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Thermodynamic Properties of Selected Metal Sulfates and Their Hydrates

By Carroll W. DeKock

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Thermodynamic data for selected metal sulfates were critically evaluated and compiled as part of the Bureau of Mines program to provide a scientific base for use in developing new technology and predicting the feasibility of new processes. Values for Cp°, S°, $H^\circ - H^\circ_{298}$, $-(G^\circ - H^\circ_{298})/T$, ΔHf°, ΔGf°, and log Kf as functions of temperature are given in tabular form. Thermodynamic data were compiled for Ag_2SO_4, $Al_2(SO_4)_3$, $Al_2(SO_4)_3 \cdot 6H_2O$, $BaSO_4$, $BeSO_4$, $BeSO_4 \cdot 2H_2O$, $BeSO_4 \cdot 4H_2O$, $CaSO_4$, $CaSO_4 \cdot 1/2H_2O$, $CaSO_4 \cdot 2H_2O$, $CdSO_4$, $CdSO_4 \cdot H_2O$, $CdSO_4 \cdot 8/3H_2O$, $2CdO \cdot CdSO_4$, Cs_2SO_4, $In_2(SO_4)_3$, K_2SO_4, $KAl(SO_4)_2$, $KAl(SO_4)_2 \cdot 12H_2O$, Li_2SO_4, $Li_2SO_4 \cdot H_2O$, $MgSO_4$, $MgSO_4 \cdot H_2O$, $MgSO_4 \cdot 2H_2O$, $MgSO_4 \cdot 4H_2O$, $MgSO_4 \cdot 6H_2O$, $MgSO_4 \cdot 7H_2O$, Na_2SO_4, $Na_2SO_4 \cdot 7H_2O$, $Na_2SO_4 \cdot 10H_2O$, $(NH_4)_2SO_4$, $NH_4Al(SO_4)_2$, $NH_4Al(SO_4)_2 \cdot 12H_2O$, $PbSO_4$, Rb_2SO_4, Tl_2SO_4, and $Zr(SO_4)_2$.

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THERMODYNAMIC PROPERTIES OF SELECTED METAL SULFATES AND THEIR HYDRATES

By Carroll W. DeKock [1]

ABSTRACT

Thermodynamic data for selected metal sulfates were critically evaluated and compiled as part of the Bureau of Mines program to provide a scientific base for use in developing new technology and predicting the feasibility of new processes. Values for $Cp°$, $S°$, $H° - H°_{298}$, $-(G° - H°_{298})/T$, $\Delta Hf°$, $\Delta Gf°$, and log Kf as functions of temperature are given in tabular form.

Thermodynamic data were compiled for Ag_2SO_4, $Al_2(SO_4)_3$, $Al_2(SO_4)_3 \cdot 6H_2O$, $BaSO_4$, $BeSO_4$, $BeSO_4 \cdot 2H_2O$, $BeSO_4 \cdot 4H_2O$, $CaSO_4$, $CaSO_4 \cdot 1/2H_2O$, $CaSO_4 \cdot 2H_2O$, $CdSO_4$, $CdSO_4 \cdot H_2O$, $CdSO_4 \cdot 8/3H_2O$, $2CdO \cdot CdSO_4$, Cs_2SO_4, $In_2(SO_4)_3$, K_2SO_4, $KAl(SO_4)_2$, $KAl(SO_4)_2 \cdot 12H_2O$, Li_2SO_4, $Li_2SO_4 \cdot H_2O$, $MgSO_4$, $MgSO_4 \cdot H_2O$, $MgSO_4 \cdot 2H_2O$, $MgSO_4 \cdot 4H_2O$, $MgSO_4 \cdot 6H_2O$, $MgSO_4 \cdot 7H_2O$, Na_2SO_4, $Na_2SO_4 \cdot 7H_2O$, $Na_2SO_4 \cdot 10H_2O$, $(NH_4)_2SO_4$, $NH_4Al(SO_4)_2$, $NH_4Al(SO_4)_2 \cdot 12H_2O$, $PbSO_4$, Rb_2SO_4, Tl_2SO_4, and $Zr(SO_4)_2$.

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[1] Research chemist, Albany Research Center, Bureau of Mines, Albany, OR; faculty member, Oregon State University, Corvallis, OR.

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

atm	atmosphere (1 atm = 101,325 pascals)
cal	thermochemical calorie (1 cal = 4.1840 joules)
cal/mol	calorie per mole
cal/(mol•K)	calorie per mole per kelvin
K	kelvin (the unit of thermodynamic temperature)
kcal/mol	kilocalorie per mole
mol	mole (gram formula weight or molar mass)
mol pct	mole percent
Pa	pascal

OTHER ABBREVIATIONS AND SYMBOLS USED IN THIS REPORT

°	Standard state, pure phase at 1 atm
C_p	Heat capacity at constant pressure
F	Faraday constant, 23,060.0 cal/(volt•equivalent)
ΔG	Gibbs energy change (ΔGf = Gibbs energy of formation)
ΔH	Enthalpy change (ΔHf = enthalpy of formation)
$H - H_{298}$	Enthalpy increment between T and 298.15 K
$H_{298} - H_0^\circ$	Enthalpy increment between 298 and 0 K
Log K	Logarithm (base 10) of the equilibrium constant
Log Kf	Logarithm (base 10) of equilibrium constant of formation
P	Pressure in atmospheres, 1 atm = 101,325 Pa
R	Gas constant, 1.98719 cal/(mol•K)
S	Entropy
T	Thermodynamic temperature in kelvins

INTRODUCTION

As part of the Bureau of Mines effort to provide thermodynamic data for mineral technology advancement, thermodynamic properties of selected metal sulfates and their hydrates were critically evaluated and compiled. A 1982 publication compiled similar data on selected transition metal sulfates (11).[2] A number of early reviews of metal sulfates exist (29, 32, 48).

The data for the early reviews are often based on high-temperature sulfate decomposition data. The thermodynamic properties here are calculated on the basis of calorimetric data, many of which were unavailable for the early reviews. No review of the hydrated metal sulfates exists.

This compilation has been prepared in the same format as Bureau of Mines Bulletin 672, "Thermodynamic Properties of the Elements and Oxides," by L. B. Pankratz (45). The values for the standard heat capacities (C_p°), high-temperature relative enthalpies ($H^\circ - H_{298}^\circ$), enthalpies of formation (ΔHf°), and Gibbs energies of formation (ΔGf°) are given in tabular form. The tables include Gibbs energy functions, $-(G^\circ - H_{298}^\circ)/T$, and logarithms (base 10) of the equilibrium constants of formation, log Kf.

Where possible, all phases of an element or compound are presented in a single table. Temperatures of transformations and thermodynamic properties at these temperatures are included in the table. Immediately below the table, the nature of these transformations is given, along with their associated enthalpies. All thermodynamic values for the elements are from Pankratz (45).

METHODS, CONVENTIONS, AND SYMBOLS

The values in this compilation are the result of a review and critical evaluation of relevant thermodynamic data through July 1984. Standard enthalpies of formation at 298.15 K are corrected to the latest CODATA (7) values where the accuracy of the original data warrants such care. The CODATA value for the standard enthalpy of formation of $SO_4^{2-}(aq)$ at infinite dilution is the major correction for this document. CODATA gives $\Delta Hf^\circ(SO_4^{2-}, \infty aq) = -217.4$ kcal/mol, while Wagman (63) reports $\Delta Hf^\circ(SO_4^{2-}, \infty aq) = -217.32$ kcal/mol. Sulfate ion corrections in this document are based on the CODATA value. Also, $\Delta Hf^\circ(H_2O,\ell) = -68.315$ kcal/mol, used throughout this review, is from Wagman (63).

The selected experimental data were fitted to a polynomial in terms of temperature by using a modified form of the computer program described by Justice (28). This program, along with a plot of function $(H^\circ - H_{298}^\circ)/(T - 298.15)$, which takes a known value of Cp° at 298.15 K, was used to merge high-temperature data smoothly with low-temperature heat capacity data. The resulting polynomial was then used in a subroutine of the program to calculate standard heat capacities, relative enthalpies, Gibbs energy functions, and standard entropies at selected temperatures. In addition, the thermodynamic tables include values for the standard enthalpy of

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[2] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

formation, Gibbs energy of formation, and the logarithm of the equilibrium constant of formation. Tabulated values are given for the substances in their standard states (indicated by the superscript "°").

Sources of data used in this compilation are given in the list of references; additional sources reviewed and considered less reliable are not included. Estimates are used where the necessary data were lacking, as explained in the section on estimation procedures. Estimated and extrapolated values are indicated in the note below each table.

The common practice of tabulating five- and sometimes six-digit values has been followed. For example, enthalpy values are given to the nearest calorie. The number of digits given is not intended to reflect the accuracy of the experimental values used, but rather to produce internal consistency in the tables. In the text, values are given to the significant figures to which they are thought to be accurate.

ESTIMATION PROCEDURES FOR HYDRATES

The same estimation procedures were used as in the first compilation in this series (11) for hydrates for which data were unknown. Briefly, the estimation methods are as follows: Heat capacities for hydrates were estimated by adding 9.3 cal/(mol•K) per mole H_2O to the heat capacity of the anhydrous compound to obtain the heat capacity at 298.15 K. The entropy of the hydrates at 298.15 K was estimated by adding 9.5 cal/(mol•K) per mole H_2O to the entropy of the anhydrous compound at 298.15 K. Other estimation procedures, tailored for individual compounds, are discussed in the text.

With the values at 298.15 K in hand, it was then necessary to estimate the heat capacities above 298.15 K. For hydrates for which low-temperature data are available, heat capacities up to 550 K were estimated by extrapolating the low-temperature data, using a least-squares fit with the quadratic equation, $Cp = a + bT + cT^2$. For salts for which data are not available, high-temperature heat capacities were estimated using the following equation:

$$Cp(T) = Cp(298.15) + b(T-298.15),$$

where b is a coefficient dependent on n, the number of water molecules. The values calculated for b are--

n	b	n	b
1	0.09	5	0.180
2	.10	6	.216
3	.132	7	.252
4	.144		

DISCUSSION OF THERMODYNAMIC PROPERTIES

$Ag_2SO_4(c)$

The values from Parker (50) for the enthalpy of formation and entropy at 298.15 K are adopted.

Ag_2SO_4 exists in the orthorhombic form at ambient temperature and transforms to the Na_2SO_4(I) structure at 698.6 K (27, 42). Low-temperature heat capacity values have been measured by Latimer (40). Heat capacity values measured by Shmidt (57) from 299.2 to 727.6 K using an adiabatic calorimeter were merged with the low-temperture values of Latimer (40). Conard (9) measured high-temperature enthalpy values over the range 568 to 1,025 K using a drop calorimeter. The results of Conard do not merge well with those of Shmidt (57). Also the values of Conard scatter badly. For these reasons the values of Shmidt (57) for the transition enthalpy and temperature were adopted. Shmidt determined the transition temperature to be 698.6 K with an enthalpy of transition equal to 3.901 kcal/mol. An enthalpy of transition equal to 3.8 kcal/mol and a transition temperature of 700 K were determined in this laboratory by differential scanning calorimetry.[3] These values are in good agreement with those of other workers using differential thermal analysis. Hedvall (25) observed a transition enthalpy of 3.8 kcal/mol. Others (9, 25) have reported a transition temperature of 703 K.

Conard (9) found a melting point of 926 K with an enthalpy of fusion equal to 4.56 kcal/mol. These values are adopted here. Their average heat capacity value for the liquid was 35 cal/(mol•K), which is the adopted value.

$Al_2(SO_4)_3$(c)

Low-temperature heat capacity data are given by Shomate (58) from 54.7 to 296.2 K. An excellent fit of these data was obtained using the appropriate polynomial equations from which the entropy and enthalpy over the range 53 to 298.15 K were obtained. The entropy and enthalpy from 0 to 53 K were obtained from the function sum given by Shomate (58) to represent the heat capacities over the entire temperature range:

$$D(155.7/T) + 3E(238/T) + 6E(528/T) + 6E(1{,}194/T).$$

The symbols D and E denote, respectively, Debye and Einstein functions. There is excellent agreement between the present data analysis and that of Shomate (58), as shown below for entropies at 298.15 K for $Al_2(SO_4)_3$:

	Shomate	This work
0 to 53 K..........	3.76	3.77
53 to 298.15 K.....	53.43	53.45
S°(298.15).........	57.19	57.22

The above entropy values at 298.15 K are both rounded to 57.2 cal/(mol•K).

The high-temperature enthalpy values were taken from Shomate (59).

The standard enthalpy of formation at 298.15 K is from Wagman (63), corrected for the enthalpy of formation of the sulfate ion at infinite dilution.

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[3] The author thanks Robert R. Brown, research chemist, Albany Research Center, Albany, OR 97321, for performing the differential scanning calorimeter measurements on various compounds.

$Al_2(SO_4)_3 \cdot 6H_2O(c)$

Low-temperature heat capacities are given by Shomate (58) from 54.5 to 296.1 K. An excellent fit of these data was obtained using the appropriate polynomial equations from which the entropy and enthalpy over the range 53 ro 298.15 K were obtained from the computer subroutine programs. The entropy and enthalpy from 0 to 53 K were obtained from the function sum given by Shomate to represent the heat capacities over the entire temperature range:

$$D(78.9/T) + 3E(142.5/T) + 8E(340/T) + 16E(872/T).$$

Good agreement exists between the present data analysis and that of Shomate as shown below for entropies at 298.15 K for $Al_2(SO_4)_3 \cdot 6H_2O$:

	Shomate	This work
0 to 53 K..........	11.23	11.24
53 to 298.15 K.....	100.88	100.95
S°(298.15).........	112.09	112.19

Accordingly 112.2 cal/(mol•K) was added as the entropy at 298.15 K.

The high-temperature enthalpy values were obtained by extrapolating the low-temperature data between 206.2 to 296.5 K using a quadratic polynomial.

The standard enthalpy of formation at 298.15 K is from Wagman (63), corrected for the enthalpy of formation of the sulfate ion at infinite dilution.

$BaSO_4(c)$

Parker's (49) enthalpy of formation for $BaSO_4(c)$, after correction for the enthalpy of formation of the sulfate ion at infinite dilution, was adopted. The entropy of $BaSO_4(c)$ at 298.15 K was recalculated from the low-temperature heat capacity data of Latimer (39). Latimer estimated the entropy at 20 K to be 0.379 cal/(mol•K), which is adopted here, and calculated $S^\circ_{298}[BaSO_4(c)] = 31.5$ cal/(mol•K). Recalculation of the data gave $S^\circ_{298}[BaSO_4(c)] = 31.6$ cal/(mol•K), which is the value reported by Parker (49). This evaluation also gave $[H^\circ_{298} - H^\circ_o] = 4.584$ kcal/mol.

The only high-temperature enthalpy study is that of Lashchenko (36) over the range 293 to 1,323 K. These data were only used above 600 K because the lower temperature data had severe scatter. The low-temperature heat capacity data of Latimer (39) were extrapolated to 500 K and joined smoothly with the high-temperature data.

$BeSO_4(c)$

Navratil (44) determined the enthalpy of formation of $BeSO_4(c)$ by sulfuric acid solution calorimetry. The value was obtained in a careful study that involved three separate Be samples and two different sulfuric acid solutions. Recalculated using the CODATA (7) SO_4^{2-} value, the Navratil value yields $\Delta Hf^\circ_{298}[BeSO_4(c)] = -287.08$ kcal/mol. This value is adopted. The value in Parker (48) for $\Delta Hf^\circ_{298}[BeSO_4(c)]$ is -288.05 kcal/mol. Low-temperature heat capacity values, high-temperature enthalpies, and the entropy at 298.15 K were those adopted by JANAF (15).

$BeSO_4 \cdot H_2O(c)$

From a study of the vapor pressure of $BeSO_4(c) + H_2O$, Broers (5-6) determined $\Delta H°(298.15\ K) = 16.27$ kcal/mol for the reaction $BeSO_4 \cdot H_2O(c) = BeSO_4(c) + H_2O(g)$. Using the adopted ΔH values for $BeSO_4(c)$ and $H_2O(g)$ gives $\Delta Hf^\circ_{298}[BeSO_4 \cdot H_2O(c)] = -361.15$ kcal/mol. This value is adopted. Parker (49) gives $\Delta Hf^\circ_{298}[BeSO_4 \cdot H_2O] = -364.2$ kcal/mol. Broers (5-6) also obtained $S^\circ_{298}[BeSO_4 \cdot H_2O] = 28.91$ cal/(mol·K) and estimated $C^\circ_p = 28.56$ cal/(mol·K). These values are adopted. The high-temperature heat capacity dependence was estimated as discussed earlier.

$BeSO_4 \cdot 2H_2O(c)$ and $BeSO_4 \cdot 4H_2O(c)$

Navratil (44) recalculated the enthalpies of formation for $BeSO_4 \cdot 2H_2O(c)$ and $BeSO_4 \cdot 4H_2O(c)$ obtained by Taylor (62) in the study of the enthalpies of formation of $BeSO_4(c)$ and the respective hydrates. After correction for the enthalpy of formation for SO_4^{2-} Navratil's (44) recalculated values are $\Delta Hf^\circ_{298}[BeSO_4 \cdot 2H_2O(c)] = -434.78$ kcal/mol and $\Delta Hf^\circ_{298}[BeSO_4 \cdot 4H_2O(c)] = -578.38$ kcal/mol. These values are adopted. Parker (49) gives $\Delta Hf^\circ_{298}[BeSO_4 \cdot 2H_2O] = -435.74$ kcal/mol and $\Delta Hf^\circ_{298}[BeSO_4 \cdot 4H_2O] = -579.29$ kcal/mol. Low-temperature heat capacity values and entropy values are taken from Gardner (23). High-temperature heat capacities were obtained by extrapolation of the low-temperature values.

$CaSO_4(c)$

There are three recognized forms of anhydrous calcium sulfate: insoluble anhydrite, (i), and two forms of soluble anhydrite, (α) and (β). The enthalpies of formation for all three forms are taken from Parker (49) after correction for the enthalpy of formation of the sulfate ion.

All entropy values were reevaluated using the low-temperature heat capacity data of Kelley (31). Debye-Einstein function sums are given by Kelley for each form of anhydrous $CaSO_4$. These were used to extrapolate the entropy and enthalpy from 0 K to approximately 50 K. The function sums for each of the forms are--

$CaSO_4(i)$: $D(208/T) + 2E(300/T) + 2E(815/T)$

$CaSO_4(\alpha)$: $D(217/T) + 2E(278/T) + 2E(821/T)$

$CaSO_4(\beta)$: $D(286/T) + 2E(246/T) + 2E(844/T)$

The calculated entropy values are compared below with those reported by Kelley.

	$CaSO_4(i)$	$CaSO_4(\alpha)$	$CaSO_4(\beta)$
S°(50.1)(Kelley)	1.51	1.76	1.57
S°(50.1)(This work)	1.655	1.89	1.48
S°(298) - S°(50.1)(Kelley)	23.95	24.17	24.33
S°(298) - S°(50.1)(This work)	23.96	24.16	24.24
S°(298)(Kelley)	25.5	25.93	25.90
S°(298)(This work)	25.62	26.05	25.72

It is clear from the above tabulation that the entropy calculated by either method is in good agreement between 50.1 and 298.15 K for both $CaSO_4$(i) and $CaSO_4(\alpha)$. For $CaSO_4(\beta)$ a difference of 0.09 cal/(mol•K) exists is this region. This is very good considering the method of calculation, i.e., Kelley determined the entropy by a graphical method, while in this work the entropy is determined by a least-squares analytical fit of the heat capacity data with a subsequent subroutine generating entropy. Kelley's (31) Debye-Einstein functions were used for the extrapolation from 0 to 50.1 K, yet in all cases the two sets differ by 0.1 cal/(mol•K) in an apparently random manner. In this work the value of the entropy calculated from the Debye-Einstein functions from 0 to 50.1 K was determined using a computer program that had been carefully checked against other data. At present it is uncertain why Kelley's (31) extrapolated values differ so significantly from those reported here.

The high-temperature enthalpy values for all three forms were taken from Lashchenko (37-38). The data scatter badly at the lower temperatures. Accordingly, some of the lower values were deleted in the analysis.

$CaSO_4 \cdot 2H_2O$(c), $CaSO_4 \cdot 1/2H_2O(\alpha$,c), and $CaSO_4 \cdot 1/2H_2O(\beta$,c)

Three hydrates of calcium sulfate are considered here: $CaSO_4 \cdot 2H_2O$(c), $CaSO_4 \cdot 1/2H_2O(\alpha$,c), and $CaSO_4 \cdot 1/2H_2O(\beta$,c).

The definitive work on the hydrates of calcium sulfate still remains that of Kelley published in 1941 (31). The enthalpies of formation and entropies at 298.15 K for all the compounds were taken from Parker (49). Heat capacity values were extrapolated to 550 K by the methods discussed in the introduction, using the heat capacity data from Kelley (31) for the hemihydrates and the data from Latimer (39) for the dihydrate. The data below 298.15 K for the dihydrate were obtained by fitting the heat capacity data of Latimer (39) to a polynomial and calculating the entropy and enthalpy at the temperatures of interest. The fit in the present work yielded S°(298) - S°(19.95) = 46.062 cal/(mol•K), while the entropy reported by Latimer (39) over the same temperature interval was 46.096 cal/(mol•K) obtained by a graphical method.

$CdSO_4$(c)

Adami (1) found the enthalpy of the reaction

$$CdO(c) + H_2SO_4 \cdot 7.068H_2O(l) = CdSO_4(c) + 8.068\ H_2O(l)$$

to be ΔH = -20.140 kcal by hydrochloric acid solution calorimetry. CODATA (7) reports $\Delta Hf^\circ_{298}[CdO(c)] = -61.7$ kcal/mol. Wagman (63) gives $\Delta Hf^\circ_{298}[H_2SO_4 \cdot 7.068H_2O] = -209.566$ kcal/mol after making the sulfate correction. These values give $\Delta Hf^\circ_{298}[CdSO_4(c)] = -223.09$ kcal/mol, which is the adopted value. Low-temperature (15.22 to 312.81 K) heat capacities and entropies are those reported by Papadopoulos (47). No high-temperature enthalpy data are available; however, the data were estimated above 300 K using the high-temperature enthalpy data for $ZnSO_4$(c) (11).

$CdSO_4 \cdot H_2O$(c) and $CdSO_4 \cdot 8/3H_2O$(c)

The enthalpies of formation for both $CdSO_4 \cdot H_2O$ and $CdSO_4 \cdot 8/3H_2O$ were taken from Wagman (63) after making the sulfate correction. Heat capacities (15 to 300 K) and entropies are from Papadopoulos (47). High-temperature data were estimated by extrapolating the low-temperature heat capacities to 550 K.

$2CdO \cdot CdSO_4(c)$

Beyer (4) measured the heat capacity of cadmium oxysulfate, $2CdO \cdot CdSO_4$, from 5.16 to 300.7 K by adiabatic calorimetry. The relative enthalpy was measured to 1,001.5 K by copper-block drop calorimetry. A nonisothermal transition was observed over the temperature range 245 to 260 K with a peak at 253 K. The value at 298.15 K for $[H^\circ_T - H^\circ_0] = 8.604$ kcal/mol.

Ko (33), using HCl solution calorimetry, found $\Delta Hf^\circ_{298}[2CdO \cdot CdSO_4(c)] = -345.70$ kcal/mol. This value is adopted. This is to be compared with Schaefer (55), who calculated a third-law value from electrochemical cell measurements, $\Delta Hf^\circ_{298}[2CdO \cdot CdSO_4(c)] = -344.4$ kcal/mol, in good agreement with the value reported by Ko (33).

$Cs_2SO_4(c)$

The enthalpy of formation, $\Delta Hf^\circ_{298}[Cs_2SO_4] = -344.97$ kcal/mol, is from Wagman (65) after correction for the enthalpy of formation of the sulfate ion at infinite dilution.

The low-temperature heat capacities of Cs_2SO_4 were measured by Paukov (51) over the range 12.82 to 308.72 K. The adopted value for $S^\circ_{298} = 50.64$ cal/(mol·K) and the value for $[H^\circ_{298} - H^\circ_0] = 6.628$ kcal are those reported by JANAF (18) in their evaluation of Paukov's (51) data. High-temperature heat capacities have been measured by Shmidt (56) over the range 297.5 to 774.0 K. Denielou (12-14) carried out high-temperature enthalpy measurements by drop calorimetry over the range 400 to 910 K. The low-temperature heat capacities of Paukov (51) were joined with the high-temperature heat capacities of Shmidt (56) to provide enthalpy values which were merged with the enthalpy values of Denielou (12-14) above 700 K.

JANAF (18) adopted a transition temperature of 940 K with an enthalpy of transition of 1.030 kcal/mol, based on the difference between the smooth enthalpy curves of the high- and low-temperature modifications. A transition temperature of 997 K and an enthalpy of transition value of 0.072 kcal/mol were determined in this laboratory by differential scanning calorimetry. The present work adopts the latter values for the enthalpy and temperature of transition for Cs_2SO_4. This transition is very similar to that for Rb_2SO_4. See the discussion of the Rb_2SO_4 system.

The melting point is that adopted by JANAF (18) at 1,278 K, and the enthalpy of fusion is calculated to be 8.47 kcal/mol from the difference in the smoothed enthalpy curves between the liquid and the solid forms.

$In_2(SO_4)_3(c)$

Barany (2) determined the enthalpy of formation to be $\Delta Hf^\circ_{298}[In_2(SO_4)_3(c)] = -651.34$ kcal/mol, using solution calorimetry. This value includes the correction for the enthalpy of formation of the sulfate ion.

Low-temperature heat capacity data for anhydrous indium sulfate were reported by Pankratz (46) from 52 to 296 K. A reevaluation of these data, including a recalculation of the Debye-Einstein function sums, yielded $S^\circ_{298}[In_2(SO_4)_3] = 72.24$ cal/(mol·K). This is good agreement with Pankratz's analysis, which yielded 72.2 cal/(mol·K).

High-temperature enthalpies were also obtained from Pankratz (46). An excellent fit between low- and high-temperature heat capacities were observed.

$K_2SO_4(c)$

All data for K_2SO_4 are taken from JANAF (16).

$KAl(SO_4)_2(c)$

Wagman (65) reported $\Delta Hf^\circ_{298}[KAl(SO_4)_2(c)] = -590.56$ kcal/mol after correction for the enthalpy of formation of the sulfate ion. This value is adopted. A recalculation of the data from Kelley (30) yielded $\Delta Hf^\circ_{298}[KAl(SO_4)_2(c)] = -590.46$ kcal/mol, in good agreement with the value reported by Wagman (65).

Low-temperature heat capacity values were reported by Kelley (30) in the range 54.6 to 296.5 K. These data were reevaluated, including a recalculation of the Debye-Einstein function sums, to obtain $S^\circ_{298}[KAl(SO_4)_2(c)] = 48.94$ cal/(mol•K). Kelley's (30) analysis yielded $S^\circ_{298}[KAl(SO_4)_2(c)] = 48.9$; Wagman (65) also reports $S^\circ_{298}[KAl(SO_4)_2(c)] = 48.9$ cal/(mol•K).

A smooth fit between the low- and high-temperature heat capacity data was obtained by giving a weight of zero to the 368.5 K point reported by Kelley (30). High-temperature heat capacities and entropies were calculated from a smooth fit of the remaining high-temperature enthalpy data (30).

$KAl(SO_4)_2 \cdot 12H_2O(c)$

The enthalpy of formation reported by Wagman (65) is $\Delta Hf^\circ_{298}[KAl(SO_4)_2 \cdot 12H_2O(c)] = -1{,}448.96$ kcal/mol after correction for the enthalpy of formation of the sulfate ion. This value is identical to that obtained from Kelley (30) using values from the present work for the enthalpy of formation of K_2SO_4 and $Al_2(SO_4)_3 \cdot 6H_2O$, together with the accepted value for the enthalpy of formation of water.

The entropy at 298.15 K is from Wagmen (65). Low-temperature heat capacities from Shomate (58) were matched with the heat capacities reported by Gronvold (24) in the region 298.15 to 358.99 K.

The transition enthalpy for $KAl(SO_4)_2 \cdot 12H_2O(c)$ to $KAl(SO_4)_2 \cdot 3H_2O$ plus aqueous solution at 358.99 K is reported by Gronvold (24) to be 22.8 kcal.mol.

$Li_2SO_4(c)$

All data for $Li_2SO_4(c)$ are taken from JANAF (17).

$Li_2SO_4 \cdot H_2O(c)$

The enthalpy of formation of $Li_2SO_4 \cdot H_2O(c)$ was determined by Barany (3) using hydrochloric acid solution calorimetry. Recalculation of the results using auxiliary data from CODATA (7) and Wagman (63) yields $\Delta Hf^\circ_{298}[Li_2SO_4 \cdot H_2O] = -414.53$ kcal. This value is adopted. Low-temperature heat capacities have been measured by Paukov (53) from 13.87 to 300.74 K. Paukov's calculated value for S°_{298} is 34.995 cal/(mol•K), which is adopted here. The value reported by Wagman (65), 39.1 cal/(mol•K), appears to be in error. The heat capacity values above 298.15 K were obtained by extrapolation of the low-temperature values of Paukov (53).

$MgSO_4(c)$

Until recently, the enthalpy of formation values for $MgSO_4(c)$ were quite uncertain. For example, JANAF (15) selected $\Delta Hf^\circ_{298}[MgSO_4(c)] = -301.6$ kcal/mol, while Parker (49) gave -307.1 kcal/mol; other values reported were -313.0 kcal/mol by Kelley (29) and -310.0 kcal/mol by Lau (41). $MgSO_4(c)$ exists in two orthorhombic crystalline forms, $MgSO_4(\alpha)$ and $MgSO_4(\beta)$ (8). The above-reported values for the enthalpy of formation make no reference to the crystalline form of $MgSO_4$. In an effort to clarify the enthalpy of formation value for $MgSO_4$, Ko (34) prepared both forms of $MgSO_4$ and determined their enthalpies of formation by hydrochloric acid solution calorimetry. The values are $\Delta Hf^\circ_{298}[MgSO_4(\alpha)] = -308.03$ kcal/mol and $\Delta Hf^\circ_{298}[MgSO_4(\beta)] = -307.11$ kcal/mol after correcting for the enthalpy of formation of the sulfate ion. Heat capacities, entropies, and high-temperature enthalpies are taken from JANAF (15).

$MgSO_4 \cdot H_2O(c)$

Correcting the value of Ko (34) for the enthalpy of formation of the sulfate ion yields $\Delta Hf^\circ_{298}[MgSO_4 \cdot H_2O(c)] = -384.80$ kcal/mol. This value was determined in the same study as the above values for α- and β-$MgSO_4(c)$. The heat capacity at 9° C was determined by Rolla (54) to be 33.2 cal/(mol•K). The heat capacity values in the $MgSO_4 \cdot H_2O$ table are estimates based on the value by Rolla. The entropy at 298.15 K is from Parker (49).

$MgSO_4 \cdot 2H_2O(c)$ and $MgSO_4 \cdot 4H_2O(c)$

The enthalpies of formation are from Parker (49) after making the SO_4^{2-} correction, while the heat capacities and entropies are estimates. The enthalpy of formation, $\Delta Hf^\circ_{298}[MgSO_4 \cdot 2H_2O(c)] = -453.3$ kcal/mol, appears to be too positive for the required stability of the dihydrate with respect to the monohydrate.

$MgSO_4 \cdot 6H_2O(c)$

The enthalpy of formation is from Parker (49) after making the SO_4^{2-} correction, while the low-temperature heat capacities and entropy values are from Cox (10). The heat capacity values above 320 K were obtained by extrapolation of the low-temperature values.

$MgSO_4 \cdot 7H_2O(c)$

The enthalpy of formation at 298.15 K after making the SO_4^{2-} correction and entropy at 298.15 K are from Parker (49). The heat capacity at 9° C was determined by Rolla (54), and the heat capacity values given in the $MgSO_4 \cdot 7H_2O$ table are estimates based on their value.

$Na_2SO_4(c)$

All data for $Na_2SO_4(c)$ are taken from JANAF (16).

$Na_2SO_4 \cdot 7H_2O(c)$

Gans (22), from equilibrium vapor pressure measurements, has established the existence of the heptahydrate as an independent stable phase. The upper temperature limit for coexistence with the saturated aqueous solution is 296.61 K for the heptahydrate. Gans values are $\Delta Hf^\circ_{298}[Na_2SO_4 \cdot 7H_2O]$ = -826.96 kcal/mol and $S^\circ_{298}[Na_2SO_4 \cdot 7H_2O]$ = 98.47 cal/(mol•K).

$Na_2SO_4 \cdot 10H_2O(c)$

The enthalpy of formation, after the sulfate correction, and entropy are taken from Wagman (65). The temperature dependence of the heat capacity was estimated using the method discussed in the introduction. Gronvold (24) reported that the peritectic transition to $Na_2SO_4(c)$ and aqueous solution occurs at 305.533 K with an enthalpy of 18.65 kcal/mol.

$(NH_4)_2SO_4(c)$

The enthalpy of formation is from Parker (50) after making the SO_4^{2-} correction.

The low-temperature heat capacity values from 52.7 to 295.4 K and high-temperature enthalpies from 402 to 640 K were reported by Kelley (30).

The entropy at 298.15 K was recalculated from the low-temperature heat capacity data (30). TheDebye-Einstein function sum given by Kelley (30) for $(NH_4)_2SO_4(c)$ up to 150 K is

$$D(121.7/T) + 2E(201/T) + 4E(472/T) + 8E(1{,}090/T).$$

This function sum gave S°(50.12) = 4.58 cal/(mol•K). The data from 50.12 to 190 K were fit with a polynomial, which resulted in an entropy of 26.71 cal/(mol•K) in this region. Kelley (30) reports a transition at 233.4 K with an entropy change of 10.47 cal/(mol•K) in the region 190 to 230 K. The data from 230 to 298.15 K were fit with a polynomial, yielding an entropy change of 10.95 cal/(mol•K) in this interval. The total yields S°_{298} = 52.71 cal/(mol•K), which is the adopted value. This value is also reported by Parker (50). This compares with S°_{298} = 52.6±0.3 cal/(mol•K) reported by Kelley (30) from analysis of the same data.

The slopes of the low-temperature heat capacity data and the heat capacities obtained from the high-temperature enthalpy data did not match smoothly. A good match was obtained by eliminating the points at 402.1 K and 639.6 K and weighting the low-temperature data appropriately.

$NH_4Al(SO_4)_2(c)$

The enthalpy of formation of $NH_4Al(SO_4)_2$ is reported by Wagman (63), after making the sulfate correction, to be $\Delta Hf^\circ_{298}[NH_4Al(SO_4)_2]$ = -562.36 kcal/mol. Kelley (30) reports $\Delta Hf^\circ_{298}[(NH_4)AlSO_4)_2]$ = -561.15 kcal/mol, which was recalculated using our adopted values for enthalpy of formation of $(NH_4)_2SO_4$ and $Al_2(SO_4)_3 \cdot 6H_2O$, giving a value of $\Delta Hf^\circ_{298}[NH_4Al(SO_4)_2]$ = -562.46 kcal/mol. The average of these two, -562.4 kcal/mol, is adopted.

Low-temperature heat capacity values from 54.7 to 296.2 K are reported by Kelley (30). High-temperature enthalpy measurements from 377.9 to 698.7 K are also reported by Kelley (30).

The entropy at 298.15 K was recalculated on the basis of the low-temperature heat capacity data of Kelley (30). The Debye-Einstein function sum given by (30) for $NH_4Al(SO_4)_2$ is

$$D(165.2/T) + 3E(248/T) + 5E(538/T) + 5E(1{,}216/T).$$

This function sum gave S°(53.09) = 3.39 cal/(mol•K), very close to Kelley's 3.37 cal/(mol•K) (30). The recalculated entropy is S°_{298} = 51.71 cal/(mol•K), which is identical with that reported by Kelley (30). The above evaluation also gave $[H^\circ_{298} - H^\circ_0]$ = 8.629 kcal/mol at 298.15 K.

$NH_4Al(SO_4)_2 \cdot 12H_2O(c)$

The enthalpy of formation, $\Delta Hf^\circ_{298}[NH_4Al(SO_4)_2 \cdot 12H_2O(c)]$ = -1,420.42 kcal/mol, is from Wagman (63), corrected for the enthalpy of formation of the sulfate ion. This value compares well with $\Delta Hf^\circ[NH_4Al(SO_4)_2 \cdot 12H_2O]$ = -1,420.59 kcal/mol, which is based on a recalculation of the data given in Kelley (30).

The heat capacity values are from Gronvold (24) merged with values to 296 K from Kelley (30). Gronvold (24) also reports that the enthalpy of fusion of $NH_4Al(SO_4) \cdot 12H_2O(c)$ at 367.13 K is 29.16 kcal/mol.

The entropy at 298.15 K is from Wagman (63).

$PbSO_4(c)$

The enthalpy of formation and entropy at 298.15 K are from CODATA (7). $H^\circ_{298} - H^\circ_0$ is also taken from CODATA (7). High-temperature enthalpy values were taken from data by Krestovnikov (35), who obtained data over the range 288 to 1,073 K by drop calorimetry. Krestovnikov's values were fit smoothly to the low-temperature heat capacity data of Gallagher (21).

Comparison of log Kf values for $PbSO_4$ obtained from solid state emf determinations by Fredriksson (20) show close correspondence between the calculated and experimental values:

T/K	log Kf($PbSO_4$) Ref(20)	 This work
1,000	28.43	28.51
1,100	23.95	23.91

It is gratifying to see this close correlation between data arrived at by calorimetric measurements (our calculations) and emf high-temperature measurements (20).

$Rb_2SO_4(c)$

The enthalpy of formation $\Delta Hf^\circ_{298}[Rb_2SO_4]$ = -343.12 kcal/mol is from CODATA (7).

The low-temperature heat capacity from 12.54 to 303.12 K was measured by Paukov (52). Paukov's calculated entropy at 298.15 K is $S^\circ_{298}[Rb_2SO_4]$ = 47.19 cal/(mol•K), which is adopted here. High-temperature heat capacities from 298.15 to 770.5 K have been measured by Shmidt (56), while Denielou (12-14) has measured the high-temperature enthalpy from 274 to 1,466 K. Both Ingraham (26) and Denielou (12-14) report a first-order transition at 931 K with transition enthalpies of 2.11 kcal/mol and 1.039 kcal/mol, respectively. The enthalpy of transition was measured in this laboratory by differential scanning calorimetry (DCS) and found to be far smaller than originally reported. The measured value is 0.104±0.01 kcal/mol in the region 925 to

938 K. The DSC data show an anomalous increase in the heat capacity beginning at about 825 K with a very small first-order component at 931 K. The data of Denielou (12-14) show this anomalous effect, which they ignored in their interpretation. The same effect is noted for Cs_2SO_4.

The low-temperature data of Paukov (52) were smoothly merged with the high-temperature data of Shmidt (56) by fitting the data to orthogonal polynomials. The data of Denielou (12-14) were not used in the region 298 to 770 K because they did not merge well with the low-temperature data of Paukov (52). The enthalpy data of Denielou (12-14) above 770 K, however, were merged with the data of Shmidt (56) to obtain the enthalpy to 931 K. Above 931 K, the data of Denielou (12-14) were available. The data in the liquid region were smoothly extrapolated to 2,000 K using a heat capacity for the liquid of 49.33 cal/(mol•K). The enthalpy of fusion ΔH°_m = 9.180 kcal/mol is adopted from Denielou (12-14). Our enthalpy values in the region above 931 K were identical to those of Denielou (12-14).

$Tl_2SO_4(c)$

The entropy and enthalpy of formation at 298.15 K are from Wagman (63) after correction for the enthalpy of formation of the sulfate ion. Shmidt (57) measured the heat capacity of Tl_2SO_4 using an adiabatic calorimeter over the temperature range 298.4 to 582.8 K. These results were fitted smoothly with the high-temperature enthalpy data of Dworkin (19) taken with a drop calorimeter. Their data span the temperature range 400.2 to 901.1 K for solid and 922.2 to 988.3 K for the liquid. They found the orthorhombic-to-hexagonal transition to occur at 774 K with an enthalpy of 0.160 kcal/mol. The melting point was found to be 916 K with an enthalpy of fusion equal to 5.870 kcal/mol. These values are adopted. For the liquid segment, a constant heat capacity of 49 cal/(mol•K) was adopted on the basis of the enthalpy values reported by Dworkin (19).

$Zr(SO_4)_2(c)$

The standard enthalpy of formation has been measured by Melnikova (43) by hydrochloric acid solution calorimetry. The enthalpy change of the reaction

$$Zr(SO_4)_2 \cdot 0.03SO_3(c) + 4KCl(c) + 0.03H_2)(1)$$

$$= ZrCl_4(c) + 2K_2SO_4(c) + 0.03H_2SO_4(soln)$$

was found to be ΔHr = 116.15 kJ(27.76 kcal). The standard enthalpy of formation can be calculated using $\Delta Hf^\circ_{298}[ZrCl_4]$ = -234.35 kcal/mol (64), $\Delta Hf^\circ_{298}[K_2SO_4]$ = -343.62 kcal/mol (16), $\Delta Hf^\circ_{298}[H_2SO_4 \cdot 800H_2O]$ = -213.208 kcal/mol (63), $\Delta Hf^\circ_{298}[KCl]$ = -104.385 kcal/mol (65), and $\Delta Hf^\circ_{298}[H_2O]$ = -68.315 kcal/mol (63).

Combining the above values yields $\Delta Hf^\circ_{298}[\alpha\text{-}Zr(SO_4)_2(c)]$ = -536.16 kcal/mol, which is the adopted value. This value is compared with $\Delta Hf^\circ_{298}[Zr(SO_4)_2]$ = -529.9 kcal/mol reported by Wagman (64).

Stern (61) estimated $S^\circ_{298}[Zr(SO_4)_2]$ = 31.8 cal/(mol•K). High-temperature enthalpy values to 1,050 K have been measured by Smith (60) using an ice calorimeter.

$Ag_2SO_4(c)$
Silver sulfate
[Formation: $2Ag(c) + S(c,l) + 2\ O_2(g) = Ag_2SO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°$_{298}$)/T	H° - H°$_{298}$	ΔHf°	ΔGf°	
298.15	31.523	48.020	48.020	0	-171.040	-147.787	108.329
300	31.606	48.215	48.022	.058	-171.040	-147.642	107.556
368.3	34.137	54.979	48.695	2.314	-170.967	-142.322	84.453
368.3	34.137	54.979	48.695	2.314	-171.063	-142.322	84.453
388.36	34.881	56.810	49.068	3.006	-171.024	-140.757	79.210
388.36	34.881	56.810	49.068	3.006	-171.437	-140.757	79.210
400	35.312	57.846	49.309	3.415	-171.427	-139.838	76.403
432.02	36.242	60.601	50.045	4.561	-171.404	-137.311	69.462
500	38.217	66.046	51.856	7.095	-171.392	-131.940	57.670
600	40.833	73.247	54.832	11.049	-171.075	-124.072	45.192
699	43.309	79.645	57.903	15.198	-170.547	-116.356	36.380
699	43.732	85.229	57.903	19.099	-166.646	-116.356	36.380
700	43.754	85.316	57.945	19.160	-166.622	-116.286	36.306
717.82	44.038	86.419	58.638	19.942	-166.494	-115.006	35.015

Phase changes: 368.3 K, orthrhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
698.6 K, first-order transition of $Ag_2SO_4(c)$; ΔH° = 3.901 kcal/mol.
717.824 K, boiling point of S to equilibrium of S_n (n = 1 to 8).

Sources: The enthalpy of formation and entropy at 298 K are from Parker (50). The heat capacity at 298 K is from Latimer (40). See text for high-temperature enthalpy values.

$Ag_2SO_4(c,l)$
Silver sulfate
[Formation: $2Ag(c) + 0.5S_2(g) + 2\ O_2(g) = Ag_2SO_4(c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°$_{298}$)/T	H° - H°$_{298}$	ΔHf°	ΔGf°	
298.15	31.523	48.020	48.020	0	-186.395	-157.301	115.303
300	31.606	48.215	48.022	.058	-186.392	-157.119	114.460
400	35.312	57.846	49.309	3.415	-186.078	-147.403	80.536
500	38.217	66.046	51.856	7.095	-185.520	-137.794	60.229
600	40.833	73.247	54.832	11.049	-184.770	-128.312	46.737
699	43.309	79.645	57.903	15.198	-183.876	-119.067	37.227
699	43.732	85.229	57.906	19.099	-179.975	-119.067	37.227
700	43.754	85.316	57.945	19.160	-179.947	-118.982	37.147
800	45.348	91.263	61.744	23.615	-178.859	-110.349	30.145
900	46.941	96.696	65.330	28.229	-177.683	-101.858	24.734
926	47.355	98.039	66.230	29.455	-177.362	-99.672	23.524
926	35.000	102.963	66.230	34.015	-172.802	-99.671	23.524
1,000	35.000	105.653	69.048	36.605	-172.807	-93.826	20.505
1,025	35.000	106.518	69.952	37.480	-172.818	-91.852	19.584

Phase changes: 698.6 K, first-order transition of $Ag_2SO_4(c)$; ΔH° = 3.901 kcal/mol.
926 K, melting point of $Ag_2SO_4(c)$; ΔH° = 4.56 kcal/mol.

Sources: The enthalpy of formation and entropy at 298 K are from Parker (50). The heat capacity at 298 K is from Latimer (40). See text for high-temperature enthalpy values.

$Al_2(SO_4)_3(c)$
Aluminum sulfate
[Formation: $2Al(c) + 3S(c,l) + 6\ O_2(g) = Al_2(SO_4)_3(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
0	0	0	∞	-9.614	-814.440	-814.440	∞
100	12.860	12.860	100.510	-8.765	-818.453	-793.673	1,734.549
200	45.650	35.790	62.385	-5.319	-821.246	-767.722	838.917
298.15	62.000	57.200	57.200	0	-822.620	-741.116	543.246
300	62.140	57.584	57.201	.115	-822.635	-740.609	539.527
368.3	71.093	71.351	58.558	4.711	-822.898	-721.899	428.370
368.3	71.093	71.351	58.558	4.711	-823.186	-721.899	428.370
388.36	73.722	75.192	59.320	6.164	-823.195	-716.380	403.138
388.36	73.722	75.192	59.320	6.164	-824.434	-716.380	403.138
400	75.248	77.392	59.814	7.031	-824.475	-713.141	389.637
432.02	78.156	83.299	61.339	9.487	-824.592	-704.226	356.249
500	84.331	95.221	65.145	15.038	-824.913	-685.243	299.516
600	90.414	111.174	71.512	23.797	-824.557	-657.329	239.429
700	94.191	125.421	78.215	33.044	-823.742	-629.516	196.541
717.82	94.570	127.794	79.417	34.726	-823.566	-624.573	190.157

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation is from Wagman (63) corrected for the sulfate ion. The entropy at 298 K and low-temperature heat capacities are from Shomate (58); see discussion in text. The high-temperature enthalpy values are from Shomate (59).

$Al_2(SO_4)_3(c)$
Aluminum sulfate
[Formation: $2Al(c,l) + 1.5S_2(g) + 6\ O_2(g) = Al_2(SO_4)_3(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
0	0	0	∞	-9.614	-860.394	-860.394	∞
100	21.870	12.860	100.510	-8.765	-865.015	-834.143	1,822.995
200	45.650	35.790	62.385	-5.319	-867.693	-802.106	876.490
298.15	62.000	57.200	57.200	0	-868.685	-769.657	564.167
300	62.140	57.584	57.201	.115	-868.691	-769.041	560.239
400	75.248	77.392	59.814	7.031	-868.428	-735.838	402.038
500	84.331	95.221	65.145	15.038	-867.295	-702.803	307.191
600	90.414	111.174	71.512	23.797	-865.641	-670.051	244.063
700	94.191	125.421	78.215	33.044	-863.717	-637.602	199.066
800	96.318	138.152	84.927	42.580	-861.714	-605.443	165.397
900	97.440	149.568	91.486	52.274	-859.744	-573.528	139.270
933.61	97.693	153.145	93.642	55.553	-859.100	-562.852	131.757
933.61	97.693	153.145	93.642	55.553	-864.260	-562.851	131.757
1,000	98.194	159.874	97.818	62.056	-862.954	-541.465	118.335
1,100	99.214	169.276	103.892	71.922	-860.982	-509.408	101.209

Phase changes: 933.61 K, melting point of Al; ΔH° = 2.580 kcal/mol.

Sources: The enthalpy of formation is from Wagman (63) corrected for the sulfte ion. The entropy at 298 K and low-temperature heat capacities are from Shomate (58); see discussion in text. The high-temperature enthalpy values are from Shomate (59).

$Al_2(SO_4)_3\cdot 6H_2O(c)$
Aluminum sulfate hexahydrate
[Formation: $2Al(c) + 3S(c,l) + 9\ O_2(g) + 6H_2(g) = Al_2(SO_4)_3\cdot 6H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°$_{298}$)/T	H° - H°$_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-18.137	-1,251.744	-1,251.744	∞
100	41.570	29.710	192.980	-16.327	-1,261.180	-1,211.238	2,647.125
200	84.140	72.090	121.925	-9.967	-1,267.011	-1,158.799	1,266.261
298.15	118.061	112.188	112.188	0	-1,269.770	-1,105.002	809.978
300	118.652	112.920	112.190	.219	-1,269.798	-1,103.979	804.238
350	133.954	132.376	113.693	6.539	-1,270.155	-1,076.306	672.067
368.3	139.085	139.334	114.796	9.037	-1,270.127	-1,066.171	632.660
368.3	139.085	139.334	114.796	9.037	-1,270.415	-1,066.172	632.660
388.36	144.710	146.871	116.256	11.890	-1,270.293	-1,055.046	593.721
388.36	144.710	146.871	116.256	11.890	-1,271.532	-1,055.047	593.721
400	147.974	151.193	117.210	13.593	-1,271.474	-1,048.560	572.899
432.02	156.131	162.909	120.162	18.468	-1,271.208	-1,030.725	521.415
450	160.712	169.369	122.000	21.316	-1,271.182	-1,020.715	495.721
500	172.166	186.906	127.620	29.643	-1,270.256	-992.929	434.003
550	182.338	203.803	133.783	38.511	-1,268.808	-965.259	383.554

<u>Phase changes</u>: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Wagman (63). See text for entropy at 298 K. Low-temperature heat capacities are from Shomate (58). High-temperature heat capacities are estimated.

$BaSO_4(c)$
Barium sulfate
[Formation: $Ba(c) + S(c,l) + 2\ O_2(g) = BaSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°$_{298}$)/T	H° - H°$_{298}$	ΔHf°	ΔGf°	
298.15	24.414	31.600	31.600	0	-352.200	-325.668	238.718
300	24.537	31.749	31.602	.044	-352.204	-325.503	237.126
368.3	27.167	37.063	32.125	1.818	-352.261	-319.417	189.540
368.3	27.167	37.063	32.125	1.818	-352.357	-319.418	189.541
388.36	27.939	38.524	32.419	2.371	-352.363	-317.623	178.740
388.36	27.939	38.524	32.419	2.371	-352.776	-317.623	178.740
400	28.387	39.356	32.608	2.699	-352.795	-316.569	172.963
432.02	29.025	41.567	33.192	3.618	-352.868	-313.667	158.675
500	30.380	45.929	34.633	5.648	-353.153	-307.474	134.395
582	31.270	50.618	36.562	8.180	-353.524	-299.955	112.636
582	31.270	50.618	36.562	8.180	-353.524	-299.955	112.636
600	31.465	51.573	36.998	8.745	-353.538	-298.298	108.654
700	32.120	56.476	39.437	11.927	-353.627	-298.084	90.255
717.82	32.196	57.284	39.870	12.500	-353.648	-287.440	87.514

<u>Phase changes</u>: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
582 K, α-β transition point of Ba; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Parker (49) after correction for the sulfate ion. The entropy at 298 K is from Parker (49); see discussion in text. The low-temperature heat capacity values are from Latimer (39), while the relative high-temperature enthalpy values are from Lashchenko (36).

$BaSO_4(c)$
Barium sulfate
[Formation: $Ba(c,l) + 0.5S_2(g) + 2\ O_2(g) = BaSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	24.414	31.600	31.600	0	-367.555	-335.182	245.692
300	24.537	31.749	31.602	.044	-367.556	-334.980	244.030
400	28.387	39.356	32.608	2.699	-367.446	-324.135	177.097
500	30.380	45.929	34.633	5.648	-367.281	-313.327	136.953
582	31.270	50.618	36.562	8.180	-367.291	-304.481	114.336
582	31.270	50.618	36.562	8.180	-367.291	-304.481	114.336
600	31.465	51.573	36.998	8.745	-367.233	-302.539	110.198
700	32.120	56.476	39.437	11.927	-366.952	-291.779	91.096
768	32.409	59.469	41.080	14.123	-366.816	-284.485	80.955
800	32.545	60.795	41.842	15.162	-366.755	-281.056	76.780
900	32.836	64.646	44.166	18.432	-366.531	-270.357	65.651
1,000	33.043	68.117	46.391	21.726	-366.307	-259.684	56.753
1,002	33.046	68.183	46.434	21.792	-366.303	-259.470	56.593
1,002	33.046	68.183	46.434	21.792	-368.155	-259.471	56.593
1,100	33.194	71.273	48.511	25.038	-367.993	-248.846	49.441
1,200	33.308	74.167	60.530	28.364	-367.805	-238.023	43.349
1,300	33.394	76.836	52.452	31.699	-367.607	-227.215	38.198

Phase changes: 582 K, α-β transition point of Ba; ΔH° = 0 kcal/mol.
768 K, β-γ transition point of Ba; ΔH° = 0 kcal/mol.
1,002 K, melting point of Ba; ΔH° = 1.852 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (49) after correction for the sulfate ion. The entropy at 298 K is from Parker (49); see discussion in text. The low-temperature heat capacity values are from Latimer (39), while the relative high-temperature enthalpy values are from Lashchenko (36).

$BeSO_4(\alpha,\beta,\gamma)$
Beryllium sulfate
[Formation: $Be(c) + S(c,l) + 2\ O_2(g) = BeSO_4(\alpha,\beta,\gamma)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-3.102	-284.510	-284.510	∞
100	7.008	4.453	32.603	-2.815	-285.785	-277.639	606.772
200	14.502	11.683	20.323	-1.728	-286.621	-268.885	293.820
298.15	20.482	18.635	18.635	0	-287.080	-260.453	190.915
300	20.581	18.762	18.635	.038	-287.085	-260.289	189.618
368.3	23.482	23.309	19.083	1.556	-287.206	-254.172	150.824
368.3	23.482	23.309	19.083	1.556	-287.302	-254.172	150.824
388.36	24.334	24.577	19.335	2.036	-287.320	-252.367	142.018
388.36	24.334	24.577	19.335	2.036	-287.733	-252.367	142.018
400	24.828	25.303	19.498	2.322	-287.757	-251.307	137.306
432.02	25.783	27.252	20.001	3.132	-287.827	-248.387	125.652
500	27.810	31.180	21.258	4.961	-288.018	-242.163	105.848
600	30.310	36.470	23.360	7.866	-288.025	-232.983	84.863
700	32.980	41.340	25.584	11.029	-287.793	-223.828	69.881
717.82	33.483	42.175	25.986	11.621	-287.724	-222.200	67.651

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is based on Navratil (44) after correction for the sulfate ion. Low-temperature heat capacity values, the entropy at 298 K, and the relative high-temperature enthalpy values are from JANAF (15).

$BeSO_4(\alpha,\beta,\gamma)$
Beryllium sulfate
[Formation: $Be(c,l) + 0.5S_2(g) + 2\ O_2(g) = BeSO_4(\alpha,\beta,\gamma)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	$Cp°$	$S°$	$-(G° - H°_{298})/T$	$H° - H°_{298}$	$\Delta Hf°$	$\Delta Gf°$	
0	0	0	∞	-3.102	-299.828	-299.828	∞
100	7.008	4.453	32.603	-2.815	-301.305	-291.129	636.254
200	14.502	11.683	20.323	-1.728	-302.103	-280.346	306.344
298.15	20.482	18.635	18.635	0	-302.435	-269.967	197.889
300	20.581	18.762	18.635	.038	-302.437	-269.766	196.522
400	24.828	25.303	19.498	2.322	-302.408	-258.872	141.439
500	27.810	31.180	21.258	4.961	-302.145	-248.017	108.407
600	30.310	36.470	23.360	7.866	-301.719	-237.224	86.408
700	32.980	41.340	25.584	11.029	-301.118	-226.524	70.723
800	35.800	45.927	27.843	14.467	-300.309	-215.920	58.986
863	37.650	48.709	29.265	16.780	-299.682	-209.295	53.002
863	37.650	49.017	29.265	17.046	-299.416	-209.295	53.002
900	38.730	50.620	30.110	18.459	-299.003	-205.439	49.887
908	38.970	50.964	30.292	18.770	-298.909	-204.608	49.247
908	38.970	56.110	30.292	23.443	-294.236	-204.608	49.247
1,000	41.690	60.004	32.844	27.160	-293.037	-195.582	42.744
1,100	43.759	64.080	35.501	31.437	-291.547	-185.909	36.936
1,200	45.222	67.953	38.045	35.890	-289.924	-176.380	32.123
1,300	46.258	71.616	40.488	40.466	-288.221	-166.982	28.072
1,400	46.984	75.072	42.836	45.130	-286.471	-157.720	24.621
1,500	47.480	78.331	45.094	49.855	-284.697	-148.596	21.650
1,527	47.567	79.179	45.690	51.138	-284.218	-146.144	20.916
1,527	47.567	79.179	45.690	51.138	-284.829	-146.144	20.916
1,560	47.673	80.198	46.410	52.710	-284.243	-143.162	20.056
1,560	47.673	80.198	46.410	52.710	-287.162	-143.164	20.056
1,600	47.802	81.407	47.269	54.620	-286.424	-139.478	19.052
1,700	47.970	84.310	49.363	59.410	-284.571	-130.360	16.759
1,800	48.000	87.053	51.381	64.209	-282.724	-121.345	14.733
1,900	48.000	89.649	53.328	69.009	-280.892	-112.414	12.930
2,000	48.000	92.111	55.207	73.809	-279.073	-103.597	11.320

Phase changes:
863 K, α-β transition point of $BeSO_4$; ΔH° = 0.266 kcal/mol.
908 K, β-γ transition point of $BeSO_4$; ΔH° = 4.673 kcal/mol.
1,527 K, α-β transition point of Be; ΔH° = 0.611 kcal/mol.
1,560 K, melting point of Be; ΔH° = 2.919 kcal/mol.

Sources: The enthalpy of formation at 298 K is based on Navratil (44) after correction for the sulfate ion. Low-temperature heat capacity values, the entropy at 298 K, and the relative high-temperature enthalpy values are from JANAF (15).

$BeSO_4 \cdot H_2O(c)$
Beryllium sulfate monohydrate
[Formation: $Be(c) + S(c,l) + 2.5\ O_2(g) = BeSO_4 \cdot H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	28.560	28.910	28.910	0	-361.150	-320.977	235.280
300	28.726	29.087	28.910	.503	-361.159	-320.728	233.647
350	33.227	33.853	29.276	1.602	-361.326	-313.974	196.052
368.3	34.874	35.588	29.547	2.225	-361.342	-311.498	184.841
368.3	34.874	35.588	29.547	2.225	-361.438	-311.498	184.841
388.36	36.679	37.485	29.907	2.943	-361.429	308.777	173.762
388.36	36.679	37.485	29.907	2.943	-361.842	-308.777	173.762
400	37.727	38.584	20.144	3.376	-361.841	-307.187	167.837
432.02	40.609	41.598	30.883	4.629	-361.808	-302.814	153.185
450	42.227	43.287	31.345	5.374	-361.829	-300.360	145.873
500	46.727	47.969	32.773	7.598	-361.584	-293.541	128.305
550	51.227	52.634	34.367	10.047	-361.126	-286.752	113.943

<u>Phase changes</u>: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is based on Broers (5); see discussion in text. The entropy and heat capacity value at 298 K are from Broers (5). High-temperature heat capacities are estimated.

$BeSO_4 \cdot 2H_2O(c)$
Beryllium sulfate dihydrate
[Formation: $Be(c,l) + S(c,l) + 3\ O_2(g) + 2H_2(g) = BeSO_4 \cdot 2H_2O)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-5.865	-428.770	-428.770	∞
100	14.330	12.890	64.290	-5.140	-431.735	-415.484	908.027
200	26.280	26.250	42.040	-3.104	-433.606	-398.188	435.114
298.15	36.630	39.010	39.010	0.000	-434.780	-381.009	279.283
300	36.808	39.237	39.010	0.068	-434.794	-380.676	277.318
350	41.383	45.261	39.475	2.025	-435.075	-371.631	232.054
368.3	42.892	47.409	39.817	2.796	-435.135	-368.312	218.554
368.3	42.892	47.409	39.817	2.796	-435.231	-368.312	218.554
388.36	44.546	49.731	40.269	3.675	-435.272	-364.665	205.213
388.36	44.546	49.731	40.269	3.675	-435.686	-364.665	205.213
400	45.506	51.061	40.563	4.199	-435.717	-362.536	198.078
432.02	47.856	54.659	41.475	5.696	-435.779	-356.676	180.432
450	49.175	56.637	42.041	6.568	-435.864	-353.384	171.625
500	52.392	61.988	43.770	9.109	-435.836	-344.219	150.456
550	55.155	67.115	45.662	11.799	-435.674	-335.061	133.139

<u>Phase changes</u>: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Navratil (44). The entropy at 298 K and low-temperature heat capacity values are from Gardner (23). High-temperature heat capacities are estimated.

$BeSO_4 \cdot 4H_2O(c)$
Beryllium sulfate tetrahydrate
[Formation: $Be(c,l) + S(c,l) + 4\ O_2(g) + 4H_2(g) = BeSO_4 \cdot 4H_2O$)]

T, K	cal/(mol•K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-8.306	-568.688	-568.688	∞
100	20.880	18.850	91.140	-7.229	-573.429	-548.825	1,199.440
200	36.720	38.180	59.840	-4.332	-576.423	-522.688	571.159
298.15	51.770	55.680	55.680	0.000	-578.380	-496.359	363.836
300	52.049	56.001	55.681	0.096	-578.405	-495.851	361.223
350	59.503	64.586	56.343	2.885	-578.899	-482.049	301.001
368.3	62.184	67.687	56.830	3.998	-579.001	-476.982	283.038
368.3	62.184	67.687	56.830	3.998	-579.097	-476.982	283.038
388.36	65.124	71.063	57.477	5.276	-579.162	-471.417	265.287
388.36	65.124	71.063	57.477	5.276	-579.575	-471.417	265.287
400	66.829	73.011	57.901	6.044	-579.609	-468.175	255.795
432.02	71.437	78.333	59.218	8.258	-579.632	-459.253	232.323
450	74.025	81.299	60.041	9.566	-579.665	-454.245	220.609
500	81.091	89.465	62.575	13.445	-579.366	-440.321	192.462
550	88.028	97.520	65.387	17.673	-578.740	-426.440	169.450

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Navratil (44). Th entropy at 298 K and low-temperature heat capacity values are from Gardner (23). High-temperature heat capacities are estimated.

$CaSO_4(i,c)$
Calcium sulfate (insoluble anhydrite)
[Formation: $Ca(c) + S(c,l) + 2\ O_2(g) = CaSO_4(i,c)$]

T, K	cal/(mol•K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.105	-340.370	-340.370	∞
100	11.007	6.707	43.307	-3.660	-341.711	-333.422	728.685
200	19.067	17.073	27.663	-2.118	-342.496	-324.790	354.909
298.15	23.878	25.620	25.620	0	-342.840	-316.009	231.638
300	23.965	25.771	25.621	.045	-342.842	-315.841	230.087
368.3	25.873	30.956	26.140	1.774	-342.881	-309.689	183.768
368.3	25.873	30.956	26.140	1.774	-342.977	-309.689	183.768
388.36	26.434	32.344	26.425	2.298	-342.983	-307.876	173.255
388.36	26.434	32.344	26.425	2.298	-343.396	-307.876	173.255
400	26.759	33.129	26.609	2.608	-343.415	-306.811	167.632
432.02	27.483	35.218	27.171	3.476	-343.475	-303.879	153.724
500	20.019	39.343	28.549	5.397	-343.668	-297.630	130.092
600	31.279	44.833	30.813	8.412	-343.704	-288.412	105.053
700	33.538	49.825	33.178	11.653	-343.551	-279.212	87.173
717.82	33.941	50.673	33.602	12.254	-343.505	-277.572	84.509

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. See text for discussion of entropy values at 298 K. Low-temperature heat capacities from Kelley (31). The high-temperature enthalpies are from Lashchenko (37).

$CaSO_4$(i,c)
Calcium sulfate (insoluble anhydrite)
[Formation: Ca(c,l) + $0.5S_2$(g) + 2 O_2(g) = $CaSO_4$(i,c)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
0	0	0	∞	-4.105	-355.688	-355.688	∞
100	11.007	6.707	43.307	-3.660	-357.232	-346.912	758.166
200	19.067	17.073	27.663	-2.118	-357.979	-336.251	367.434
298.15	23.878	25.620	25.620	0	-358.195	-325.523	238.612
300	23.965	25.771	25.621	.045	-358.194	-325.319	236.991
400	26.759	33.129	26.609	2.608	-358.066	-314.377	171.765
500	29.019	39.343	28.549	5.397	-357.796	-303.483	132.651
600	31.279	44.833	30.813	8.412	-357.398	-292.653	106.597
700	33.538	49.825	33.178	11.653	-356.876	-281.907	88.014
720	33.990	50.776	33.654	12.328	-356.758	-279.765	84.919
720	33.990	50.776	33.654	12.328	-356.978	-279.765	84.919
800	35.798	54.451	35.551	15.120	-356.406	-271.212	74.091
900	38.058	58.797	37.895	18.812	-355.592	-260.596	63.280
1,000	40.318	62.924	40.193	22.731	-354.719	-250.105	54.660
1,100	42.577	66.873	42.440	26.876	-353.727	-239.687	47.621
1,112	42.848	67.336	42.706	27.389	-353.600	-238.452	46.864
1,112	42.848	67.336	42.706	27.389	-355.641	-238.452	46.864
1,200	44.837	70.674	44.635	31.247	-354.288	-229.225	41.747
1,300	47.097	74.352	46.780	35.843	-352.559	-218.874	36.796
1,400	49.356	77.925	48.878	40.666	-350.623	-208.660	32.573

Phase changes: 720 K, α-β transition point of Ca; ΔH° = 0.220 kcal/mol.
1,112 K, melting point of Ca; ΔH° = 2.040 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. See text for discussion of entropy values at 298 K. Low-temperature heat capacities are from Kelley (31). The high-temperature enthalpies are from Lashchenko (37).

$CaSO_4$(β,c)
Calcium sulfate (β-soluble anhydrite)
[Formation: Ca(c) + S(c,l) + 2 O_2(g) = $CaSO_4$(β,c)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
0	0	0	∞	-4.146	-337.231	-337.231	∞
100	11.576	6.579	43.479	-3.690	-338.561	-330.260	721.772
200	19.149	17.138	27.758	-2.124	-339.322	-321.629	351.455
298.15	23.690	25.720	25.720	0	-339.660	-312.859	229.329
300	23.754	25.871	25.721	.045	-339.662	-312.691	227.793
368.3	25.806	31.059	26.240	1.775	-339.700	-306.546	181.903
368.3	25.806	31.059	26.240	1.775	-339.796	-306.546	181.903
388.36	26.409	32.444	26.525	2.299	-339.803	-304.734	171.487
388.36	26.409	32.444	26.525	2.299	-340.216	-304.735	171.487
400	26.759	33.229	26.709	2.608	-340.235	-303.671	165.916
432.02	27.483	35.318	27.271	3.476	-340.296	-300.742	152.137
500	20.019	39.443	28.649	5.397	-340.488	-294.500	128.724
600	31.279	44.933	30.913	8.412	-340.524	-285.292	103.916
700	33.538	49.925	33.278	11.653	-340.371	-276.102	86.202
717.82	33.941	50.773	33.702	12.254	-340.325	-274.464	83.563

Phase change: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. See text for discussion of entropy values at 298 K. Low-temperature heat capacities are from Kelley (31). The high-temperature enthalpies are from Lashchenko (37).

$CaSO_4$(β,c)

Calcium sulfate (β-soluble anhydrite)
[Formation: $Ca(c,l) + 0.5S_2(g) + 2\ O_2(g) = CaSO_4(\beta,c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.146	-352.549	-352.549	∞
100	11.576	6.579	43.479	-3.690	-354.082	-343.749	751.254
200	19.149	17.138	27.758	-2.124	-354.805	-333.090	363.979
298.15	23.690	25.720	25.720	0	-355.015	-322.373	236.302
300	23.754	25.871	25.721	.045	-355.014	-322.169	234.697
400	26.759	33.229	26.709	2.608	-354.886	-311.237	170.050
500	29.019	39.443	28.649	5.397	-354.616	-300.353	131.283
600	31.279	44.933	30.913	8.412	-354.219	-289.533	105.461
700	33.538	49.925	33.278	11.653	-353.696	-278.797	87.043
720	33.990	50.876	33.754	12.328	-353.578	-276.657	83.976
720	33.990	50.876	33.754	12.328	-353.798	-276.657	83.976
800	35.798	54.551	35.651	15.120	-353.227	-268.112	73.244
900	38.058	58.897	37.995	18.812	-352.413	-257.506	62.530
1,000	40.318	63.024	40.293	22.731	-351.539	-247.025	53.986
1,100	42.577	66.973	42.540	26.876	-350.547	-236.617	47.011
1,112	42.848	67.436	42.806	27.389	-350.421	-235.384	46.261
1,112	42.848	67.436	42.806	27.389	-352.461	-235.384	46.261
1,200	44.837	70.774	44.735	31.247	-351.108	-226.165	41.190
1,300	47.097	74.452	46.880	35.843	-349.379	-215.824	36.283
1,400	49.356	78.025	48.978	40.666	-347.443	-205.620	32.098

Phase changes: 720 K, α-β transition point of Ca; ΔH° = 0.220 kcal/mol.
1,112 K, melting point of Ca; ΔH° = 2.040 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. See text for discussion of entropy values at 298 K. Low-temperature heat capacities are from Kelley (31). The high-temperature enthalpies are from Lashchenko (37).

$CaSO_4$(α,c)

Calcium sulfate (α-soluble anhydrite)
[Formation: $Ca(c) + S(c,l) + 2\ O_2(g) = CaSO_4(\alpha,c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.156	-338.301	-338.301	∞
100	11.350	6.920	43.860	-3.694	-339.625	-331.358	724.172
200	19.149	17.450	28.095	-2.129	-340.387	-322.756	352.687
298.15	23.940	26.050	26.050	0	-340.720	-314.017	230.178
300	24.010	26.201	26.051	.045	-340.722	-313.850	228.637
368.3	25.888	31.386	26.570	1.774	-340.761	-307.728	182.604
368.3	25.888	31.386	26.570	1.774	-340.857	-307.728	182.604
388.36	26.439	32.773	26.855	2.298	-340.863	-305.923	172.156
388.36	26.439	32.773	26.855	2.298	-341.276	-305.923	172.156
400	26.759	33.559	27.039	2.608	-341.295	-304.863	166.567
432.02	27.483	35.647	27.601	3.476	-341.355	-301.945	152.746
500	29.019	39.773	28.979	5.397	-341.548	-295.725	129.260
600	31.279	45.263	31.243	8.412	-341.584	-286.550	104.375
700	33.538	50.255	33.608	11.653	-341.431	-277.393	86.605
717.82	33.941	51.103	34.032	12.254	-341.385	-275.761	83.958

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. See text for discussion of entropy values at 298 K. Low-temperature heat capacities are from Kelley (31). The high-temperature enthalpies are from Lashchenko (37).

$CaSO_4(\alpha,c)$
Calcium sulfate (α-soluble anhydrite)
[Formation: $Ca(c,l) + 0.5S_2(g) + 2\ O_2(g) = CaSO_4(\alpha,c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.156	-353.619	-353.619	∞
100	11.350	6.920	43.860	-3.694	-355.146	-344.848	753.654
200	19.149	17.450	28.095	-2.129	-355.870	-334.218	365.211
298.15	23.940	26.050	26.050	0	-356.075	-323.531	237.152
300	24.010	26.201	26.051	.045	-356.074	-323.328	235.541
400	26.759	33.559	27.039	2.608	-355.946	-312.429	170.701
500	29.019	39.773	28.979	5.397	-355.676	-301.578	131.818
600	31.279	45.263	31.243	8.412	-355.279	-290.791	105.919
700	33.538	50.255	33.608	11.653	-354.756	-280.088	87.446
720	33.990	51.206	34.084	12.328	-354.638	-277.954	84.370
720	33.990	51.206	34.084	12.328	-354.858	-277.954	84.370
800	35.798	54.881	35.981	15.120	-354.286	-269.436	73.606
900	38.058	59.227	38.325	18.812	-353.473	-258.863	62.860
1,000	40.318	63.354	40.623	22.731	-352.599	-248.415	54.290
1,100	42.577	67.303	42.870	26.876	-351.607	-238.040	47.294
1,112	42.848	67.766	43.136	27.389	-351.480	-236.810	46.542
1,112	42.848	67.766	43.136	27.389	-353.521	-236.810	46.542
1,200	44.837	71.104	45.065	31.247	-352.168	-227.621	41.455
1,300	47.097	74.782	47.210	35.843	-350.439	-217.313	36.533
1,400	49.356	78.355	49.308	40.666	-348.503	-207.142	32.336

Phase changes: 720 K, α-β transition point of Ca; ΔH° = 0.220 kcal/mol.
1,112 K, melting point of Ca; ΔH° = 2.040 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. See text for discussion of entropy values at 298 K. Low-temperature heat capacities are from Kelley (31). The high-temperature enthalpies are from Lashchenko (37).

$CaSO_4{\cdot}2H_2O(c)$
Calcium sulfate dihydrite
[Formation: $Ca(c) + S(c,l) + 2H_2(g) + 3\ O_2(g) = CaSO_4{\cdot}2H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-7.419	-478.221	-487.221	∞
100	19.150	12.410	78.530	-6.612	-481.328	-464.661	1,015.502
200	34.310	30.630	50.120	-3.898	-482.925	-447.281	488.760
298.15	44.102	46.400	46.400	0	-483.500	-429.645	314.934
300	44.236	46.673	46.400	.082	-483.504	-429.309	312.748
350	47.157	53.729	46.952	2.372	-483.547	-420.273	262.427
368.3	47.742	56.147	47.349	3.240	-483.543	-416.964	247.424
368.3	47.742	56.147	47.349	3.240	-483.639	-416.964	247.424
388.36	48.384	58.711	47.871	4.210	-483.623	-413.333	232.600
388.36	48.384	58.711	47.871	4.210	-484.036	-413.333	232.600
400	48.756	60.145	48.208	4.775	-484.045	-411.214	224.674
432.02	48.933	63.919	49.231	6.345	-484.082	-405.382	205.071
450	49.033	65.916	49.858	7.226	-484.182	-402.106	195.287
500	47.988	71.040	51.726	9.657	-484.334	-392.978	171.768
550	45.621	75.513	53.691	12.002	-484.584	-383.829	152.518

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. The entropy at 298 K is from Parker (49). Low-temperature heat capacity values are from Latimer (39), while the high-temperature values are estimated.

$CaSO_4 \cdot 1/2H_2O(\alpha,c)$
Calcium sulfate hemihydrite (α-soluble hemihydrate)
[Formation: $Ca(c) + S(c,l) + 0.5H_2(g) + 2.25\ O_2(g) = CaSO_4 \cdot 1/2H_2O(\alpha,c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	28.543	31.200	31.200	0	-376.930	-343.458	251.758
300	28.632	31.377	31.200	.053	-376.934	-343.249	250.053
350	30.745	35.957	31.557	1.540	-376.997	-337.629	210.822
368.3	31.295	37.538	31.815	2.108	-377.004	-335.570	199.126
368.3	31.295	37.538	31.815	2.108	-377.100	-335.570	199.126
388.36	31.899	39.220	32.155	2.744	-377.101	-333.308	187.567
388.36	31.899	39.220	32.155	2.744	-377.514	-333.308	187.567
400	32.249	40.167	32.375	3.117	-377.530	-331.983	181.385
432.02	32.822	42.678	33.044	4.162	-377.584	-328.335	166.095
450	33.144	44.023	33.456	4.755	-377.684	-326.284	158.463
500	33.429	47.536	34.694	6.421	-377.801	-320.567	140.118
550	33.105	50.711	36.007	8.087	-377.924	-314.835	125.102

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. The entropy at 298 K is from Parker (49). The heat capacity at 298 K is from Kelley (31). High-temperature heat capacities are estimated.

$CaSO_4 \cdot 1/2H_2O(\beta,c)$
Calcium sulfate hemihydrite (β-soluble hemihydrate)
[Formation: $Ca(c) + S(c,l) + 0.5H_2(g) + 2.25\ O_2(g) = CaSO_4 \cdot 1/2H_2O(\beta,c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	29.690	32.100	32.100	0	-376.430	-343.226	251.588
300	29.802	32.284	32.101	.055	-376.432	-343.019	249.886
350	32.995	37.119	32.476	1.625	-376.412	-337.451	210.711
368.3	34.137	38.830	32.750	2.239	-376.373	-335.415	199.033
368.3	34.137	38.830	32.750	2.239	-376.469	-335.415	199.033
388.36	35.388	40.673	33.111	2.937	-376.408	-333.179	187.494
388.36	35.388	40.673	33.111	2.937	-376.821	-333.179	187.494
400	36.114	41.729	33.347	3.353	-376.794	-331.872	181.324
432.02	38.064	44.585	34.074	4.541	-376.705	-328.280	166.068
450	39.159	46.159	34.526	5.235	-376.704	-326.265	158.454
500	42.129	50.439	35.903	7.268	-376.453	-320.672	140.164
550	45.025	54.591	37.415	9.447	-376.064	-315.109	125.211

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (49) corrected for the heat of formation of the sulfate ion. The entropy at 298 K is from Parker (49). Low-temperature heat capacity values are from Latimer (39), while the high-temperature valkues are estimated.

$CdSO_4(c)$
Cadmium sulfate
[Formation: $Cd(c,l) + S(c,l) + 2\ O_2(g) = CdSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	23.806	29.408	29.408	0	-223.100	-196.671	144.162
300	23.875	29.555	29.408	.044	-223.103	-196.506	143.152
368.3	25.922	34.652	29.917	1.744	-223.183	-190.442	113.007
368.3	25.922	34.652	29.917	1.744	-223.279	-190.442	113.007
388.36	26.523	36.044	30.198	2.270	-223.288	-188.653	106.163
388.36	26.523	36.044	30.198	2.270	-223.701	-188.653	106.163
400	26.872	36.832	30.380	2.581	-223.721	-187.602	102.500
432.02	27.718	38.934	30.937	3.455	-223.783	-184.709	93.439
500	29.513	43.117	32.311	5.403	-223.962	-178.541	78.039
594.26	31.806	48.409	34.452	8.294	-223.953	-169.976	62.511
594.26	31.806	48.409	34.452	8.294	-225.433	-169.976	62.511
600	31.946	48.715	34.587	8.477	-225.428	-169.435	61.716
700	34.289	53.816	36.975	11.789	-225.182	-160.123	49.992
717.82	34.701	54.683	37.403	12.404	-225.112	-158.467	48.247

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
594.26 K, melting point of Cd; ΔH° = 1.480 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is based on Adami (1); see text. The entropy and heat capacity at 298 K are from Papadopoulos (47). High-temperature enthalpies were estimated.

$CdSO_4(c)$
Cadmium sulfate
[Formation: $Cd(c,l) + 0.5S_2(g) + 2\ O_2(g) = CdSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	23.806	29.408	29.408	0	-238.455	-206.185	151.136
300	23.875	29.555	29.408	.044	-238.455	-205.983	150.056
400	26.872	36.832	30.380	2.581	-238.372	-195.168	106.633
500	29.513	43.117	32.311	5.403	-238.090	-184.394	80.598
594.26	31.806	48.409	34.452	8.294	-237.670	-174.307	64.104
594.26	31.806	48.409	34.452	8.294	-239.150	-174.307	64.104
600	31.946	48.715	34.587	8.477	-239.122	-173.676	63.261
700	34.289	53.816	36.975	11.789	-238.507	-162.818	50.833
800	36.600	58.546	39.380	15.333	-237.705	-152.059	41.540

Phase changes: 594.26 K, melting point of Cd; ΔH° = 1.480 kcal/mol.

Sources: The enthalpy of formation at 298 K is based on Adami (1); see text. The entropy and heat capacity at 298 K are from Papadopoulos (47). High-temperature enthalpies were estimated.

$CdSO_4 \cdot H_2O(c)$
Cadmium sulfate monohydrate
[Formation: $Cd(c) + S(c,l) + H_2(g) + 2.5\ O_2(g) = CdSO_4 \cdot H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	32.167	36.814	36.814	0	-296.340	-255.509	187.291
300	32.284	37.013	36.813	.060	-296.346	-255.254	185.950
350	35.284	42.220	37.220	1.750	-296.477	-248.397	155.104
368.3	36.259	44.043	37.514	2.405	-296.497	-245.882	145.905
368.3	36.259	44.043	37.514	2.405	-296.593	-245.882	145.905
388.36	37.329	45.997	37.902	3.144	-296.600	-243.119	136.814
388.36	37.329	45.997	37.902	3.144	-297.013	-243.119	136.814
400	37.949	47.109	38.154	3.582	-297.029	-241.504	131.950
432.02	39.440	50.091	38.928	4.822	-297.063	-237.058	119.921
450	40.278	51.716	39.407	5.539	-297.141	-234.559	113.916
500	42.273	56.066	40.856	7.605	-297.133	-227.603	99.484
550	43.933	60.176	42.429	9.761	-297.039	-220.655	87.679

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Wagman (63) after correction for the heat of formation of the sulfate ion. The entropy and heat capacity at 298 K are from Papadopoulos (47). High-temperature enthalpies were estimated.

$CdSO_4 \cdot 8/3H_2O(c)$
Cadmium sulfate 8/3 hydrate
[Formation: $Cd(c) + S(c,l) + 2.667H_2(g) + 3.3333\ O_2(g) = CdSO_4 \cdot 8/3H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	50.985	54.883	54.883	0	-413.410	-350.281	256.760
300	51.209	55.199	54.882	.095	-413.414	-349.888	254.890
350	57.141	63.542	55.531	2.804	-413.396	-339.300	211.866
368.3	59.214	66.507	56.003	3.869	-413.327	-335.428	199.041
368.3	59.214	66.507	56.003	3.869	-413.423	-335.428	199.041
388.36	61.486	69.710	56.627	5.081	-413.309	-331.181	186.370
388.36	61.486	69.710	56.627	5.081	-413.722	-331.181	186.370
400	62.805	71.545	57.035	5.804	-413.658	-328.709	179.596
432.02	66.261	76.515	58.295	7.871	-413.431	-321.917	162.849
450	68.201	79.256	59.078	9.080	-413.336	-318.111	154.494
500	73.330	86.710	61.470	12.620	-412.743	-307.559	134.432
550	78.191	93.929	64.094	16.409	-411.912	-297.078	118.047

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Wagman (63) after correction for the heat of formation of the sulfate ion. The entropy and heat capacity at 298 K are from Papadopoulos (47). High-temperature enthalpies were estimated.

$2CdO \cdot CdSO_4(c)$
Cadmium oxysulfate
[Formation: $3Cd(c,l) + S(c,l) + 3\ O_2(g) = 2CdO \cdot CdSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	46.126	58.929	58.929	0	-345.690	-306.070	224.352
300	46.341	59.215	58.928	.086	-345.686	-305.820	222.787
368.3	51.574	69.256	59.929	3.435	-345.461	-296.769	176.101
368.3	51.574	69.256	59.929	3.435	-345.557	-296.769	176.101
388.36	52.955	72.034	60.483	4.486	-345.443	-294.114	165.511
388.36	52.955	72.034	60.483	4.486	-345.856	-294.114	165.511
400	53.756	73.610	60.843	5.107	-345.800	-292.564	159.848
432.02	55.612	77.825	61.945	6.861	-345.632	-288.309	145.848
500	59.053	86.211	64.683	10.764	-345.265	-279.310	122.085
594.26	62.373	96.711	68.946	16.499	-344.422	-266.947	98.173
594.26	62.373	96.711	68.946	16.499	-348.862	-266.948	98.174
600	62.551	97.311	69.214	16.858	-348.812	-266.143	96.941
700	64.696	107.129	73.945	23.229	-347.705	-252.459	78.820
717.82	64.955	108.759	74.789	24.384	-347.489	-250.037	76.126

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
594.26 K, melting point of Cd; ΔH° = 1.480 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Ko (33). The entropy and heat capacity at 298 K are from Beyer (4), as are the high-temperature enthalpy values.

$2CdO \cdot CdSO_4(c)$
Cadmium oxysulfate
[Formation: $3Cd(c,l,g) + 0.5S_2(g) + 3\ O_2(g) = 2CdO \cdot CdSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	46.126	58.929	58.929	0	-361.045	-315.583	231.326
300	46.341	59.215	58.928	.086	-361.038	-315.297	229.691
400	53.756	73.610	60.843	5.107	-360.451	-300.130	163.981
500	59.053	86.211	64.683	10.764	-359.392	-285.164	124.643
594.26	62.373	96.711	68.946	16.499	-358.140	-271.279	99.766
594.26	62.373	96.711	68.946	16.499	-362.580	-271.289	99.766
600	62.551	97.311	69.214	16.858	-362.507	-270.384	98.486
700	64.696	107.129	73.945	23.229	-361.030	-255.155	79.662
800	66.012	115.859	78.648	29.769	-359.449	-240.134	65.601
900	67.098	123.696	83.225	36.424	-357.806	-225.307	54.711
1,000	68.630	130.838	87.634	43.204	-356.081	-210.670	46.041
1,040	69.723	133.551	89.348	45.971	-355.347	-204.895	43.057
1,040	69.723	133.551	89.348	45.971	-426.774	-204.895	43.057
1,100	71.362	137.495	91.868	50.190	-425.230	-192.136	38.173

Phase changes: 594.26 K, melting point of Cd; ΔH° = 1.480 kcal/mol.
1,040 K, boiling point of Cd; ΔH° = 23.809 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Ko (33). The entropy and heat capacity at 298 K are from Beyer (4), as are the high-temperature enthalpy values.

$Cs_2SO_4(c,l)$
Cesium sulfate
[Formation: $2Cs(c,l) + S(c,l) + 2\ O_2(g) = Cs_2SO_4(c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
0	0	0	0	-6.628	-342.706	-342.706	0
100	21.340	21.970	75.900	-5.393	-344.049	-335.041	732.222
200	27.430	38.760	53.430	-2.934	-344.657	-325.770	355.980
298.15	32.619	50.640	50.640	0	-344.970	-316.416	231.936
300	32.697	50.842	50.642	.060	-344.974	-316.238	230.376
301.55	32.750	51.011	50.643	.111	-344.977	-316.089	229.084
301.55	32.750	51.011	50.643	.111	-345.977	-316.089	229.084
368.3	35.014	57.806	51.338	2.382	-346.046	-309.465	183.635
368.3	35.014	57.806	51.338	2.382	-346.142	-309.465	183.635
388.36	35.695	59.681	51.721	3.091	-346.143	-307.467	173.025
388.36	35.695	59.681	51.721	3.091	-346.556	-307.467	173.025
400	36.090	60.741	51.969	3.509	-346.569	-306.295	167.350
432.02	37.053	63.557	52.724	4.680	-346.606	-303.072	153.315
500	39.097	69.114	54.580	7.267	-346.708	-296.207	129.470
600	42.455	76.532	57.630	11.341	-346.485	-286.119	104.217
700	46.388	83.363	60.823	15.778	-345.884	-276.099	86.201
717.82	47.203	84.539	61.397	16.612	-345.732	-274.324	83.520

Phase changes: 301.55 K, melting point of Cs; ΔH° = 0.500 kcal/mol.
368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Wagman (65) after correction for the heat of formation of the sulfate ion. The low-temperature heat capacities are from Paukov (51), while the high-temperature enthalpy values are from Shmidt (56) and Denielou (12); see text.

Cs_2SO_4(c,l)
Cesium sulfate
[Formation: $2Cs(c,l,g) + 0.5S_2(g) + 2\ O_2(g) = Cs_2SO_4(c,l)$]

T, K	cal/(mol•K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-6.628	-358.024	-358.024	∞
100	21.340	21.970	75.900	-5.393	-359.570	-348.531	761.704
200	27.430	38.760	53.430	-2.934	-360.139	-337.231	368.504
298.15	32.619	50.640	50.640	0	-360.325	-325.930	238.910
300	32.697	50.842	50.642	.060	-360.326	-325.715	237.280
301.55	32.750	51.011	50.643	.111	-360.327	-325.536	235.931
301.55	32.750	51.011	50.643	.111	-361.327	-325.536	235.931
400	36.090	60.741	51.969	3.509	-361.220	-313.861	171.483
500	39.097	69.114	54.580	7.267	-360.836	-302.060	132.029
600	42.455	76.532	57.630	11.341	-360.180	-290.360	105.762
700	46.388	83.363	60.823	15.778	-359.209	-278.794	87.042
800	50.959	89.849	64.049	20.640	-357.859	-267.397	73.049
900	56.175	96.146	67.267	25.991	-356.053	-256.192	62.211
952	59.208	99.380	68.932	28.987	-354.915	-250.478	57.501
952	59.208	99.380	68.932	28.987	-387.311	-250.478	57.501
997	61.832	103.175	70.370	31.710	-385.981	-244.040	53.495
997	46.293	102.248	70.370	31.782	-385.909	-244.041	53.495
1,000	46.405	102.387	70.466	31.921	-385.863	-243.613	53.241
1,100	50.109	106.984	73.578	36.747	-384.156	-229.467	45.590
1,200	53.813	111.502	76.549	41.943	-382.100	-215.490	39.246
1.278	56.702	114.981	78.789	46.253	-380.253	-204.718	35.008
1,278	49.393	121.609	78.790	54.723	-371.783	-204.719	35.008
1,300	49.393	122.452	79.522	55.809	-371.394	-201.847	33.933
1,400	49.393	126.112	82.720	60.749	-369.637	-188.870	29.484
1,500	49.393	129.520	85.728	65.688	-367.894	-176.020	25.646
1,600	49.393	132.708	88.566	70.627	-366.172	-163.286	22.303
1,700	49.393	135.702	91.251	75.567	-364.466	-150.656	19.368
1,800	49.393	138.526	93.800	80.506	-362.779	-138.127	16.771
1,900	49.393	141.196	96.225	85.445	-361.111	-125.694	14.458
2,000	49.393	143.730	98.537	90.385	-359.464	-113.345	12.386

Phase changes: 301.55 K, melting point of Cs; ΔH° = 0.500 kcal/mol.
925 K, calculated boiling point of Cs to ideal monatomic gas; ΔH° = 16.198 kcal/mol.
997 K, II-I transition of Cs_2SO_4; ΔH° = 0.072 kcal/mol.
1,278 K, melting point of Cs_2SO_4; ΔH° = 8.47 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Wagman (65) after correction for the heat of formation of the sulfate ion. The low-temperature heat capacities are from Paukov (51), while the high-temperature enthalpy values are from Shmidt (56) and Denielou (12); see text.

$In_2(SO_4)_3(c)$
Indium sulfate
[Formation: $2In(c,l) + 3S(c,l) + 6\ O_2(g) = In_2(SO_4)_3(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	65.704	72.240	72.240	0	-651.340	-570.120	417.904
300	65.972	72.647	72.240	.122	-651.350	-569.614	414.958
368.3	73.163	87.039	73.665	4.926	-651.489	-550.986	326.952
368.3	73.163	87.039	73.665	4.926	-651.777	-550.987	326.952
388.36	75.275	90.977	74.460	6.415	-651.780	-545.495	306.973
388.36	75.275	90.977	74.460	6.415	-653.019	-545.495	306.974
400	76.501	93.218	74.973	7.298	-653.062	-542.272	296.280
429.78	78.510	98.784	76.432	9.606	-653.170	-534.020	271.554
429.78	78.510	98.784	76.432	9.606	-654.730	-534.020	271.554
432.02	78.661	99.192	76.550	9.782	-654.768	-533.391	269.828
500	83.247	111.051	80.447	15.302	-655.223	-514.240	224.771
600	88.701	126.722	86.880	23.905	-655.125	-486.041	177.038
700	93.716	140.775	93.592	33.028	-654.470	-457.905	142.963
717.82	94.595	143.142	94.793	34.706	-654.297	-452.902	137.890

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
429.78 K, melting point of In; ΔH° = 0.780 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Barany (2) after correction for the enthalpy of formation of the sulfate ion. The entropy, heat capacity values, and high-temperature enthalpy values at 298 K are from Pankratz (46).

$In_2(SO_4)_3(c)$
Indium sulfate
[Formation: $2In(c,l) + 1.5S_2(g) + 6\ O_2(g) = In_2(SO_4)_3(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	65.704	72.240	72.240	0	-697.405	-598.661	438.825
300	65.792	72.647	72.240	.122	-697.406	-598.046	435.671
400	76.501	93.218	74.973	7.298	-697.015	-564.969	308.681
429.78	78.510	98.784	76.432	9.606	-696.785	-555.146	282.297
429.78	78.510	98.784	76.432	9.606	-698.345	-555.146	282.297
500	83.247	111.051	80.447	15.302	-697.606	-531.800	232.447
600	88.701	126.722	86.880	23.905	-696.208	-498.764	181.672
700	93.716	140.775	93.592	33.028	-694.445	-465.991	145.487
800	98.648	153.610	100.303	42.646	-692.318	-433.500	118.425
900	103.667	165.518	106.896	52.760	-689.799	-401.295	97.446
1,000	108.863	176.707	113.322	63.385	-686.857	-369.392	80.730
1,100	114.287	187.335	119.570	74.541	-683.468	-337.801	67.114

Phase changes: 429.78 K, melting point of In; ΔH° = 0.780 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Barany (2) after correction for the enthalpy of formation of the sulfate ion. The entropy, heat capacity values, and high-temperature enthalpy values at 298 K are from Pankratz (46).

K_2SO_4(c,l)
Potassium sulfate

[Formation: 2K(c,l) + S(c,l) + 2 O_2(g) = K_2SO_4(c,l)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
0	0	0	∞	-6.079	-341.109	-341.109	∞
100	18.928	14.725	66.295	-5.157	-342.567	-333.760	729.422
200	26.450	30.436	44.676	-2.848	-343.283	-324.639	354.745
298.15	31.386	41.956	41.956	0	-343.620	-315.406	231.196
300	31.469	42.150	41.957	.058	-343.624	-315.230	229.642
336.35	32.858	45.829	42.180	1.227	-343.711	-311.786	202.586
336.35	32.858	45.829	42.180	1.227	-344.827	-311.786	202.586
368.3	34.078	48.879	42.628	2.303	-344.877	-308.645	183.148
368.3	34.078	48.879	42.628	2.303	-344.973	-308.645	183.148
388.36	34.844	50.707	42.999	2.994	-344.992	-306.665	172.574
388.36	34.844	50.707	42.999	2.994	-345.405	-306.665	172.574
400	35.289	51.743	43.238	3.402	-345.428	-305.504	166.917
432.02	36.290	54.499	43.972	4.548	-345.488	-302.306	152.928
500	38.416	59.959	45.779	7.090	-345.625	-295.495	129.159
600	41.235	67.205	48.758	11.068	-345.466	-285.477	103.984
700	44.543	73.812	51.872	15.358	-344.964	-275.514	86.018
717.82	45.107	74.939	52.431	16.157	-344.838	-273.747	83.345

Phase changes: 336.35 K, melting point of K; ΔH° = 0.558 kcal/mol.
368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Source: All data are from JANAF (16).

$K_2SO_4(c,l)$
Potassium sulfate
[Formation: $2K(c,l,g) + 0.5S_2(g) + 2\ O_2(g) = K_2SO_4(c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-6.079	-356.427	-356.427	∞
100	18.928	14.725	66.295	-5.157	-358.087	-347.249	758.903
200	26.450	30.426	44.676	-2.848	-358.765	-336.101	367.269
298.15	31.386	41.956	41.956	0	-358.975	-324.920	238.170
300	31.469	42.150	41.957	.058	-358.976	-324.708	236.546
336.35	32.858	45.829	42.180	1.227	-359.004	-320.554	208.284
336.35	32.858	45.829	42.180	1.227	-360.120	-320.554	208.284
400	35.289	51.743	43.238	3.402	-360.079	-313.070	171.051
500	38.416	59.959	45.779	7.090	-359.753	-301.348	131.718
600	41.235	67.205	48.758	11.068	-359.160	-289.718	105.528
700	44.543	73.812	51.872	15.358	-358.289	-278.209	86.860
800	47.710	79.966	55.002	19.971	-357.132	-266.847	72.898
857	49.515	83.312	56.775	22.742	-356.345	-260.441	66.416
857	43.977	85.669	56.775	24.762	-354.325	-260.441	66.416
900	44.810	87.842	58.208	26.671	-353.923	-255.740	62.101
1,000	46.750	92.663	61.414	31.249	-352.885	-244.886	53.519
1,043.7	47.602	94.681	62.765	33.311	-352.387	-240.175	50.292
1,043.7	47.602	94.681	62.765	33.311	-390.463	-240.175	50.292
1,100	48.700	97.211	64.465	36.021	-389.513	-232.094	46.112
1,200	50.640	101.531	67.374	40.988	-387.686	-217.859	39.677
1,300	52.580	105.661	70.162	46.149	-385.684	-203.788	34.259
1,342	53.390	107.346	71.299	48.375	-384.791	-197.925	32.232
1,342	48.150	113.471	71.299	56.595	-376.571	-197.925	32.232
1,400	48.150	115.509	73.090	59.387	-375.626	-190.224	29.695
1,500	48.150	118.831	76.030	64.202	-374.008	-177.039	25.794
1,600	48.150	121.938	78.802	69.017	-372.408	-163.960	22.396
1,700	48.150	124.857	81.426	73.832	-370.820	-150.981	19.410
1,800	48.150	127.609	83.916	78.647	-369.251	-138.093	16.767
1,900	48.150	130.213	86.286	83.462	-367.698	-125.295	14.412
2,000	48.150	132.682	88.544	88.277	-366.161	-112.576	12.302

Phase changes: 336.35 K, melting point of K; ΔH° = 0.558 kcal/mol.
857 K, α-β transition of K_2SO_4; ΔH° = 2.020 kcal/mol.
1,043.7 K, calculated boiling point of K to ideal monatomic gas; ΔH° = 19.038 kcal/mol.
1,342 K, melting point of K_2SO_4; ΔH° = 8.220 kcal/mol.

Source: All data are from JANAF (16).

$KAl(SO_4)_2(c)$
Potassium aluminum sulfate
[Formation: K(c,l) + Al(c) + 2S(c,l) + 4 O_2(g) = $KAl(SO_4)_2$(c)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-7.701	-585.069	-585.069	∞
100	19.490	13.860	82.270	-6.841	-587.830	-571.043	1,247.998
200	35.490	32.680	52.850	-4.034	-589.655	-553.484	604.812
298.15	46.141	48.940	48.940	0	-590.560	-535.511	392.535
300	46.776	49.229	48.942	.086	-590.570	-535.169	389.865
336.35	49.844	54.754	49.278	1.842	-590.728	-528.448	343.365
336.35	49.844	54.754	49.278	1.842	-591.286	-528.448	343.365
368.3	52.541	59.526	49.958	3.524	-591.310	-522.478	310.035
368.3	52.541	59.526	49.958	3.524	-591.502	-522.478	310.035
388.36	54.234	62.359	50.527	4.595	-591.518	-518.717	291.904
388.36	54.234	62.359	50.527	4.595	-592.344	-518.717	291.905
400	55.217	63.975	50.895	5.232	-592.376	-516.510	282.204
432.02	56.807	68.288	52.026	7.026	-592.472	-510.434	258.215
500	60.184	76.867	54.829	11.019	-592.754	-497.493	217.451
600	63.782	88.171	59.463	17.225	-592.659	-478.439	174.269
700	66.735	98.231	64.297	23.754	-592.240	-459.432	143.439
717.82	67.200	99.914	65.160	24.947	-592.136	-456.052	138.849

Phase changes:
336.35 K, melting point of K; ΔH° = 0.558 kcal/mol.
368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from Wagman (65) after correction for the sulfate ion. Low-temperature heat capacity and entropy values are from Kelley (30). High-temperature enthalpy values are from Kelley (30).

$KAl(SO_4)_2(c)$
Potassium aluminum sulfate

[Formation: $K(c,l,g) + Al(c,l) + S_2(g) + 4\ O_2(g) = KAl(SO_4)_2(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-7.701	-615.705	-615.705	∞
100	19.490	13.860	82.270	-6.841	-618.871	-598.023	1,306.961
200	35.490	32.680	52.850	-4.034	-620.620	-576.407	629.861
298.15	46.141	48.940	48.940	0.000	-621.270	-554.538	406.482
300	46.776	49.229	48.942	0.086	-621.274	-554.123	403.673
336.35	49.844	54.754	49.278	1.842	-621.313	-545.985	354.760
336.35	49.844	54.754	49.278	1.842	-621.872	-545.985	354.760
400	55.217	63.975	50.895	5.232	-621.678	-531.641	290.471
500	60.184	76.867	54.829	11.019	-621.009	-509.199	222.568
600	63.782	88.171	59.463	17.225	-620.048	-486.921	177.359
700	66.735	98.231	64.297	23.754	-618.890	-464.823	145.122
800	69.343	107.315	69.115	30.560	-617.578	-442.905	120.995
900	71.751	115.623	73.827	37.616	-616.130	-421.157	102.269
933.61	72.519	118.268	75.380	40.040	-615.616	-413.885	96.886
933.61	72.519	118.268	75.380	40.040	-618.196	-413.885	96.886
1,000	74.035	123.302	78.396	44.906	-617.106	-399.395	87.287
1,043.7	74.998	126.489	80.343	48.162	-616.351	-389.896	81.643
1,043.7	74.998	126.489	80.343	48.162	-635.389	-389.896	81.643
1,100	76.238	130.462	82.807	52.421	-634.238	376.682	74.839

Phase changes: 336.35 K, melting point of K; ΔH° = 0.558 kcal/mol.
933.61 K, melting point of Al; ΔH° = 2.580 kcal/mol.
1,043.7 K, calculated boiling point of K to ideal monatomic gas; ΔH° = 19.038 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Wagman (65) after correction for the sulfate ion. Low-temperature heat capacity and entropy values are from Kelley (30). High-temperature enthalpy values are from Kelley (30).

$KAl(SO_4)_2 \cdot 12H_2O(c)$
Potassium aluminum sulfate dodecahydrate

[Formation: $K(c,l,g) + Al(c,l) + S(c,l) + 12\ H_2(g) + 10\ O_2(g) = KAl(SO_4)_2 \cdot 12H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	156.107	164.300	164.300	0	-1,448.960	-1,228.988	900.861
300	156.909	165.268	164.301	.290	-1,449.000	-1,227.622	894.311
336.35	172.528	184.094	165.426	6.279	-1,449.477	-1,200.766	780.211
336.35	172.528	184.094	165.426	6.279	-1,450.035	-1,200.766	780.211
350	178.393	191.074	166.291	8.674	-1,450.082	-1,190.648	743.464
358.99	182.218	195.646	166.968	10.295	-1,450.075	-1,183.983	720.789

Phase changes: 336.35 K, melting point of K; ΔH° = 0.558 kcal/mol.
358.99 K, melting point of $KAl(SO_4)_2 \cdot 12H_2O(c)$; ΔH° = 22.8 kcal/mol.

Sources: The enthalpy of formation at 298 K are from Wagmann (65). Heat capacities from Shomate (58) were matched to those of Gronvold (24).

$Li_2SO_4(c,l)$
Lithium sulfate
[Formation: $2Li(c,l) + S(c,l) + 2\ O_2(g) = Li_2SO_4(c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	$Cp°$	$S°$	$-(G° - H°_{298})/T$	$H° - H°_{298}$	$\Delta Hf°$	$\Delta Gf°$	
0	0	0	∞	-4.454	-340.340	-340.340	∞
100	10.485	6.915	46.995	-4.008	-341.684	-333.446	728.736
200	20.763	17.454	29.594	-2.428	-342.769	-324.746	354.861
298.15	28.109	27.234	27.234	0	-343.300	-315.767	231.461
300	28.209	27.408	27.235	.052	-343.306	-315.596	229.909
368.3	31.672	33.571	27.846	2.109	-343.430	-309.270	183.519
368.3	31.672	33.571	27.846	2.109	-343.526	-309.271	183.519
388.36	32.690	35.278	28.186	2.754	-343.545	-307.404	172.989
388.36	32.690	35.278	28.186	2.754	-343.958	-307.404	172.990
400	33.280	36.252	28.407	3.138	-343.982	-306.308	167.357
432.02	34.446	38.860	29.086	4.222	-344.058	-303.295	153.428
453.7	35.235	40.570	29.593	4.981	-344.179	-301.244	145.109
453.7	35.235	40.570	29.593	4.981	-345.613	-301.244	145.109
500	36.920	44.076	30.774	6.651	-345.704	-296.707	129.689
600	40.215	51.099	33.584	10.509	-345.639	-286.906	104.504
700	43.450	57.544	36.554	14.693	-345.211	-277.149	86.529
717.82	43.997	58.643	37.089	15.472	-345.097	-275.417	83.853

Phase changes:
368.3 K, orthorhombic-monoclinic transformation of S; $\Delta H° = 0.096$ kcal/mol.
388.36 K, melting point of S; $\Delta H° = 0.413$ kcal/mol.
432.02 K, second-order transformation of S; $\Delta H° = 0$ kcal/mol.
453.7 K, melting point of Li; $\Delta H° = 0.717$ kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n ($n = 1$ to 8).

Source: All data are from JANAF (17).

$Li_2SO_4(c,l)$
Lithium sulfate
[Formation: $2Li(c,l,g) + 0.5S_2(g) + 2\ O_2(g) = Li_2SO_4(c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.454	-355.658	-355.658	∞
100	10.485	6.915	46.995	-4.008	-357.204	-346.936	758.217
200	20.763	17.454	29.594	-2.428	-358.251	-336.207	367.386
298.15	28.109	27.234	27.234	0	-358.655	-325.281	238.434
300	28.209	27.408	27.235	.052	-358.658	-325.074	236.813
400	33.280	36.252	28.407	3.138	-358.633	-313.874	171.490
453.7	35.235	40.570	29.593	4.981	-358.522	-307.874	148.303
453.7	35.235	40.570	29.593	4.981	-359.956	-307.874	148.303
500	36.920	44.076	30.774	6.651	-359.831	-302.561	132.247
600	40.215	51.099	33.584	10.509	-359.333	-291.146	106.049
700	43.450	57.544	36.554	14.693	-358.536	-279.844	87.370
800	46.520	63.531	39.555	19.181	-357.464	-268.673	73.397
848	48.454	66.296	40.991	21.459	-356.837	-263.363	67.874
848	51.000	74.315	40.991	28.259	-350.037	-263.363	67.874
900	51.000	77.351	43.005	30.911	-349.183	-258.075	62.668
1,000	51.000	82.724	46.713	36.011	-347.561	-248.038	54.208
1,100	51.000	87.585	50.211	41.111	-345.962	-238.162	47.318
1,132	51.000	89.047	51.288	42.743	-345.455	-235.033	45.376
1,132	49.000	90.858	51.288	44.793	-343.405	-253.033	45.376
1,200	49.000	93.717	53.613	48.125	-342.471	-228.552	41.625
1,300	49.000	97.639	56.851	53.025	-341.110	-219.115	36.836
1,400	49.000	101.270	59.895	57.925	-339.767	-209.781	32.748
1,500	49.000	104.651	62.768	62.825	-338.434	-200.545	29.219
1,600	49.000	107.813	65.485	67.725	-337.116	-191.393	26.143
1,638	49.000	108.963	66.480	69.587	-336.617	-187.939	25.075
1,638	49.000	108.963	66.480	69.587	-406.937	-187.940	25.075
1,700	49.000	110.784	68.063	72.625	-405.905	-179.665	23.097
1,800	49.000	113.584	70.515	77.525	-404.247	-166.402	20.204
1,900	49.000	116.234	72.852	82.425	-402.607	-153.237	17.626
2,000	49.000	118.747	75.085	87.325	-400.979	-140.151	15.315

Phase changes: 453.7 K, melting point of Li; ΔH° = 0.717 kcal/mol.
848 K, α-β transition point for $Li_2SO_4(c)$, ΔH° = 6.80 kcal/mol.
1,132 K, melting point of $Li_2SO_4(c)$, ΔH° = 2.050 kcal/mol.
1,638 K, calculated boiling point of Li to ideal monatomic gas; ΔH° = 35.160 kcal/mol.

Source: All data from JANAF (17).

$Li_2SO_4 \cdot H_2O(c)$
Lithium sulfate monohydrate
[Formation: $2Li(c,l) + S(c,l) + 2.5\ O_2(g) + H_2(g) = Li_2SO_4 \cdot H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-5.697	-409.751	-409.751	∞
100	13.360	9.067	60.217	-5.115	-412.023	-399.526	873.152
200	26.490	22.512	38.012	-3.100	-413.665	-386.329	422.156
298.15	36.100	34.995	34.995	0	-414.530	-372.701	273.194
300	36.248	35.219	34.996	.067	-414.541	-372.442	271.320
350	39.772	41.083	35.452	1.971	-414.742	-365.407	228.167
368.3	40.728	43.134	35.783	2.708	-414.795	-362.826	215.299
368.3	40.728	43.134	35.783	2.708	-414.891	-362.826	215.299
388.36	41.776	45.331	36.218	3.539	-414.935	-359.987	202.580
388.36	41.776	45.331	36.218	3.539	-415.348	-359.987	202.581
400	42.384	46.574	36.502	4.029	-415.389	-358.327	195.779
432.02	43.473	49.889	37.374	5.407	-415.511	-353.761	178.958
450	44.084	51.674	37.910	6.194	-415.646	-351.188	170.558
453.7	44.142	52.035	38.023	6.357	-415.671	-350.658	168.912
453.7	44.142	52.035	38.023	6.357	-417.105	-350.658	168.912
500	44.872	56.367	39.523	8.422	-417.296	-343.862	150.300
550	44.748	60.645	41.250	10.667	-417.490	-336.507	133.714

Phase changes: 368.3 K, orthrhomibc-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
453.7 K, melting point of Li; ΔH° = 0.717 kcal/mol.

Sources: The enthalpy of formation is based on Barany (3). Low-temperature heat capacities and entropies are from Paukov (53). High-temperature enthalpies are estimated.

$MgSO_4(\beta,c,l)$
Magnesium sulfate (β,c,l)
[Formation: $Mg(c,l,g) + 0.5S_2(g) + 2\ O_2(g) = MgSO_4(\beta,c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	$Cp°$	$S°$	$-(G° - H°_{298})/T$	$H° - H°_{298}$	$\Delta Hf°$	$\Delta Gf°$	
0	0	0	∞	-3.678	-319.706	-319.706	∞
100	8.679	4.775	38.315	-3.354	-321.290	-310.932	679.532
200	17.521	13.751	23.791	-2.008	-322.253	-300.259	328.104
298.15	23.000	21.844	21.844	0	-322.465	-289.302	212.061
300	23.050	21.987	21.844	.043	-322.466	-289.094	210.602
400	26.290	29.085	22.790	2.518	-322.420	-277.973	151.875
500	28.540	35.199	24.675	5.262	-322.190	-266.886	116.654
600	30.500	40.581	26.886	8.217	-321.835	-255.853	93.193
700	32.100	45.404	29.193	11.348	-321.385	-244.889	76.457
800	33.580	49.788	31.497	14.633	-320.853	-234.001	63.925
900	34.950	53.823	33.756	18.060	-320.245	-223.175	54.194
922	35.236	54.671	34.245	18.832	-320.101	-220.808	52.339
922	35.236	54.671	34.245	18.832	-322.240	-220.808	52.339
1,000	36.250	57.574	35.953	21.621	-321.699	-212.254	46.388
1,100	37.450	61.086	38.081	25.306	-320.939	-201.349	40.004
1,200	38.580	64.394	40.136	29.109	-320.113	-190.514	34.697
1,300	39.520	67.520	42.123	33.016	-319.223	-179.737	30.216
1,363	40.012	69.402	43.341	35.522	-318.643	-173.009	27.741
1,363	40.012	69.402	43.341	35.522	-348.893	-173.009	27.741
1,400	40.301	70.478	44.044	37.008	-348.401	-168.244	26.264
1,400	38.000	73.034	44.044	40.586	-344.823	-168.244	26.264
1,500	38.000	75.656	46.065	44.386	-343.723	-155.673	22.681
1,600	38.000	78.108	47.992	48.186	-342.639	-143.170	19.556
1,700	38.000	80.412	49.832	51.986	-341.569	-130.736	16.807
1,800	38.000	82.584	51.592	55.786	-340.513	-118.362	14.371
1,900	38.000	84.639	53.278	59.586	-339.474	-106.050	12.198
2,000	38.000	86.588	54.895	63.386	-338.447	-93.791	10.249

Phase changes: 922 K, melting point of Mg; ΔH° = 2.139 kcal/mol.
1,363 K, boiling point of Mg; ΔH° = 30.250 kcal/mol.
1,400 K, melting point of $MgSO_4$; ΔH° = 3.5 kcal/mol.

Sources: The enthalpy of formation is based on Ko (34) after correction for the sulfate ion. All other data are from JANAF (15).

$MgSO_4(\alpha,c)$
Magnesium sulfate (α,c)

[Formation: $Mg(c) + S(c,l) + 2\ O_2(g) = MgSO_4(\alpha,c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-3.678	-305.308	-305.308	∞
100	8.679	4.775	38.315	-3.354	-306.690	-298.362	652.061
200	17.521	13.751	23.791	-2.008	-307.691	-289.718	316.585
298.15	23.000	21.844	21.844	0	-308.030	-280.708	205.762
300	23.050	21.987	21.844	.043	-308.034	-280.537	204.369
368.3	25.263	26.957	22.339	1.701	-308.139	-274.265	162.747
368.3	25.263	26.957	22.339	1.701	-308.235	-274.265	162.747
388.36	25.913	28.314	22.613	2.214	-308.252	-272.414	153.299
388.36	25.913	28.314	22.613	2.214	-308.665	-272.414	153.299
400	26.290	29.085	22.790	2.518	-308.689	-271.327	148.244
432.02	27.010	31.137	23.334	3.371	-308.763	-268.334	135.743
500	28.540	35.199	24.675	5.262	-308.983	-261.953	114.498
600	30.500	40.581	26.886	8.217	-309.061	-252.532	91.984
700	32.100	45.404	29.193	11.348	-308.980	-243.114	75.903
717.82	32.364	46.214	29.605	11.922	-308.951	-241.437	73.508

Phase changes:
368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation is based on Ko (34) after correction for the sulfate ion. All other data are from JANAF (15).

$MgSO_4(\alpha,c,l)$
Magnesium sulfate (α,c,l)
[Formation: $Mg(c,l,g) + 0.5S_2(g) + 2\ O_2(g) = MgSO_4(\alpha,c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-3.678	-320.626	-320.626	∞
100	8.679	4.775	38.315	-3.354	-322.211	-311.852	681.543
200	17.521	13.751	23.791	-2.008	-323.173	-301.179	329.109
298.15	23.000	21.844	21.844	0	-323.385	-290.222	212.736
300	23.050	21.987	21.844	.043	-323.386	-290.014	211.273
400	26.290	29.085	22.790	2.518	-323.340	-278.893	152.378
500	28.540	35.199	24.675	5.262	-323.111	-267.806	117.057
600	30.500	40.581	26.886	8.217	-322.755	-256.773	93.528
700	32.100	45.404	29.193	11.348	-322.305	-245.809	76.744
800	33.580	49.788	31.497	14.633	-321.773	-234.921	64.177
900	34.950	53.823	33.756	18.060	-321.165	-224.095	54.417
922	35.236	54.671	34.245	18.832	-321.021	-221.728	52.558
922	35.236	54.671	34.245	18.832	-323.160	-221.728	52.558
1,000	36.250	57.574	35.953	21.621	-322.619	-213.174	46.589
1,100	37.450	61.086	38.081	25.306	-321.859	-202.269	40.187
1,200	38.580	64.394	40.136	29.109	-321.034	-191.434	34.864
1,300	39.520	67.520	42.123	33.016	-320.143	-180.657	30.371
1,363	40.012	69.402	43.341	35.522	-319.563	-173.929	27.888
1,363	40.012	69.402	43.341	35.522	-349.813	-173.929	27.888
1,400	40.301	70.478	44.044	37.008	-349.322	-169.164	26.407
1,400	38.000	73.034	44.044	40.586	-345.743	-169.164	26.407
1,500	38.000	75.656	46.065	44.386	-344.643	-156.593	22.815
1,600	38.000	78.108	47.992	48.186	-343.559	-144.090	19.682
1,700	38.000	80.412	49.832	51.986	-342.490	-131.656	16.925
1,800	38.000	82.584	51.592	55.786	-341.434	-119.282	14.483
1,900	38.000	84.639	53.278	59.586	-340.394	-106.970	12.304
2,000	38.000	86.588	54.895	63.386	-339.367	-94.711	10.349

Phase changes: 922 K, melting point of Mg; ΔH° = 2.139 kcal/mol.
1,363 K, boiling point of Mg; ΔH° = 30.250 kcal/mol.
1,400 K, melting point of $MgSO_4$; ΔH° = 3.5 kcal/mol.

Sources: The enthalpy of formation is based on Ko (34) after correction for the sulfate ion. All other data are from JANAF (15).

$MgSO_4(\beta,c)$
Magnesium sulfate (β,c)
[Formation: $Mg(c) + S(c,l) + 2\ O_2(g) = MgSO_4(\beta,c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	$Cp°$	$S°$	$-(G° - H°_{298})/T$	$H° - H°_{298}$	$\Delta Hf°$	$\Delta Gf°$	
0	0	0	0	-3.678	-304.388	-304.388	0
100	8.679	4.775	38.315	-3.354	-305.770	-297.442	650.051
200,	17.521	13.751	23.791	-2.008	-306.771	-288.798	315.579
298.15	23.000	21.844	21.844	0	-307.110	-279.788	205.088
300	23.050	21.987	21.844	.043	-307.114	-279.617	203.698
368.3	25.263	26.957	22.339	1.701	-307.219	-273.345	162.201
368.3	25.263	26.957	22.339	1.701	-307.315	-273.345	162.202
388.36	25.913	28.314	22.613	2.214	-307.332	-271.494	152.781
388.36	25.913	28.314	22.613	2.214	-307.745	-271.494	152.782
400	26.290	29.085	22.790	2.518	-307.769	-270.407	147.742
432.02	27.010	31.137	23.334	3.371	-307.843	-267.414	135.278
500	28.540	35.199	24.675	5.262	-308.063	-261.033	114.096
600	30.500	40.581	26.886	8.217	-308.141	-251.612	91.648
700	32.100	45.404	29.193	11.348	-308.060	-242.194	75.615
717.82	32.364	46.214	29.605	11.922	-308.031	-240.517	73.228

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; $\Delta H°$ = 0.096 kcal/mol.
388.36 K, melting point of S; $\Delta H°$ = 0.413 kcal/mol.
432.02 K, second-order transformation of S; $\Delta H°$ = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n ($n = 1$ to 8).

Sources: The enthalpy of formation is based on Ko (34) after correction for the sulfate ion. All other data are from JANAF (15).

$MgSO_4 \cdot H_2O(c)$
Magnesium sulfate monohydrate
[Formation: $Mg(c) + S(c,l) + 2.5\ O_2(g) + H_2(g) = MgSO_4 \cdot H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	$Cp°$	$S°$	$-(G° - H°_{298})/T$	$H° - H°_{298}$	$\Delta Hf°$	$\Delta Gf°$	
298.15	34.600	30.200	30.200	0	-384.800	-343.360	251.686
300	34.767	30.415	30.202	.064	-384.802	-343.102	249.946
350	39.274	36.112	30.641	1.915	-384.759	-336.154	209.901
368.3	40.923	38.156	30.964	2.649	-384.695	-333.614	197.964
368.3	40.923	38.156	30.964	2.649	-384.792	-333.614	197.964
388.36	42.731	40.374	31.391	3.489	-384.693	-330.827	186.171
388.36	42.731	40.374	31.391	3.489	-385.106	-330.827	186.171
400	43.780	41.651	31.671	3.992	-385.053	-329.201	179.865
4332.02	46.666	45.132	32.542	5.439	-384.873	-324.738	164.276
450	48.287	47.068	33.084	6.293	-384.810	-322.239	156.499
500	52.794	52.388	34.748	8.820	-384.328	-315.309	137.820
550	57.301	57.631	36.589	11.573	-383.626	-308.435	122.559

Phase changes: 368.3 K, orthrhombic-monoclinic transformation of S; $\Delta H°$ = 0.096 kcal/mol.
388.36 K, melting point of S; $\Delta H°$ = 0.413 kcal/mol.
432.02 K, second-order transformation of S; $\Delta H°$ = 0 kcal/mol.

Sources: The enthalpy of formation is based on Ko (34) after correction for the sulfate ion. The entropy at 298 K is from Parker (49). The heat capacity estimates are based on Rolla (54).

$MgSO_4 \cdot 2H_2O(c)$
Magnesium sulfate dihydrate

[Formation: $Mg(c) + S(c,l) + 3\ O_2(g) + 2H_2(g) = MgSO_4 \cdot 2H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	42.000	40.000	40.000	0	-453.300	-398.172	291.864
300	42.185	40.260	40.000	.078	-453.308	-397.828	289.814
350	47.193	47.139	40.533	2.312	-453.404	-388.573	242.633
368.3	49.026	49.591	40.923	3.192	-453.386	-385.183	228.566
368.3	49.026	49.591	40.923	3.192	-453.482	-385.183	228.566
388.36	51.034	52.244	41.439	4.196	-453.431	-381.464	214.666
388.36	51.034	52.244	41.439	4.196	-453.844	-381.464	214.666
400	52.200	53.768	41.776	4.797	-453.817	-379.295	207.234
432.02	55.407	57.909	42.818	6.520	-453.700	-373.334	188.859
450	57.208	60.205	43.467	7.532	-453.670	-369.992	179.690
500	62.215	66.492	45.456	10.518	-453.263	-360.713	157.665
550	67.223	72.657	47.650	13.754	-452.615	-351.484	139.665

Phase chnages: 368.3 K, orthrhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation is from Parker (49) after correction for the sulfate ion. The heat capacity and entropy values are estimates.

$MgSO_4 \cdot 4H_2O(c)$
Magnesium sulfate tetrahydrate

[Formation: $Mg(c) + S(c,l) + 4\ O_2(g) + 4H_2(g) = MgSO_4 \cdot 4H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	60.000	59.000	59.000	0	-596.800	-514.117	376.853
300	60.259	59.372	59.002	.111	-596.814	-513.603	374.155
350	67.270	69.187	59.761	3.299	-597.001	-499.717	312.033
368.3	69.836	72.681	60.317	4.554	-596.993	-494.630	293.510
368.3	69.836	72.681	60.317	4.554	-597.089	-494.630	293.510
388.36	72.648	76.458	61.053	5.983	-597.036	-489.050	275.210
388.36	72.648	76.458	61.053	5.983	-597.449	-489.050	275.210
400	74.280	78.628	61.533	6.838	-597.413	-485.801	265.426
432.02	78.770	84.518	63.016	9.289	-597.246	-476.872	241.236
450	81.291	87.781	63.941	10.728	-597.173	-471.866	229.166
500	88.301	69.709	66.775	14.967	-596.580	-457.972	200.176
550	85.312	105.454	69.894	19.558	-595.651	-444.149	176.486

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation is from Parker (49) after correction for the sulfate ion. The heat capacity and entropy values are estimates.

$MgSO_4 \cdot 6H_2O(c)$
Magnesium sulfate hexahydrate
[Formation: $Mg(c) + S(c,l) + 5\ O_2(g) + 6H_2(g) = MgSO_4 \cdot 6H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-13.244	-726.355	-726.355	∞
100	31.810	23.110	141.340	-11.823	-733.024	-699.682	1,529.135
200	61.130	54.500	90.120	-7.124	-736.624	-664.853	726.508
298.15	83.200	83.200	83.200	0	-737.880	-629.193	461.205
300	83.573	83.716	83.203	.154	737.890	-628.518	457.869
350	93.090	97.327	84.256	4.575	-737.889	-610.283	381.073
368.3	96.175	102.150	85.026	6.307	-737.789	-603.614	358.181
368.3	96.175	102.150	85.026	6.307	-737.885	-603.614	358.181
388.36	99.557	107.351	86.044	8.275	-737.715	-596.304	335.566
388.36	99.557	107.351	86.044	8.275	-738.128	-596.304	335.566
400	101.520	110.320	86.708	9.445	-738.023	-592.055	323.479
432.02	106.223	118.327	88.756	12.775	-737.655	-580.384	293.600
450	108.864	122.712	90.025	14.709	-737.470	-573.845	278.694
500	115.121	134.516	93.890	20.313	-736.580	-555.709	242.897
550	120.291	145.739	98.097	26.203	-735.426	-537.672	213.648

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation is from Parker (49) after correction for the sulfate ion. The low-temperature heat capacity and entropy values are from Cox (10), while the high-temperature enthalpy values are extrapolated.

$MgSO_4 \cdot 7H_2O(c)$
Magnesium sulfate heptahydrate
[Formation: $Mg(c) + S(c,l) + 5.5\ O_2(g) + 7H_2(g) = MgSO_4 \cdot 7H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	91.000	89.000	89.000	0.000	-810.000	-686.432	503.162
300	91.463	89.564	89.001	0.169	-810.014	-685.664	499.500
350	103.982	104.604	90.161	5.055	-810.071	-644.927	415.194
368.3	108.564	110.020	91.014	7.000	-809.950	-657.341	390.062
368.3	108.564	110.020	91.014	7.000	-810.046	-657.341	390.062
388.36	113.587	115.909	92.147	9.228	-809.827	-649.028	365.236
388.36	113.587	115.909	92.147	9.228	-810.240	-649.028	365.236
400	116.501	119.306	92.889	10.567	-810.089	-644.199	351.969
432.02	124.518	128.581	95.190	14.426	-809.533	-630.939	319.175
450	129.020	133.750	96.628	16.705	-809.193	-623.516	302.817
500	141.538	147.992	101.054	23.469	-807.677	-602.961	263.551
550	154.057	162.069	105.962	30.859	-805.560	-582.583	231.494

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation and entropy at 298 K are from Parker (49) after correction for the sulfate ion. The heat capacity values are estimates based on Rolla (54).

$Na_2SO_4(c)$
Sodium sulfate
[Formation: $2Na(c,l) + S(c,l) + 2\ O_2(g) = Na_2SO_4(c)$]

T, K	cal/(mol•K)			kcal/mol			Log Kf
	$Cp°$	$S°$	$-(G° - H°_{298})/T$	$H° - H°_{298}$	$\Delta Hf°$	$\Delta Gf°$	
0	0	0	∞	-5.549	-328.959	-328.959	∞
100	15.904	10.306	59.036	-4.873	-330.475	-321.789	703.261
200	25.255	24.620	38.390	-2.754	-331.315	-312.732	341.733
298.15	30.627	35.754	35.754	0	-331.696	-303.517	222.481
300	30.711	35.944	35.754	.057	-331.699	-303.340	220.980
368.3	33.422	42.529	36.412	2.253	-331.819	-296.872	176.162
368.3	33.422	42.529	36.412	2.253	-331.915	-296.872	176.162
371	33.529	42.773	36.458	2.343	-331.919	-296.615	174.729
371	33.529	42.773	36.458	2.343	-333.163	-296.615	174.729
388.36	34.218	44.323	36.776	2.931	-333.189	-294.904	165.955
388.36	34.218	44.323	36.776	2.931	-333.602	-294.904	165.955
400	34.680	45.340	37.010	3.332	-333.632	-293.744	160.492
432.02	35.766	48.055	37.728	4.461	-333.709	-290.548	146.980
458	36.647	50.169	38.374	5.402	-333.847	-287.947	137.402
458	36.647	50.302	38.374	5.463	-333.786	-287.947	137.402
500	37.980	53.575	39.515	7.030	-333.815	-283.742	124.022
514	38.411	54.630	39.912	7.565	-333.819	-282.340	120.048
514	40.806	59.726	39.912	10.185	-331.199	-282.340	120.048
600	41.905	66.121	43.231	13.734	-330.920	-274.192	99.873
700	43.270	72.682	46.981	17.991	-330.431	-264.777	82.666
717.82	43.536	73.773	47.632	18.764	-330.325	-263.106	80.105

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
371 K, melting point of Na; ΔH° = 0.622 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
458 K, V-IV transition of Na_2SO_4; ΔH° = 0.061 kcal/mol.
514 K, IV-I transition of Na_2SO_4; ΔH° = 2.607 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Source: All data are from JANAF (16).

Na_2SO_4(c,l)
Sodium sulfate
[Formation: 2Na(c,l,g) + $0.5S_2$(g) + 2 O_2(g) = Na_2SO_4(c,l)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-5.549	-344.277	-344.277	∞
100	15.904	10.306	59.036	-4.873	-345.996	-335.279	732.743
200	25.255	24.620	38.390	-2.754	-346.798	-324.194	354.258
298.15	30.627	35.754	35.754	0	-347.051	-313.031	229.455
300	30.711	35.944	35.754	.057	-347.051	-312.818	227.885
371	33.529	42.773	36.458	2.343	-347.057	-304.716	179.500
371	33.529	42.773	36.458	2.343	-348.301	-304.716	179.501
400	34.680	45.340	37.010	3.332	-348.283	-301.309	164.626
458	36.647	50.169	38.374	5.402	-348.097	-294.503	140.530
458	36.647	50.302	38.374	5.463	-347.943	-294.503	140.530
500	37.980	53.575	39.515	7.030	-347.943	-289.595	126.580
514	38.411	54.630	39.912	7.565	-347.879	-287.962	122.438
514	40.806	59.726	39.911	10.185	-345.259	-287.962	122.438
600	41.905	66.121	43.231	13.734	-344.615	-278.433	101.418
700	43.270	72.682	46.981	17.991	-343.756	-267.472	83.507
800	44.760	78.556	50.566	22.392	-342.777	-256.639	70.110
900	46.330	83.919	53.978	26.947	-341.670	-245.937	59.721
1,000	47.875	88.880	57.223	31.657	-340.437	-235.365	51.438
1,100	49.410	93.515	60.313	36.522	-339.090	-224.923	44.687
1,157	50.279	96.033	62.005	39.370	-338.259	-219.012	41.369
1,157	47.092	100.960	62.006	45.070	-332.559	-219.012	41.369
1,177	47.092	101.767	62.675	46.012	-332.331	-217.052	40.302
1,177	47.092	101.767	62.675	46.012	-378.901	-217.052	40.302
1,200	47.092	102.678	63.438	47.088	-378.552	-213.903	38.957
1,300	47.092	106.448	66.604	51.797	-377.002	-200.242	33.663
1,400	47.092	109.938	69.577	56.506	-375.474	-186.705	29.146
1,500	47.092	113.187	72.377	61.215	-373.961	-173.278	25.246
1,600	47.092	116.226	75.023	65.925	-372.464	-159.946	21.847
1,700	47.092	119.081	77.532	70.634	-370.983	-146.709	18.860
1,800	47.092	121.773	79.916	75.343	-369.516	-133.558	16.216
1,900	47.092	124.319	82.186	80.052	-368.064	-120.489	13.859
2,000	47.092	126.734	84.354	84.761	-366.626	-107.495	11.746

Phase changes: 371 K, melting point of Na; ΔH° = 0.622 kcal/mol.
458 K, V-IV transition of Na_2SO_4; ΔH° = 0.061 kcal/mol.
514 K, IV-I transition of Na_2SO_4; ΔH° = 2.607 kcal/mol.
1,157 K, melting point of Na_2SO_4; ΔH° = 5.700 kcal/mol.
1,177 K, boiling point of Na to ideal monatomic gas; ΔH° = 23.285 kcal/mol.

Source: All data re from JANAF (16).

$Na_2SO_4 \cdot 10H_2O(c)$
Sodium sulfate decahydrate

[Formation: $2Na(c,l) + S(c,l) + 10H_2(g) + 7\ O_2(g) = Na_2SO_4 \cdot 10H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°$_{298}$)/T	H° - H°$_{298}$	ΔHf°	ΔGf°	
298.15	124.000	141.500	141.500	0	-1,034.240	-871.491	638.812
300	124.666	142.269	141.502	.230	-1,034.265	-870.480	634.136
350	142.666	162.838	143.087	6.913	-1,034.487	-843.154	526.482
368.3	149.254	170.277	144.254	9.584	-1,034.373	-833.152	494.387
368.3	149.254	170.277	144.254	9.584	-1,034.469	-833.152	494.388
371	150.226	171.371	144.448	9.988	-1,034.444	-831.677	489.920
371	150.226	171.371	144.448	9.988	-1,035.688	-831.677	489.921
388.36	156.476	178.381	145.805	12.651	-1,035.468	-822.133	462.650
388.36	156.476	178.381	145.805	12.651	-1,035.881	-822.133	462.650
400	160.666	183.064	146.822	14.497	-1,035.696	-815.729	445.688
432.02	172.193	195.874	149.983	19.826	-1,034.966	-798.147	403.761
450	178.666	203.027	151.960	22.980	-1,034.477	-788.302	382.847
500	196.666	222.783	158.057	32.363	-1,032.356	-761.054	332.652
550	214.666	242.371	164.831	42.647	-1,029.352	-734.062	291.685

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
371 K, melting point of Na; ΔH° = 0.622 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Source: The enthalpy of formation and entropy at 298 K are from Wagman (65) after the sulfate correction. Heat capacity values are estimated.

$(NH_4)_2SO_4(c)$
Ammonium sulfate

[Formation: $N_2(g) + 4H_2(g) + S(c,l) + 2\ O_2(g) = (NH_4)_2SO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°$_{298}$)/T	H° - H°$_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-8.512	-275.800	-275.800	∞
100	19.024	13.672	90.382	-7.671	-280.072	-259.425	566.965
200	43.996	33.445	56.875	-4.686	-282.144	-237.807	259.860
298.15	44.812	52.710	52.710	0	-282.660	-216.006	158.335
300	44.936	52.988	52.711	.083	-282.678	-215.593	157.057
368.3	49.349	62.645	53.673	3.304	-283.175	-200.261	118.834
368.3	49.349	62.645	53.673	3.304	-283.271	-200.261	118.834
388.36	50.645	65.297	54.207	4.307	-283.373	-195.736	110.149
388.36	50.645	65.297	54.207	4.307	-283.786	-195.737	110.149
400	51.397	66.804	54.552	4.901	-283.853	-193.097	105.502
432.02	53.567	70.845	55.611	6.581	-284.017	-185.826	94.004
500	58.173	78.988	58.240	10.374	-284.278	-170.348	74.458
600	65.745	90.250	62.647	16.562	-283.970	-147.579	53.755
650	69.886	95.674	64.979	19.952	-283.522	-136.229	45.804

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Parker (50) after correction for the SO_4^{2-} ion. The entropy at 298 K is based on Kelley (30). Low-temperature heat capacity values and high-temperature enthalpies are from Kelley (30); see text.

$NH_4Al(SO_4)_2(c)$
Ammonium aluminum sulfate

[Formation: $0.5N_2(g) + 2H_2(g) + Al(c,l) + 2S(c) + 4\ O_2(g) = NH_4Al(SO_4)_2(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	$C_p°$	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-8.620	-554.437	-554.437	∞
100	20.215	11.852	90.282	-7.843	-558.648	-535.793	1,170.959
200	40.973	32.717	56.282	-4.713	-561.166	-511.855	559.322
298.15	54.114	51.715	51.715	0	-562.400	-487.355	357.236
300	54.315	52.050	51.717	.100	-562.416	-486.889	354.694
368.3	61.840	64.370	52.916	4.218	-562.586	-469.661	278.694
368.3	61.840	64.370	52.916	4.218	-562.778	-469.661	278.694
388.36	64.051	67.710	53.596	5.481	-562.799	-464.588	261.444
388.36	64.051	67.710	53.596	5.481	-563.625	-464.588	261.444
400	65.333	69.620	54.035	6.234	-563.656	-461.620	252.214
432.02	66.768	74.706	55.381	8.349	-563.750	-453.449	229.388
500	69.816	84.730	58.700	13.015	-564.047	-436.059	190.599
600	72.512	97.714	64.147	20.140	-564.063	-410.454	149.506
650	73.552	103.560	66.957	23.792	-563.985	-397.656	133.702

Phase changes: 368.3 K, orthrhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.

Source: See text.

$NH_4Al(SO_4)_2 \cdot 12H_2O(c)$
Ammonium aluminum sulfate dodecahydrate

[Formation: $0.5N_2(g) + 14H_2(g) + Al(c) + 10\ O_2(g) = NH_4Al(SO_4)_2 \cdot 12H_2O(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	$C_p°$	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	162.962	166.600	166.600	0	-1,420.420	-1,180.311	865.180
300	163.740	167.610	166.603	.302	-1,420.468	-1,178.821	858.759
350	183.761	194.379	168.670	8.998	-1,421.170	-1,138.476	710.887
367.13	190.175	203.313	170.080	12.201	-1,421.212	-1,124.638	669.480

Phase changes: 367.13 K, melting point of $NH_4Al(SO_4)_2 \cdot 12H_2O(c)$; ΔH° = 29.16 kcal/mol.

Sources: The enthalpy of formation and entropy at 298 K are from Wagman (63) after correction for the sulfate ion. Heat capacity values are from Kelley (30) and Gronvold (24).

$PbSO_4(c)$
Lead sulfate
[Formation: $Pb(c,l) + S(c,l) + 2\ O_2(g) = PbSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°298)/T	H° - H°298	ΔHf°	ΔGf°	
0	0	0	∞	-4.792	-217.814	-217.814	∞
100	14.408	14.516	54.396	-3.988	-218.985	-210.978	461.086
200	20.356	26.492	37.632	-2.228	-220.849	-203.936	222.848
298.15	24.667	35.490	35.490	0	-219.870	-194.327	142.444
300	24.717	35.636	35.489	.044	-219.874	-194.168	141.449
368.3	25.502	40.612	35.992	1.702	-220.003	-188.302	111.737
368.3	25.502	40.612	35.992	1.702	-220.099	-188.302	111.737
388.36	25.733	41.971	36.266	2.216	-220.121	-186.569	104.990
388.36	25.733	41.971	36.266	2.216	-220.534	-186.569	104.990
400	25.867	42.733	36.443	2.516	-220.565	-185.551	101.379
432.02	26.674	44.756	36.985	3.357	-220.660	-182.745	92.445
500	28.388	48.772	38.318	5.227	-220.918	-176.754	77.258
600	31.033	54.180	40.518	8.197	-221.008	-167.910	61.161
600.65	31.051	54.214	40.533	8.217	-221.007	-167.851	61.073
600.65	31.051	54.214	40.533	8.217	-222.154	-167.851	61.073
600	33.735	59.167	42.831	11.435	-221.999	-158.879	49.604
717.82	34.222	60.021	43.247	12.040	-221.941	-157.273	47.883

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
600.65 K, melting point of Pb; ΔH° = 1.147 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation and entropy at 298 K are from CODATA (7). Low-temperature heat capacity values are from Gallagher (21), while high-temperature enthalpy values are from Krestovnikov (35).

$PbSO_4(c)$
Lead sulfate
[Formation: $Pb(c,l) + 0.5S_2(g) + 2\ O_2(g) = PbSO_4(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°298)/T	H° - H°298	ΔHf°	ΔGf°	
0	0	0	∞	-4.792	-233.132	-233.132	∞
100	14.408	14.516	54.396	-3.988	-234.506	-224.468	490.568
200	20.356	26.492	37.632	-2.228	-236.331	-215.397	235.372
298.15	24.667	35.490	35.490	0	-235.225	-203.841	149.417
300	24.717	35.636	35.489	.044	-235.226	-203.645	148.353
400	25.867	42.733	36.443	2.516	-235.216	-193.116	105.512
500	28.388	48.772	38.318	5.227	-235.045	-182.608	79.817
600	31.033	54.180	40.518	8.197	-234.702	-172.151	62.705
600.65	31.051	54.214	40.533	8.217	-234.699	-172.082	62.612
600.65	31.051	54.214	40.533	8.217	-235.846	-172.081	62.612
700	33.735	59.167	42.831	11.435	-235.324	-161.574	50.445
800	36.469	63.849	45.168	14.945	-234.570	-151.086	41.274
900	39.220	68.304	47.493	18.730	-233.564	-140.707	34.168
1,000	41.983	72.579	49.789	22.790	-232.308	-130.459	28.511
1,100	44.753	76.710	52.049	27.127	-230.796	-120.350	23.911

Phase changes: 600.65 K, melting point of Pb; ΔH° = 1.147 kcal/mol.

Sources: The enthalpy of formation and entropy at 298 K are from CODATA (7). Low-temperature heat capacity values are from Gallagher (21), while high-temperature enthalpy values are from Krestovnikov (35).

Rb_2SO_4(c)
Rubidium sulfate
[Formation: 2Rb(c,l) + S(c,l) + 2 O_2(g) = Rb_2SO_4(c)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
298.15	32.011	47.190	47.190	0	-343.120	-314.742	230.709
300	32.087	47.388	47.191	.059	-343.125	-314.566	229.158
312.64	32.539	48.722	47.226	.467	-343.156	-313.362	219.051
312.64	32.539	48.722	47.226	.467	-344.204	-313.362	219.051
368.3	34.529	54.238	47.873	2.344	-344.331	-307.855	182.679
368.3	34.529	54.238	47.873	2.344	-344.427	-307.855	182.680
388.36	35.247	56.089	48.250	3.044	-344.452	-305.862	172.122
388.36	35.247	56.089	48.250	3.044	-344.865	-305.862	172.122
400	35.663	57.136	48.494	3.457	-344.891	-304.693	166.474
432.02	36.610	59.919	49.239	4.614	-344.960	-301.473	152.507
500	38.619	65.405	51.069	7.168	-345.115	-294.617	128.775
600	41.692	72.719	54.079	11.184	-344.940	-284.527	103.637
700	45.230	79.394	57.224	15.519	-344.391	-274.495	85.700
717.82	46.496	80.547	57.789	16.336	-344.243	-272.717	83.031

Phase changes: 312.64 K, melting point of Rb; ΔH° = 0.524 kcal/mol.
368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is from CODATA (7). The entropy at 298 K was calculated by Paukov (52). Low-temperature heat capacities are from Paukov (52). High-temperature enthalpies are from Denielou (13). See text for high-temperature discussion.

Rb_2SO_4(c,l)
Rubidium sulfate
[Formation: 2Rb(c,l,g) + $0.5S_2$(g) + 2 O_2(g) = Rb_2SO_4(c,l)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
298.15	32.011	47.190	47.190	0	-358.475	-324.255	237.683
300	32.087	47.388	47.191	.059	-358.477	-324.043	236.062
312.64	32.539	48.722	47.226	.467	-358.488	-322.592	225.504
312.64	32.539	48.722	47.226	.467	-359.536	-322.592	225.504
400	35.663	57.136	48.494	3.457	-359.542	-312.259	170.608
500	38.619	65.405	51.069	7.168	-359.242	-300.470	131.334
600	41.692	72.719	54.079	11.184	-358.635	-288.768	105.182
700	45.230	79.394	57.224	15.519	-357.716	-277.190	86.541
800	52.335	85.828	60.397	20.345	-356.319	-265.774	72.605
900	69.840	92.855	63.602	26.328	-353.784	-254.577	61.819
931	78.971	95.367	64.616	28.629	-352.558	-251.180	58.963
931	43.881	95.479	64.616	28.733	-352.454	-251.180	58.963
974.5	45.053	97.509	66.040	30.667	-352.035	-246.465	55.274
974.5	45.053	97.509	66.040	30.667	-386.495	-246.465	55.274
1,000	45.740	98.682	66.857	31.825	-386.129	-242.806	53.065
1,100	48.435	103.168	69.955	36.534	-384.539	-228.547	45.408
1,200	51.129	107.498	72.905	41.512	-382.703	-214.446	39.056
1,300	53.824	111.697	75.729	46.759	-380.614	-200.507	33.708
1,339	54.874	113.303	76.799	48.879	-379.732	-195.116	31.846
1,339	49.335	120.203	76.799	58.059	-370.552	-195.116	31.846
1,400	49.335	122.401	78.780	61.069	-369.484	-187.210	29.224
1,500	49.335	125.805	81.804	66.002	-367.748	-174.253	25.388
1,600	49.335	128.989	84.655	70.935	-366.030	-161.411	22.047
1,700	49.335	131.980	87.351	75.869	-364.326	-148.673	19.113
1,800	49.335	134.800	89.910	80.802	-362.637	-136.034	16.517
1,900	49.335	137.467	92.343	85.736	-360.966	-123.492	14.205
2,000	49.335	139.998	94.664	90.669	-359.314	-111.039	12.134

Phase changes: 312.64 K, melting point of Rb; ΔH° = 0.524 kcal/mol.
931 K, transition for Rb_2SO_4; ΔH° = 0.104 kcal/mol.
974.5 K, calculated boiling point of Rb to ideal monatomic gas; ΔH° = 17.230 kcal/mol.
1,339 K, melting point of Rb_2SO_4; 9.18 kcal/mol.

Sources: The enthalpy of formation is from CODATA (7). The entropy at 298 K was calculated by Paukov (52). Low-temperature heat capacities are from Paukov (52). High-temperature enthalpies are from Denielou (13). See text for high-temperature discussion.

Tl_2SO_4(c)
Thallium sulfate
[Formation: 2Tl(c,l) + S(c,l) + 2 O_2(g) = Tl_2SO_4(c)]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	32.045	55.100	55.100	0	-322.800	-198.575	145.558
300	32.151	55.299	55.102	.059	-222.801	-198.425	144.551
368.3	35.664	62.263	55.794	2.383	-222.696	-192.884	114.456
368.3	35.664	62.263	55.794	2.383	-222.792	-192.884	114.456
388.36	36.695	64.182	56.179	3.108	-222.733	-191.257	107.628
388.36	36.695	64.182	56.179	3.108	-223.146	-191.257	107.628
400	37.294	65.275	56.428	3.539	-223.123	-190.301	103.975
432.02	38.753	68.203	57.193	4.757	-223.057	-187.677	94.941
500	41.852	74.092	59.094	7.499	-222.916	-182.113	79.600
507	42.155	74.676	59.305	7.793	-222.889	-181.541	78.255
507	42.155	74.676	59.305	7.793	-223.069	-181.541	78.255
577	45.185	80.322	61.516	10.851	-222.750	-175.822	66.595
577	45.185	80.322	61.516	10.851	-224.730	-175.822	66.595
600	46.181	82.108	62.271	11.902	-224.548	-173.879	63.335
700	50.400	89.544	65.641	16.732	-223.494	-165.503	51.672
717.82	51.143	90.820	66.250	17.637	-223.261	-164.029	49.940

Phase changes: 368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.906 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
507 K, α-β transition point of Tl; ΔH° = 0.090 kcal/mol.
577 K, melting point of Tl; ΔH° = 0.990 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation after correction for the heat of formation of the sulfate ion and entropy at 298 K are from Wagman (63). High-temperature heat capacities are from Shmidt (57) and are matched with high-temperature enthalpy values of Dworkin (19).

$Tl_2SO_4(c,l)$
Thallium sulfate
[Formation: $2Tl(c,l) + 0.5S_2(g) + 2\ O_2(g) = Tl_2SO_4(c,l)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	32.045	55.100	55.100	0	-238.155	-208.089	152.531
300	32.151	55.299	55.102	.059	-238.153	-207.902	151.455
400	37.294	65.275	56.428	3.539	-237.774	-197.867	108.108
500	41.852	74.092	59.094	7.499	-237.044	-187.966	82.159
507	42.155	74.676	59.305	7.793	-236.983	-187.278	80.728
507	42.155	74.676	50.305	7.793	-237.163	-187.278	80.728
577	45.185	80.322	61.516	10.851	-236.538	-180.427	68.339
577	45.185	80.322	61.516	10.851	-238.518	-180.427	68.339
600	46.181	82.108	62.271	11.902	-238.243	-178.120	64.879
700	50.400	89.544	65.641	16.732	-236.819	-168.198	52.513
774	53.484	94.762	68.178	20.576	-235.526	-161.023	45.467
774	45.949	94.968	68.178	20.736	-235.366	-161.023	45.467
800	45.238	96.473	69.073	21.920	-235.083	-158.530	43.308
900	48.210	101.894	72.421	26.526	-233.965	-149.018	36.186
916	49.358	102.754	72.944	27.306	-233.745	-147.511	35.194
916	40.000	109.162	72.944	33.176	-227.876	-147.511	35.194
1,000	40.000	112.672	76.136	36.536	-227.472	-140.156	30.631

Phase changes:
507 K, α-β transition point of Tl; ΔH° = 0.090 kcal/mol.
577 K, melting point of Tl; ΔH° = 0.990 kcal/mol.
774 K, orthorhombic to hexagonal transition for $Tl_2SO_4(c)$, ΔH° = 0.160 kcal/mol.
916 K, melting point of $Tl_2SO_4(c)$; ΔH° = 5.870 kcal/mol.

Sources: The enthalpy of formation after correction for the heat of formation of the sulfate ion and entropy at 298 K are from Wagman (63). High-temperature heat capacities are from Shmidt (57) and are matched with high-temperature enthalpy values of Dworkin (19).

$Zr(SO_4)_2(c)$
Zirconium sulfate
[Formation: $Zr(c) + 2S(c,l) + 4\ O_2(g) = Zr(SO_4)_2(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	$-(G° - H°_{298})/T$	$H° - H°_{298}$	ΔHf°	ΔGf°	
298.15	37.828	31.800	31.800	0	-536.200	-479.891	351.765
300	38.183	32.035	31.802	.070	-536.213	-479.540	349.340
368.3	46.142	40.942	32.661	3.050	-536.367	-466.610	276.884
368.3	46.142	40.942	32.661	3.050	-536.559	-466.610	276.884
388.36	48.480	43.452	33.156	3.999	-536.552	-462.799	260.437
388.36	48.480	43.452	33.156	3.999	-537.378	-462.799	260.437
400	49.836	44.904	33.477	4.571	-537.392	-460.564	251.637
432.02	51.162	48.793	34.469	6.188	-537.438	-454.414	229.875
500	53.978	56.550	36.954	9.798	-537.630	-441.324	192.900
600	55.165	66.525	41.073	15.271	-537.583	-422.064	153.735
700	54.955	75.025	45.332	20.785	-537.494	-402.818	125.764
717.82	54.785	76.404	46.086	21.763	-537.483	-399.389	121.598

Phase changes:
368.3 K, orthorhombic-monoclinic transformation of S; ΔH° = 0.096 kcal/mol.
388.36 K, melting point of S; ΔH° = 0.413 kcal/mol.
432.02 K, second-order transformation of S; ΔH° = 0 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture of S_n (n = 1 to 8).

Sources: The enthalpy of formation at 298 K is based on Melnikova (43). The entropy at 298 K was estimated by Stern (61). High-temperature enthalpy values are from Shmidt (60).

$Zr(SO_4)_2(c)$
Zirconium sulfate
[Formation: $Zr(c) + S_2(g) + 4\ O_2(g) = Zr(SO_4)_2(c)$]

T, K	cal/(mol·K)			kcal/mol			Log Kf
	Cp°	S°	-(G° - H°_{298})/T	H° - H°_{298}	ΔHf°	ΔGf°	
298.15	37.828	31.800	31.800	0	-566.910	-498.918	365.712
300	38.183	32.035	31.802	.070	-566.917	-498.495	363.149
400	49.836	44.904	33.477	4.571	-566.694	-475.696	259.905
500	53.978	56.550	36.954	9.798	-565.885	-453.031	198.017
600	55.165	66.525	41.073	15.271	-564.972	-430.546	156.824
700	54.955	75.025	45.332	20.785	-564.144	-408.209	127.447
800	54.001	82.308	49.512	26.237	-563.490	-385.984	105.445
900	52.615	88.591	53.512	31.571	-563.046	-363.823	88.347
1,000	50.961	94.051	57.299	36.752	-562.835	-341.701	74.678
1,050	50.063	96.516	59.109	39.277	-565.355	-319.528	63.484

Sources: The enthalpy of formation at 298 K is based on Melnikova (43). The entropy at 298 K was estimated by Stern (61). High-temperature enthalpy values are from Smith (60).

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