.96 ^a	59.25 ^d	1.769 ^a	5.955 ^a	197.68 ^a	263.14 ^a	d	2000	- 71.4 ^d	- 71.7 ^d	- 69.3 ^d	- 60.6 ^d	- 52.0 ^d	----
	SO ₃	-110.1 ^g	----	0.47 ^a	9.99 ^a	290.0 ^a	316.5 ^a	c	1200	- 89.1 ^g	----	----	----	----	----
Sb	----	----	10.5 ^a	4.75 ^d	46.7 ^d	903.7 ^d	1713 ^d	c	1300	----	----	----	----	----	----
	SbCl ₃	- 91.4 ^e	44.8 ^e	3.03 ^a	10.80 ^a	346.4 ^a	494 ^a	c, d	1000	- 51.8 ^w	- 47.0 ^w	- 43.2 ^w	- 37.6 ^w	- 26.5 ^w	----
	SbCl ₅	-104.9 ^e	79 ^e	2.40 ^f	11.57 ^f	277 ^f	445 ^f	-	----	- 86 ^e	- 73 ^e	----	----	----	----
	SbF ₃	-216.6 ^d	34	4	14 ^f	565 ^d	649 ^f	-	----	-202	-192	-181	-172	-155	-133
			(est.)	(est.)											
	SbF ₅	-104.9 ^e	62	----	9.5 ^f	279 ^f	423 ^f	-	----	- 84.0	- 72.4	- 50.6	- 25.7	+ 6.7	+ 46.3
			(est.)												
	Sb ₂ O ₃	-167 ^g	29.4 ^d	14.74 ^a	17.83 ^a	928 ^a	1729 ^a	d	930	-148	-134	-104	- 77	- 37	+ 5
	SbO ₂	-106 ^d	15.2 ^d	----	----	dec. 1203°K. ^g		d	1198	- 92.8	- 83.9	- 61.8	----	----	----
	Sb ₆ O ₁₃	-598 ^g	----	----	----	dec. 1003°K. ^g		-	----	-507 ^g	----	----	----	----	----
Sb ₂ O ₅	-230 ^g	29.9 ^a	----	----	dec. 673°K. ^g		-	----	-180 ^g	----	----	----	----	----	
Sc	----	----	9 ^e	4 ^b	80 ^b	1670 ^b	3000 ^b	-	----	----	----	----	----	----	----
	ScCl ₃	-221 ^e	39	19 ^f	46 ^f	1233 ^f	1240 ^f	-	----	-206	-196	-175	-169	-145	-119
			(est.)												
	ScF ₃	-367 ^e	26.5	12 ^f	55 ^f	1500 ^f	1800 ^f	-	----	-350	-339	-315	-301	-294	-292
			(est.)												
	Sc ₂ O ₃	-411 ^g	24.8 ^d	----	----	>2500 (est.)	----	d	2500	-391	-378	-345	-311	-278	-242
Se	----	----	10.0 ^a	1.30 ^c	28.54 ^b	490 ^c	1000 ^b	d	790	----	----	----	----	----	----
	SeCl	- 11.1 ^e	30 ^e	----	9	188 ^f	403 ^f	-	----	- 9.1	- 2.1	- 16.4	- 20.4	- 14.3	- 8.6
					(est.)										
	SeCl ₄	- 46.1 ^e	51.5 (est.)	----	18 (subl., est.)	----	469 ^a (subl.)	-	----	- 26.7	- 15.1	- 1.6	+ 14.5	+ 41.7	+ 68.4
	SeF ₆	-246 ^a	75.1 ^a	----	6.27 ^a (subl.)	----	226.6 ^a (subl.)	c	2000	-222	-205	-164	-121	- 72	- 11
	SeO(g)	+ 9.48 ^a	----	----	----	----	----	c	2000	----	----	----	----	----	----
	SeO ₂	- 55.0 ^d	----	----	24.5 ^d (subl.)	----	603 ^d (subl.)	-	----	----	----	----	----	----	
Si	----	----	4.50 ^e	11.1 ^b	71 ^b	1683 ^b	2750 ^b	d	1683	----	----	----	----	----	----
	Si ₂ Cl ₆	-270 ^e	90 ^e	----	11 ^f	272 ^a	412 ^f	-	----	-246 ^e	----	----	----	----	----
	SiCl ₄	-150.1 ^e	57.2 ^a	1.84 ^a	6.859 ^f	205 ^a	330 ^f	c, d	1000	-134	-127	-112	- 96.1	- 79.5	- 62.6

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Si	SiF ₄	-370.8 ^d	68.0 ^a	----	6.15 ^a (subl.)	----	177.7 ^a (subl.)	c	2000	-361	-354	-338	-321	-308	-293
	SiO	-104.6 ^g	----	----	----	>2000 ^g	----	-	----	- 98 ^g	----	----	----	----	----
	SiO ₂	-208.3 ^d	10.06 ^d	2.1 ^d	----	1986 ^d	3773 ^d	d	1700	-195	-187	-165	-144	-122	- 98
Sn	----	----	12.3 ^e	1.72 ^b	70 ^b	505 ^b	3000 ^b	c	1300	----	----	----	----	----	----
	SnCl ₂	- 83.6 ^a	32.5 ^d	3.05 ^f	19.8 ^f	520 ^f	925 ^f	d	520	- 73.7	- 67.3	- 55.7	- 53.2	- 50.2	- 47.6
	SnCl ₄	-127.4 ^e	62.0 ^d	2.19 ^a	8.325 ^f	239.9 ^a	386 ^f	c, d	1000	-110	-102	- 84.9	- 67.6	- 50.2	- 34.4
	SnF ₂	-158 ^e	29 ^e	----	----	>900 ^f	>1500 ^f	-	----	-148 ^e	-142 ^e	----	----	----	----
	SnO	- 68.4 ^a	13.5 ^a	----	----	dec. 660 ^g	660 ^g	d	1273	- 61.5	- 56.6	- 43.7	----	----	----
	SnO ₂	-138.8 ^a	12.5 ^a	----	----	----	2123 ^d (subl.)	c	1500	-124	-114	- 89	- 64.8	- 48.6	- 30
Sr	----	----	12.5 ^d	2.2 ^a	33.8 ^a	1043 ^a	1657 ^a	c	1000	----	----	----	----	----	----
	SrCl ₂	-197.8 ^e	28 ^a	4.1 ^f	55 ^f	1145 ^f	2300 ^f	c	1200	-186	-179	-162	-147	-127	-106
	SrF ₂	-289.0 ^d	20.5 (est.)	4.26 ^f	71 ^f	1673 ^f	2750 ^f	-	----	-277	-269	-250	-232	-208	-183
	SrO	-140.8 ^g	13.0 ^q	----	----	2703 ^d	3273 ^d	c	2000	-134	-129	-116	-102	80.4	54.8
	SrO ₂	-153.2 ^g	----	----	----	dec. 488 ^g	488 ^g	-	----	-141.2 ^g	----	----	----	----	----
Ta	----	----	9.9 ^a	----	----	3250 ^a	6300 ^b	d	2800	----	----	----	----	----	----
	TaCl ₂	----	31 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	TaCl ₃	-295 ^e	38 ^e	----	----	----	----	-	----	-280 ^e	-269 ^e	-244 ^e	----	----	----
	TaCl ₄	----	47 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	TaCl ₅	----	63.0 ^d	9.0 ^f	12.5 ^f	480 ^f	507 ^f	-	----	----	----	----	----	----	----
	TaF ₂	----	24 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	TaF ₃	----	26 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	TaF ₅	----	60 ^e	4.5 ^f	11 ^f	370 ^f	502 ^f	-	----	----	----	----	----	----	----
	Ta ₂ O ₅	-489 ^g	34.2 ^a	48 (est.)	----	2150 ^g	>2500 (est.)	d	2150	-457	-435	-383	-331	-281	-240
Te	----	----	11.88 ^a	4.28 ^a	11.9 ^a	723 ^a	1360 ^a	d	873	----	----	----	----	----	----
	TeCl ₂	----	36 ^e	----	15.3 ^f	448 ^f	595 ^f	-	----	----	----	----	----	----	----
	TeCl ₄	- 77.4 ^e	52.0 ^d	4.51 ^a	16.83 ^f	497.3 ^a	655 ^f	c	550	- 57.6	- 44.8	- 27.3	- 9.4	+ 5	+ 20
	TeF ₆	-315.0 ^a	80.67 ^a	----	6.7 ^f (subl.)	----	234 ^f (subl.)	c	2000	-292	-276	-235	-192	-149	- 90
	TeO ₂	- 77.69 ^a	16.99 ^a	6.0 (est.)	----	1006 ^d	>2000 (est.)	d	1006	- 64.6	- 55.9	- 31.5	- 9.3	+14.5	----
Th	----	----	13.6 ^a	4.6 ^b	----	2100 ^b	----	d	1500	----	----	----	----	----	----

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
Th	ThCl ₃	-242 (est.)	44.5 (est.)	9 ^f	46 ^f	1100 ^f	1890 ^f	-	----	-227	-218	-196	-179	-172	-161
	ThCl ₄	-285.2 ^e	54.0 ^d	9.6 ^d	36.5 ^f	1043 ^d	1195 ^f	-	----	-276	-265	-223	-209	-201	-191
	ThF ₃	----	----	8 ^f	60 ^f	1500 ^f	2550 ^f	-	----	----	----	----	----	----	----
	ThF ₄	-477 ^a	34 (est.)	17 ^f	50 ^f	1300 ^f	2000 ^f	-	----	-454	-438	-403	-373	-350	-339
	ThO	-145 ^g	16.1 (est.)	----	----	>2500 (est.)	----	-	----	-138	-134	-123	-113	-102	-91
	ThO ₂	-293.2 ^g	19.6 ^d	----	----	3225 ^g	4670 ^g	d	1970	-280	-272	-251	-230	-209	-187
Ti	----	----	7.24 ^a	4.5 ^d	101 ^b	1998 ^d	3550 ^b	c	1500	----	----	----	----	----	----
	TiCl ₂	-114 ^a	29.0 ^d	6 ^f	35 ^f	950 ^f	1750 ^f	-	----	-105	-98	-84	-74	-67	-66
	TiCl ₃	-165 ^e	39.0 ^d	12	28.5	1200 ^f	1300	-	----	-151	-141	-119	-105	-98	-92
	TiCl ₄	-181.4 ^e	60.4 ^a	(est.) 2.24 ^a	(est.) 8.346 ^f	250 ^a	409 ^f	c, d	2000	-166	-157	-143	-128	-112	-97
	TiF ₂	-198 ^e	18 ^e	----	----	----	----	-	----	-187 ^e	-179 ^e	-160 ^e	-142 ^e	----	----
	TiF ₃	-315 ^a	28 ^e	12 ^f	49 ^f	1500 ^f	1700 ^f	-	----	-299	-289	-266	-243	-234	-223
	TiF ₄	-370 ^a	39.5 (est.)	----	22 ^f (subl.)	----	557 ^f (subl.)	-	----	-351	-338	-326	-316	-305	-294
	Ti _{1.43} O	-125 ^g	----	----	----	disproportionates 1198°K. ^g		-	----	-118 ^g	----	----	----	----	----
	TiO	-123.9 ^g	8.31 ^a	14.0 ^d	----	2293 ^d	----	c	1800	-117	-112	-101	-90.3	-78.7	-69.1
	Ti ₂ O ₃	-363.0 ^g	18.83 ^a	38.4 (est.)	----	2400 ^g	----	c	1800	-342	-329	-297	-265	-234	-204
	Ti ₃ O ₅	-587.0 ^g	30.92 ^a	----	----	>2500 (est.)	----	c	1400	-553	-531	-481	-434	-386	-341
	TiO ₂	-225.6 ^g	12.01 ^a	15.5 ^d	----	2123 ^d	3273 ^d	c	1800	-212	-204	-182	-161	-139	-120
Tl	----	----	15.4 ^a	1.03 ^a	38.81 ^b	576.8 ^a	1730 ^b	c	800	----	----	----	----	----	----
	TlCl	-48.99 ^a	25.6 ^e	4.0 ^a	24.8 ^a	702 ^a	1079 ^a	c	850	-44.1	-40.9	-34.4	-39	-38	-35
	TlCl ₃	-60 ^e	45 ^e	----	----	>370 ^f	----	-	----	-45 ^e	----	----	----	----	----
	TlF	-65 ^e	22 (est.)	3.5 (est.)	20.4 ^f	600 ^f	928 ^f	-	----	-60	-56	-52	-57	-55	-42
	TlF ₃	-175 ^e	36 ^e	7.5 (est.)	35.0 (est.)	823 ^a	1600 (est.)	-	----	-159	-149	-128	-110	-97	-73
	Tl ₂ O	-42.5 ^g	23.8 ^a	5 (est.)	19 (est.)	573 ^a	773	-	----	-33.1	-27.1	-18.4	-15.6	+1.1	+40.3
	Tl ₂ O ₃	-84 ^g	32 (est.)	14.5 (est.)	----	990 ^a	>2500 (est.)	-	----	-62	-48	-12	+17	+58	+146

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
U	----	----	12. 03 ^a	3. 0 ^b	110 ^b	1405 ^b	3800 ^b	c	1300	----	----	----	----	----	----
	UCl ₃	-212. 2 ^x	37. 99 ^y	9 ^y	41 ^y	1108 ^y	2000 ^y	x	1108	-196	-186	-161	-137	-126	-117
	UCl ₄	-251. 1 ^x	47. 14 ^x	7	33 ^y	863 ^y	1060 ^y	x	863	-230	-216	-186	-173	-161	-151
				(est.)											
	UCl ₅	-262. 3 ^x	62 ^y	8. 5 ^y	18 ^y	600 ^y	800 ^y	-	----	-238	-221	-196	-176	-158	-137
	UCl ₆	-272. 6 ^x	68. 3 ^y	7	5	452 ^y	550 ^y	-	----	-242	-222	-184	-144	-100	- 60
				(est.)	(est.)										
	UF ₃	-340	26 ^y	8. 5 ^y	61 ^y	1700 ^y	2550 ^y	-	----	-322	-310	-281	-252	-228	-205
		(est.)													
	UF ₄	-443 ^y	36 ^y	5. 7 ^y	57. 5 ^y	1309 ^y	1690 ^y	-	----	-421	-407	-373	-339	-319	-308
	UF ₅	-488 ^y	43 ^y	8 ^y	23. 0 ^y	600 ^y	1000 ^y	-	----	-461	-444	-409	-389	-370	-348
	UF ₆ (g)	-505 ^y	90. 34 ^z	4. 588 ^{aa}	11. 9 ^y	338 ^y	329 ^y	z	1000	-485	-468 ^{bb}	-422 ^{bb}	----	----	----
					(subl.)	(subl.)									
	UO	-129 ^g	17	----	----	>2500	----	-	----	-123	-120	-110	- 99	- 87	- 77
			(est.)			(est.)									
	UO ₂	-259. 03 ^{cc}	18. 6 ^y	----	----	3000 ^g	----	dd	1500	-247	-238	-218	-198	-177	-157
	UO ₂ . 25	-270 ^g	----	----	----	----	----	-	----	-256 ^g	----	----	----	----	----
	UO ₂ . 62	-286 ^g	----	----	----	----	dec. 1950°K. g	-	----	-270 ^g	----	----	----	----	----
U ₃ O ₈	-854 ^g	66 ^y	----	----	----	dec. 1950°K. y	-	----	-859 ^{bb}	-835 ^{bb}	-777 ^{bb}	----	----	----	
UO ₃	-291. 9 ^g	23. 57 ^y	----	----	----	dec. 925°K. g	dd	900	-286	-273	-242	----	----	----	
V	----	----	7. 05 ^a	4. 0 ^b	106 ^b	2003 ^a	3800 ^b	d	2003	----	----	----	----	----	----
	VCl ₂	-115. 0 ^d	23. 2 ^a	8 ^f	35 ^f	1300 ^f	1650 ^f	c	1300	-104	- 97	- 80	- 65	- 61	- 59
	VCl ₃	-139 ^e	31. 3 ^a	----	----	disproportionates ^f	----	c	900	-123 ^e	-112 ^e	- 85 ^e	----	----	----
	VCl ₄	-141 ^e	61 ^e	2. 2 ^f	7. 7 ^f	247 ^f	437 ^f	-	----	-125 ^e	-115 ^e	----	----	----	----
	VF ₂	-180 ^e	19. 5	6 ^f	65 ^f	1400 ^f	2500 ^f	-	----	-169	-163	-147	-132	-121	-108
			(est.)												
	VF ₃	-285 ^e	28 ^e	11 ^f	49 ^f	1400 ^f	1700 ^f	-	----	-270	-259	-236	-215	-209	-205
	VF ₄	-325 ^e	38 ^e	6 ^f	17 ^f	600 ^f	600 ^f	-	----	-305 ^e	-291 ^e	----	----	----	----
	VF ₅	-335 ^e	50 ^e	----	8. 5 ^f	375 ^f	384 ^f	-	----	-312 ^e	-298 ^e	----	----	----	----
	VO	- 98 ^g	10. 2 ^d	----	----	>2500	3400 ^g	-	----	- 92	- 87	- 78	- 69	- 61	- 52
						(est.)									
	V ₂ O ₃	-296 ^g	23. 58 ^a	28	----	2250 ^a	dec.	c	1800	-277	-264	-235	-207	-182	-158
				(est.)			3300 ^g	-	----	----	----	----	----	----	----
	V ₃ O ₅	< -467. 5 ^g	----	----	----	----	----	-	----	----	----	----	----	----	----
	VO ₂	-171 ^g	12. 32 ^a	13. 6 ^d	----	1818 ^d	dec.	c	1900	-158	-150	-131	-113	- 98	- 84
							3000 ^g								
	V ₂ O ₅	-372. 5 ^g	31. 3 ^a	15. 56 ^a	----	943 ^a	2573 ^d	c	1500	-341	-320	-272	-234	-196	-163

TABLE 1

Element	Compound	Heat of Formation at 298°K., kcal. /mole	Entropy at 298°K., e. u.	Heat of Fusion at M. Pt., kcal. /mole	Heat of Evaporation at B. Pt., kcal. /mole	Melting Pt., °K.	Boiling Pt., °K.	Experimental Heat Capacity		Calculated Free Energy of Formation, kcal. /mole					
								Ref.	Max. Exptl. Temp. °K.	298°K	500°K	1000°K	1500°K	2000°K	2500°K
W	----	----	8.0 ^a	8.42 ^b	184.58 ^b	3650 ^b	5950 ^b								
	WCl ₂	- 36 ^e	31 ^e	----	----	disproportionates at 700°K. ^t	----	-	----	- 27 ^t	- 21 ^t	- 9 ^t	+ 3 ^t	- 2 ^t	----
	WCl ₄	- 69 ^e	50 ^e	----	----	disproportionates at 500°K. ^t	----	-	----	- 50 ^t	- 37 ^t	- 21 ^t	- 10 ^t	+ 2 ^t	----
	WCl ₅	- 82 ^e	66 ^e	----	----	521 ^a	549 ^a	-	----	- 60 ^t	- 45 ^t	- 30 ^t	- 17 ^t	- 3 ^t	----
	WCl ₆	- 96.9 ^e	75 ^e	2.3 ^f	15.2 ^f	557 ^f	610 ^f	-	----	- 74 ^t	- 46.5 ^t	- 24 ^t	- 2 ^t	+ 2 ^t	----
	WF ₄	----	35 ^e	----	----	----	----	-	----	----	----	----	----	----	----
	WF ₅	----	59 ^e	4.5 ^f	11.5 ^f	380 ^f	510 ^f	-	----	----	----	----	----	----	----
	WF ₆	-300.0 ^d	89 ^d	1.8 ^f	6.35 ^f	273 ^f	290 ^f	-	----	----	----	----	----	----	----
	WO ₂	-134 ^g	15.0 ^d	11.5 ^d	----	1543 ^d	dec. 2125°K. ^g	-	----	-121	-113	- 93	- 74	- 60	- 45
	WO ₃	-200.84 ^a	19.9 ^a	15 (est.)	----	1743 ^a	> 2500 (est.)	d	1743	-182	-170	-141	-116	- 95	- 73
Zn	----	----	9.95 ^a	1.74 ^d	27.5 ^d	692.7 ^d	1180 ^d	c	1200	----	----	----	----	----	----
	ZnCl ₂	- 99.5 ^d	25.9 ^a	5.54 ^f	28.71 ^f	556 ^f	1005 ^f	c	556	- 88.4	- 81.2	- 68.5	- 63.5	- 54.7	- 46.3
	ZnF ₂	-176 ^e	21.5 (est.)	7 ^f	44 ^t	1145 ^f	1775 ^f	-	----	-165	-158	-140	-118	-100	- 88
	ZnO	- 83.17 ^a	10.4 ^d	12.5 (est.)	----	2248 ^g	----	c	1600	- 76.0	- 71.2	- 58.9	- 38.9	- 15.5	+ 6.0
Zr	----	----	9.28 ^{ee}	5.5 ^b	----	2400 ^b	----	ff	1400	----	----	----	----	----	----
	ZrCl ₂	-145 ^a	29.5 (est.)	7.3 (est.)	35 ^f	1000 ^f	1750 ^f	-	----	-135	-129	-114	-105	-101	-103
	ZrCl ₃	-208 ^a	40 ^e	----	----	900 ^f	disp.	-	----	-193 ^e	-183 ^e	-162 ^e	----	----	----
	ZrCl ₄	-230 ^a	44.5 ^a	----	25.29 ^f (subl.)	----	604 ^f (subl.)	ff	604	-219	-195	-177	-164	-149	-134
	ZrF ₂	-230 ^a	21.5 (est.)	14.5 (est.)	----	1800 (est.)	> 2500 (est.)	-	----	-219	-212	-196	-183	-174	-168
	ZrF ₃	-350 ^a	28 (est.)	13 ^f	58 ^f	1600 ^f	2400 ^f	-	----	-334	-323	-300	-280	-267	-258
	ZrF ₄	-445 ^a	35.5 (est.)	----	45 ^f (subl.)	----	1200 ^f (subl.)	-	----	-424	-415	-378	-360	-361	-340
	ZrO ₂	-261.8 ^g	12.03 ^a	20.8 ^a	----	2950 ^a	4570 ^g	ff	1850	-248	-239	-216	-194	-173	-152

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Figure 1b.
Chlorides of Elements of Group II.

Figure 2e.

Fluorides of Group V Elements.

7216 40

37570

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A SURVEY OF THE FREE ENERGIES OF FORMATION OF THE FLUORIDES, CHLORIDES, AND OXIDES OF ELEMENTS TO 2500°K. ALVIN GLASSNER. AUG. 1953. (ANL-5107)

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The free energies of formation of oxides, fluorides, and chlorides in the range from 298 to 2500°K were calculated with the aid of the free-energy functions $(F^{\circ}_{298})/T$ for the compound and its constituent elements, together with a knowledge of H°_{298} to give $(\Delta F^{\circ} - \Delta H^{\circ}_{298})/T$, where T = the absolute temperature, F = the free energy at temperature T , H°_{298} = the heat content at 298.16°K, and H°_{298} = the heat of formation at 298.16°K. The free-energy functions themselves were calculated from the values of the heat capacities at constant pressure, the entropies at 298.16°K, and latent heats of transformation. The results of the survey are summarized in tabular form. The data are also presented in terms of free energy vs. temperature diagrams for the various groups of the periodic table for chlorides, fluorides, and oxides separately. (J.A.G.)

1. Chlorides -- Formation
2. Fluorides -- Formation
3. Oxides -- Formation

I. Glassner, Alvin

II. Argonne National Lab.

Contract W-31-109-eng-38

N-6

For NEA:

Chlorides -- free energies of formation of from 298 to 2500°K

(over)

Fluorides -- free energies of formation of, from 298 to 2500°K

Oxides -- free energies of formation of, from 298 to 2500°K

11/4/53/JAG/mg