Information Circular 8910

Thermodynamic Properties of Selected Transition Metal Sulfates and Their Hydrates

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UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary

BUREAU OF MINES
Robert C. Horton, Director

This publication has been cataloged as follows:

DeKock, Carroll W

Thermodynamic properties of selected transition metal sulfates and their hydrates.

(Information circular / United States Department of the Interior, Bureau of Mines ; 8910)

Bibliography: p. 42-45.

Supt. of Docs. no.: I 28.27:8910.

1. Transition metal compounds–Thermal properties. 2. Sulphates–Thermal properties. 3. Hydrates–Thermal properties. I. Title. II. Series: Information circular (United States. Bureau of Mines) ; 8910.

TN295.U4 [TN693.T7] 622s [549'.75] 82-600258

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THERMODYNAMIC PROPERTIES OF SELECTED TRANSITION 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°, $H^\circ - H^\circ_{298}$, $-(G^\circ - H^\circ_{298})/T$, ΔHf°, ΔGf°, and log Kf as a function of temperature are given in tabular form. Thermodynamic data were compiled for $VOSO_4$, $Cr_2(SO_4)_3$, $MnSO_4$, $FeSO_4$, $Fe_2(SO_4)_3$, $CoSO_4$, $NiSO_4$, Cu_2SO_4, $CuSO_4$, $CuO \cdot CuSO_4$, $ZnSO_4$, and $ZnO \cdot 2ZnSO_4$, together with their stable hydrates.

INTRODUCTION

As a part of the Bureau of Mines continuing effort to provide thermodynamic data for mineral technology advancement, thermodynamic properties of selected transition metal sulfates and their hydrates were critically evaluated and compiled. This compilation is the first in a planned series on the thermodynamic properties of metal sulfates. Kellogg (22),[2] in 1964, reviewed the thermodynamic properties of many of the anhydrous metal sulfates found in this compilation. His values were based on high-temperature sulfate decomposition data. The thermodynamic properties here are calculated on the basis of calorimetric data, many of which were unavailable in 1964. 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 (36). The values for the standard heat capacities (Cp°), high-temperature relative enthalpies ($H^\circ - H^\circ_{298}$), enthalpies of formation (ΔHf°), and Gibbs energies of formation (ΔGf°) are given in tabular form. The tables include Gibbs energy functions, $-(G^\circ - H^\circ_{298})/T$, 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 transformations are given along with their associated enthalpies. All thermodynamic values for the elements are from Pankratz (36).

METHODS, CONVENTIONS, AND SYMBOLS

The values in this compilation are the result of a review and critical evalua-

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

tion of relevant thermodynamic data through July 1981. Standard enthalpies of formation at 298.15 K are corrected to the latest CODATA (8) values where the accuracy of the original data warrants such care. The CODATA value for the standard heat of formation of SO_4^{2-} (aq) at infinite dilution is the major correction for this document. CODATA gives $\Delta Hf°(SO_4^{2-}, \infty aq)$ = -217.4 kcal/mol, while Wagman (47) reports $\Delta Hf°(SO_4^{2-}, \infty aq)$ = -217.32 kcal/mol. Sulfate ion corrections in this document are all based on the CODATA value. Also, $\Delta Hf°(H_2O,\ell)$ = -68.315 kcal/mol, used throughout this review, is from Wagman (47).

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 (20). This program, along with a plot of the function $(H° - H°_{298})/(T-298.15)$, 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, tables 1-52 include values for the standard enthalpy of 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 "°").

References for data used in this compilation are given in the bibliography. 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 source 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.

The following is a list of symbols and constants used:

T	Thermodynamic temperature in kelvin.
K	Kelvin, the unit of thermodynamic temperature.
Cp	Heat capacity at constant pressure.
S	Entropy.
$H - H_{298}$	Enthalpy increment between T and 298.15 K.
$(G - H_{298})/T$	Gibbs energy function, $[(H - H_{298})/T] - S$.
ΔH	Enthalpy change (ΔHf = enthalpy of formation).
ΔG	Gibbs energy change (ΔGf = Gibbs energy of formation).
Log K	Logarithm (base 10) of the equilibrium constant (Log Kf = logarithm of equilibrium constant of formation).
cal	Thermochemical calorie, 1 cal = 4.1840 j.
mol	Mole, gram formula weight or molar mass.
ln	Natural logarithm, base e = 2.7183.
P	Pressure in atmospheres, 1 atm = 101.325 kPa.
R	Gas constant, 1.98719 cal/mol•K.
F	Faraday constant, 23,060.9 cal/v•equiv.
°	Standard state.

ESTIMATION PROCEDURES FOR HYDRATES

The entropies and heat capacities for a number of hydrated sulfates in this study required estimation. Excellent heat capacity and entropy data are known for the 3d transition metal sulfate hydrates $FeSO_4 \cdot 7H_2O$, $CoSO_4 \cdot 6H_2O$, $CoSO_4 \cdot 7H_2O$, $NiSO_4 \cdot 6H_2O$, $NiSO_4 \cdot 7H_2O$, $CuSO_4 \cdot H_2O$, $CuSO_4 \cdot 3H_2O$, $CuSO_4 \cdot 5H_2O$, $ZnSO_4 \cdot 6H_2O$, and $ZnSO_4 \cdot 7H_2O$. The average increase in heat capacity per water molecule for these 10 compounds is 9.3 cal/mol•K. Phillipson and Finlay (38), in a review of 31 hydrates, found a similar increase of 9.26 cal/mol•K per H_2O molecule. Accordingly, the heat capacities for hydrates were estimated by adding 9.3 cal/mol•K per mole H_2O to the heat capacity of the anhydrous compounds to obtain the heat capacity at 298.15 K. The entropy increase per mole of H_2O for the 10 hydrates is 9.46 cal/mol•K. In the absence of other data for estimation, 9.5 cal/mol•K per mole H_2O was added to the entropy of the anhydrous compound to obtain the entropy of the hydrate at 298.15 K. This was the only estimation method used for the vanadium and chromium sulfate hydrates. Other estimation procedures, tailored for individual compounds, are discussed in the text.

With the values at 298.15 K in hand, it then was necessary to estimate the heat capacities above 298.15 K. This was a more complex problem because no data exist for any hydrates above about 350 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
1	0.09
2	.10
3	.132
4	.144
5	.180
6	.216
7	.252

These values of b were determined by observing that the heat capacity increase for tetrahydrates, hexahydrates, and heptahydrates averaged 1.8 cal/mol•K per mole H_2O over the temperature range 250 to 300 K, a 50-degree interval. Similar data for dihydrates show an increase of 2.5 cal/mol•K, and for monohydrates, 4.5 cal/mol•K (14). By linear interpolation, a value of 2.2 cal/mol•K was assigned for the trihydrates.

DISCUSSION OF THERMODYNAMIC PROPERTIES

Vanadium

$VOSO_4(c)$

The enthalpy of formation at 298.15 K and entropy at 298.15 K are from Wagman (49). The heat capacity at 298.15 K was estimated to be 29 cal/mol•K by adding the heat capacity of VO (10.86 cal/mol•K) to the estimated heat capacity of the sulfate ion (18 cal/mol•K) (28). High-temperature enthalpies were estimated by comparison with the known high-temperature enthalpies of $MnSO_4(c)$ (42).

$VOSO_4 \cdot nH_2O(c)$

Reggiani, Tachez, and Bernard (41) determined the hydration enthalpies for the hydrated vanadyl sulfates, $VOSO_4 \cdot nH_2O$, by solution calorimetry. The standard enthalpies of formation of the hydrates at 298.15 K were determined from these data and the standard enthalpy of formation of $VOSO_4(c)$ as reported by Wagman (49). The entropies at 298.15 K for the various hydrates were estimated by adding 9.5 cal/mol•K per mole H_2O to the entropy of $VOSO_4(c)$. Heat capacities for the various hydrates were estimated as discussed earlier.

Chromium

$Cr_2(SO_4)_3(c)$

Jacob, Rao, and Nelson (18) studied the decomposition of $Cr_2(SO_4)_3(c)$ over the temperature range 882 to 1,040 K, using thermogravimetric and differential thermal analyses. Over this temperature range, the change in the standard Gibbs energy for the reaction

$$Cr_2O_3(c) + 3SO_3(g) = Cr_2(SO_4)_3(c)$$

was found to be $\Delta G^\circ = -143.078 + 0.1296T$ kcal/mol. This yielded a second-law value for $\Delta H^\circ_r = -143.078$ kcal/mol at 961 K for the above reaction. High-temperature enthalpies for $Cr_2(SO_4)_3(c)$ were estimated by adding the difference in known heat capacities between $Cr_2(SO_4)_3(c)$ and $Fe_2(SO_4)_3(c)$ at 298.15 K (2.2 cal/mol•K) to the known high-temperature heat capacity of $Fe_2(SO_4)_3(c)$ (37). This yielded an enthalpy difference between 298.15 K and 961 K equal to 61.4 kcal/mol. Combining this value with the appropriate enthalpies of $Cr_2O_3(s)$ and $SO_3(g)$ from Pankratz (36) yielded $\Delta Hf^\circ[Cr_2(SO_4)_3(c)] = -710$ kcal/mol at 298.15 K. Alternatively, a third-law value may be obtained by combining the above heat capacity values with the low-temperature heat capacities measured by Vasileff and Grayson-Smith (45) to obtain the absolute entropy of $Cr_2(SO_4)_3$ in the temperature range of interest. The latter work yielded $S^\circ_{298} = 61.85$ cal/mol•K (28). This value and the heat capacities were used to obtain a third-law value of $\Delta Hf^\circ[Cr_2(SO_4)_3(c)] = -705$ kcal/mol, which is the adopted value.

$Cr_2(SO_4)_3 \cdot nH_2O(c)$

Heat capacities and entropies for the chromium sulfate hydrates were estimated as discussed earlier for $VOSO_4 \cdot nH_2O(c)$.

Manganese

$MnSO_4(c)$

The CODATA (8) enthalpy of formation value for the sulfate ion at infinite dilution was used in recalculating the results of Southard and Shomate (42) to obtain $\Delta Hf°[MnSO_4(c)] = -254.70$ kcal/mol. This value is adopted.

The enthalpy of solution at infinite dilution, $\Delta H°soln\ [MnSO_4(c)] = -15.5$ kcal/mol, is from Wagman (48). When this value was combined with the CODATA value for $SO_4^{2-}(aq)$ and Wagman's $Mn^{2+}(aq)$ value for the enthalpy of formation of the infinitely dilute ions, $\Delta Hf°[MnSO_4(c)] = -254.66$ kcal/mol was obtained, which is in excellent agreement with the adopted value.

The entropy at 298.15 K is from Moore and Kelley (34), who measured the low-temperature heat capacities of $MnSO_4(c)$. The high-temperature enthalpies are from Southard and Shomate (42).

$MnSO_4 \cdot H_2O(\alpha,c)$

The enthalpy of formation of $MnSO_4 \cdot H_2O(\alpha,c)$ is from Wagman (48), corrected for the enthalpy of formation of the sulfate ion at infinite dilution. The entropy at 298.15 K was estimated as follows: The average difference in entropy between the monohydrates and anhydrous salts for the sulfates of Fe, Ni, Cu, and Zn is 8.18 cal/mol•K. Adding this value to the entropy of $MnSO_4(c)$ yielded $S°_{298} = 35$ cal/mol•K (rounded).

The heat capacity of $MnSO_4 \cdot H_2O(c)$ was estimated by adding 9.3 cal/mol•K to the heat capacity of $MnSO_4(c)$ to give $Cp°_{298} = 33$ cal/mol•K.

$MnSO_4 \cdot 4H_2O(c)$

The enthalpy of formation of $MnSO_4 \cdot 4H_2O(c)$ at 298.15 K was taken from Wagman (48) after correcting for the enthalpy of formation of the sulfate ion (8). The heat capacity at 298.15 K was estimated by adding 4•9.3 cal/mol•K to the heat capacity of $MnSO_4(c)$. The entropy at 298.15 K was estimated to be 65 cal/mol•K as discussed under "$MnSO_4 \cdot 7H_2O$."

$MnSO_4 \cdot 5H_2O(c)$

The enthalpy of formation of $MnSO_4 \cdot 5H_2O(c)$ at 298.15 K was taken from Wagman (48) after correcting for the enthalpy of formation of the sulfate ion (8). The heat capacity at 298.15 K is from Wagman. The entropy was estimated to be 75 cal/mol•K as discussed under "$MnSO_4 \cdot 7H_2O$."

$MnSO_4 \cdot 7H_2O(c)$

The enthalpy of formation of $MnSO_4 \cdot 7H_2O(c)$ at 298.15 K was taken from Wagman (48) after correcting for the enthalpy of formation of the sulfate ion (8). The entropy at 298.15 K was estimated as follows. The entropies of the heptahydrates of the sulfates of Fe, Co, Ni, and Zn are well known (4, 30, 40, 43). The average difference between the entropies of these heptahydrates and their anhydrous sulfates is 67.65 ±1.25 cal/mol•K. Adding this value to the entropy of $MnSO_4(s)$ at 298.15 K yielded $S°_{298}[MnSO_4 \cdot 7H_2O(c)] = 94$ cal/mol•K (rounded). The entropies for $MnSO_4 \cdot$

$4H_2O(c)$ and $MnSO_4 \cdot 5H_2O(c)$ were then estimated by taking the difference for the monohydrate and heptahydrate (59 cal/mol·K) and adding the linear extrapolated entropy proportion to the entropy of the monohydrate to obtain the entropy of the tetra- and pentahydrate.

The heat capacity of $MnSO_4 \cdot 7H_2O(c)$ was estimated in the same manner as the entropy.

Dissociation of $MnSO_4 \cdot nH_2O$

Thermodynamic values for reactions of the type

$$MnSO_4 \cdot YH_2O(c) = MnSO_4 \cdot XH_2O(c) + (Y-X)H_2O(\ell)$$

were calculated as a function of temperature. The foregoing data gave reasonable decomposition temperatures for all the compounds. However, enthalpy of formation values for the hydrates that were calculated on the basis of either the enthalpy of solution values reported by Jamieson (19) or those reported by Phillipson and Finlay (38) led to inconsistent results and were not sufficiently negative to lead to stable hydrates.

Iron

$FeSO_4(c)$ and Hydrates

Adami and Kelley (1) determined the enthalpy of formation of $FeSO_4 \cdot H_2O(c)$ and $FeSO_4 \cdot 7H_2O(c)$ by sulfuric acid solution calorimetry. Recalculation of their results using the latest CODATA (8) value for $SO_4^{2-}(aq)$ yielded $\Delta Hf°[FeSO_4 \cdot H_2O(c)] = -297.40$ kcal/mol and $\Delta Hf°[FeSO_4 \cdot 7H_2O(c)] = -720.44$ kcal/mol. These values are adopted. Wagman (48) reported $\Delta Hf°[FeSO_4 \cdot H_2O(c)] = -297.25$ kcal/mol and $\Delta Hf°[FeSO_4 \cdot 7H_2O(c)] = -720.5$ kcal/mol. The enthalpies of solution at infinite dilution, $\Delta H°soln[FeSO_4 \cdot H_2O(c)] = -10.6$ kcal/mol and $\Delta H°soln[FeSO_4 \cdot 7H_2O(c)] = 2.82$ kcal/mol, have been measured by Larson (29). The enthalpy of formation for $Fe^{2+}(aq)$ may be obtained by combining these values with $\Delta Hf°$ values for $H_2O(\ell)$ (47) and $SO_4^{2-}(aq)$ (8). This leads to $\Delta Hf°[Fe^{2+}(aq)] = -22.3$ kcal/mol($FeSO_4 \cdot H_2O$) and $\Delta Hf°[Fe^{2+}(aq)] = -22.0$ kcal/mol($FeSO_4 \cdot 7H_2O$), respectively. These are more negative than the value given by Wagman (48), $\Delta Hf°[Fe^{2+}(aq)] = -21.3$ kcal/mol. Larson (29) noted a similar discrepancy and chose $\Delta Hf°[Fe^{2+}(aq)] = -22.1$ kcal/mol. We have adopted his value in our further calculations.

Combining the enthalpy of solution at infinite dilution from Wagman (48), $\Delta H°soln\ [FeSO_4(c)] = +16.7$ kcal/mol, with the above enthalpy of formation for $Fe^{2+}(aq)$ and the enthalpy of formation for $SO_4^{2-}(aq)$ from CODATA (8) yielded $\Delta Hf°[FeSO_4(c)] = -222.8$ kcal/mol, which is the value adopted here. This compares with $\Delta Hf°[FeSO_4(c)] = -221.9$ kcal/mol given by Wagman (48).

Combining the enthalpy of solution at infinite dilution, $\Delta H°soln[FeSO_4 \cdot 4H_2O(c)] = -3.3$ kcal/mol (29), with the enthalpies of formation of $SO_4^{2-}(aq)$ (8), $H_2O(\ell)$ (47), and $Fe^{2+}(aq)$ yielded $\Delta Hf°[FeSO_4 \cdot 4H_2O(c)] = -509.5$ kcal/mol, which is the adopted value. This compares with $\Delta Hf°[FeSO_4 \cdot 4H_2O(c)] = -508.9$ kcal/mol reported by Wagman (48).

Malinin, Drakin, and Ankudimov (32) measured the entropy of the reaction $FeSO_4 \cdot 7H_2O(c) = FeSO_4 \cdot 4H_2O(c) + 3H_2O(g)$ by an isopiestic method. Their value for

this reaction was $\Delta S = 105.0$ cal/mol·K. Combining this value with the entropies of $FeSO_4 \cdot 7H_2O(c)$ (30) and $H_2O(g)$ (47) led to $S^\circ_{298}[FeSO_4 \cdot 4H_2O(c)] = 67.5$ cal/mol·K. S°_{298} for $FeSO_4 \cdot H_2O(c)$ is from Pribylov (39). The heat capacity for $FeSO_4 \cdot H_2O(c)$ was estimated as discussed earlier. The heat capacity for $FeSO_4 \cdot 4H_2O(c)$ was reported by Kelley (21) to be 63.6 cal/mol·K at 282 K.

The heat capacity above 307 K for $FeSO_4 \cdot 7H_2O(c)$ was estimated by extrapolating the low-temperature results of Lyon and Giauque (30).

$Fe_2(SO_4)_3(c)$

Barany and Adami (3) determined the enthalpy of formation of $Fe_2(SO_4)_3(c)$ by solution calorimetry. Recalculation of their results using the latest CODATA value for the enthalpy of formation of $SO_4^{2-}(aq)$ (8) and Wagman's enthalpy of formation for $Fe_2O_3(c)$ (48) yielded $\Delta Hf^\circ[Fe_2(SO_4)_3] = -617.1$ kcal/mol, which is adopted here.

The low-temperature and high-temperature heat capacities are those reported by Pankratz and Weller (37). The entropy at 298.15 K is also taken from reference 37.

Cobalt

$CoSO_4(c)$

The CODATA ΔH°_f value (8) for $SO_4^{2-}(aq)$ and the heat of formation value recommended by Cyr, Dellacherie, and Balesdent (9) for CoO were used in recalculating the results of Adami and King (2) to obtain $\Delta Hf^\circ[CoSO_4(c)] = -212.3$ kcal/mol. This value is adopted here.

The low-temperature (52-298.15 K) heat capacities are those reported by Weller (50) with the low-temperature entropies and enthalpies those evaluated by JANAF (11). Heat capacities in the temperature range 300-1,400 K were estimated by comparison with $CuSO_4(c)$.

The transition temperature and enthalpy for $CoSO_4(\alpha,c) = CoSO_4(\beta,c)$ are from the differential thermal analysis studies of Ingraham and Marier (17).

$CoSO_4 \cdot H_2O(c)$

Goldberg (15) reported $\Delta H^\circ = -6.1$ kcal/mol for the process $CoSO_4(c) + H_2O(\ell) = CoSO_4 \cdot H_2O(c)$. Combining this result with the standard enthalpies of formation of $H_2O(\ell)$ and $CoSO_4(c)$ yielded $\Delta Hf^\circ[CoSO_4 \cdot H_2O(c)] = -286.7$ kcal/mol. Alternatively, Goldberg reported $\Delta H^\circ = -12.8$ kcal/mol for the process $CoSO_4 \cdot H_2O(c) + 5H_2O(\ell) = CoSO_4 \cdot 6H_2O(c)$. Combining this result with the standard enthalpies of formation of $H_2O(\ell)$ (47) and $CoSO_4 \cdot 6H_2O(c)$ (see below) yielded $\Delta Hf^\circ[CoSO_4 \cdot H_2O(c)] = -287.0$ kcal/mol. The average of these two values, $\Delta Hf^\circ[CoSO_4 \cdot H_2O(c)] = -286.8$ kcal/mol, is adopted. The entropy at 298.15 K is that selected by Goldberg (15). Heat capacities were estimated as described earlier.

$CoSO_4 \cdot 6H_2O(c)$

Ko and Brown (25), from sulfuric acid solution calorimetry, obtained $\Delta Hf^\circ[CoSO_4 \cdot 6H_2O(c)] = -641.33$ kcal/mol, which is adopted here. The low-temperature (15-330 K) heat capacities and S°_{298} are those reported by Rao and Giauque (40). Broers and Van Welie (6) reported $CoSO_4 \cdot 6H_2O(c)$ to dissociate to $CoSO_4 \cdot H_2O(c)$ and

saturated solution at 337 K.

$CoSO_4 \cdot 7H_2O(c)$

Brodale and Giauque (5) reported $\Delta H^\circ = -2.455$ kcal/mol for the process $CoSO_4 \cdot 6H_2O(c) + H_2O(\ell) = CoSO_4 \cdot 7H_2O(c)$. Combining this value with the standard enthalpies of formation of $H_2O(\ell)$ and $CoSO_4 \cdot 6H_2O(c)$ yielded $\Delta Hf^\circ[CoSO_4 \cdot 7H_2O(c)] = -712.10$ kcal/mol, which is the adopted value. The low-temperature (15-310 K) heat capacities and S°_{298} are those reported by Rao and Giauque (40). They found that the transition $CoSO_4 \cdot 7H_2O(c)$ to $CoSO_4 \cdot 6H_2O(c)$ and saturated solution occurs at 317.78 K with an enthalpy of transition equal to 2.848 kcal/mol heptahydrate.

Nickel

$NiSO_4(c)$

The CODATA $\Delta Hf^\circ[SO_4^{2-}(aq)]$ value (8) was used in recalculating the results of Adami and King (2) to obtain $\Delta Hf^\circ[NiSO_4(c)] = -208.71$ kcal/mol. This value is adopted. Low-temperature (9-70 K) heat capacities of $NiSO_4(c)$ were measured by Stuve, Ferrante, and Ko (44) and have been combined with earlier work of Weller (50) to provide data to 300 K. It is noted that $Cp_{298}[NiSO_4(c)] = 33$ cal/mol·K, reported by Wagman (48), is in error. The correct value is 23.33 cal/mol·K, as reported by Weller (50). High-temperature enthalpy data (to 1,200 K) for $NiSO_4(c)$ are taken from the work of Stuve, Ferrante, and Ko.

$NiSO_4 \cdot H_2O(c)$

The enthalpy of solution at infinite dilution, $\Delta H^\circ soln[NiSO_4 \cdot H_2O(c)] = -14.0$ kcal/mol, is taken from the work of Goldberg (15). Combining this result with the CODATA value for $SO_4^{2-}(aq)$ (8) and Wagman's value for $Ni^{2+}(aq)$ (48) for the enthalpy of formation of the infinitely dilute ions, yielded $\Delta Hf^\circ[NiSO_4 \cdot H_2O(c)] = -284.61$ kcal/mol. S°_{298} estimated by Mah and Pankratz (31) is adopted, and the heat capacities were estimated as discussed in the section "Estimation Procedures for Hydrates."

$NiSO_4 \cdot 4H_2O(c)$

Kohler and Zaske (26) reported the vapor pressure as a function of temperature over the range 313-326 K, for the reaction $NiSO_4 \cdot 6H_2O(c) = NiSO_4 \cdot 4H_2O(c) + 2H_2O(g)$. Their data gave $\Delta G^\circ_{298} = +5.053$ kcal for this reaction. The entropy of $NiSO_4 \cdot 4H_2O(c)$ was estimated by noting that $S^\circ_{298}[NiSO_4 \cdot 6H_2O(c)] = 79.94$ cal/mol·K, while $S^\circ_{298}[NiSO_4(c)] = 24.2$ cal/mol·K. Linear interpolation yielded $S^\circ_{298}[NiSO_4 \cdot 4H_2O(c)] = 61$ cal/mol·K. Combining the above value with the standard Gibbs energy change for $H_2O(g)$ to $H_2O(\ell)$ (47) yielded $\Delta H = -5.3$ kcal for the reaction $NiSO_4 \cdot 4H_2O(c) + 2H_2O(\ell) = NiSO_4 \cdot 6H_2O(c)$. This value combined with the standard enthalpy of formation of $NiSO_4 \cdot 6H_2O$ (see below) and $H_2O(\ell)$ (47) yielded $\Delta Hf^\circ[NiSO_4 \cdot 4H_2O(c)] = -499.4$ kcal/mol, which is the adopted value. Wagman (48) reported $\Delta Hf^\circ[NiSO_4 \cdot 4H_2O(c)] = -502.9$ kcal/mol. However, using the latter value with the above estimated entropy requires $NiSO_4 \cdot 6H_2O(c)$ to be unstable with respect to $NiSO_4 \cdot 4H_2O(c)$ and $2H_2O(\ell)$ at 298 K. Alternatively, accepting Wagman's value for the enthalpy of formation of $NiSO_4 \cdot 4H_2O(c)$ (48) together with the above Gibbs energy data of Kohler and Zaske (26) requires $S^\circ_{298}[NiSO_4 \cdot 4H_2O(c)] = 53$ cal/mol·K. This value is too low to be acceptable. Using the above adopted value $\Delta Hf^\circ[NiSO_4 \cdot 4H_2O(c)] = -499.4$ kcal/mol, $NiSO_4 \cdot 6H_2O(c)$ was calculated to be stable to 360 K with respect to $NiSO_4 \cdot 4H_2O(c)$ and

$2H_2O(\ell)$. $Cp°(NiSO_4 \cdot 4H_2O)$ and its temperature dependence were estimated as described earlier.

$NiSO_4 \cdot 6H_2O(c)$

Goldberg (15) reported the enthalpy of solution at infinite dilution, $\Delta H°soln[NiSO_4 \cdot 6H_2O(c)] = +1.15$ kcal/mol. Combining this result with CODATA (8) values for the heat of formation of $SO_4^{2-}(aq)$ ion at infinite dilution and $\Delta Hf(H_2O,\ell)$ together with $\Delta Hf°[Ni^{2+}(aq)]$ (48) yielded $\Delta Hf°[NiSO_4 \cdot 6H_2O(c)] = -641.34$ kcal/mol, which is the adopted value. Low-temperature (1.1-320.98 K) heat capacities and entropies are those reported by Stout (43).

$NiSO_4 \cdot 7H_2O(c)$

Goldberg (15) reported the enthalpy of solution at infinite dilution, $\Delta H°soln[NiSO_4 \cdot 7H_2O(c)] = +2.89$ kcal/mol. Combining this value with the enthalpies of formation of $Ni^{2+}(aq)$ and $SO_4^{2-}(aq)$ at infinite dilution together with the standard enthalpy of formation of water yielded $\Delta Hf°[NiSO_4 \cdot 7H_2O(c)] = -711.40$ kcal/mol, which is the adopted value. Low-temperature (1-300 K) heat capacities and entropies are those reported by Stout (43). Stout (43) reported the transition from $NiSO_4 \cdot 7H_2O(c)$ to $NiSO_4 \cdot 6H_2O(c)$, and saturated solution occurs at 304 K. Additional differential scanning calorimeter (DSC) data for the above nickel sulfate hydrates were given by Friesen, Burt, and Mitchell (13).

Copper

$CuSO_4(c)$

The CODATA (8) values for the standard enthalpy of formation and entropy at 298 K for $CuSO_4(c)$ are adopted. The heat capacities are those adopted by King, Mah, and Pankratz (23). The enthalpy of solution at infinite dilution, $\Delta H°soln[CuSO_4(c)] = -17.56$ kcal/mol was reported by Larson (29). Combining this result with the CODATA values for the enthalpies of formation of the infinitely dilute ions yielded $\Delta Hf°[CuSO_4(c)] = -184.14$ kcal/mol, which is to be compared with the adopted CODATA value of -184.3 kcal/mol.

$CuSO_4 \cdot H_2O(c)$ and $CuSO_4 \cdot 3H_2O(c)$

The standard enthalpies of formation, entropies, and heat capacities at 298.15 K are those from Wagman (48). The high-temperature heat capacities were estimated.

$CuSO_4 \cdot 5H_2O(c)$

The heat of solution at infinite dilution, $\Delta H°soln[CuSO_4 \cdot 5H_2O(c)] = +1.43$ kcal/mol, was reported by Larson (29). Combining this result with the heat of solution of $CuSO_4$ (see above) yielded $\Delta H° = +18.99$ kcal/mol for the reaction $CuSO_4 \cdot 5H_2O(c) = CuSO_4(c) + 5H_2O(\ell)$. Combining this result with the CODATA (8) values for the standard enthalpies of formation of $CuSO_4(c)$ and $H_2O(\ell)$ yielded $\Delta Hf°[CuSO_4 \cdot 5H_2O(c)] = -544.87$ kcal/mol, which is the adopted value. Alternatively, combining the enthalpies of formation of the ions at infinite dilution with the enthalpy of formation of water and the enthalpy of solution at infinite dilution of $CuSO_4 \cdot 5H_2O(c)$ gave $\Delta Hf°[CuSO_4 \cdot 5H_2O(c)] = -544.71$ kcal/mol, in good agreement with the adopted value. The entropy and heat capacity values at 298.15 K are those reported by Wagman (48). The high-temperature heat capacities were estimated.

Malinin, Drakin, and Ankudimov (33), from vapor pressure measurements of water over $CuSO_4 \cdot 5H_2O(c)$ at 24.06 and 31.47° C, calculated $\Delta G°$ = 5.4 kcal, $\Delta S°$ = 72 cal/K, and $\Delta H°$ = 27 kcal at 298.15 K for the reaction

$$CuSO_4 \cdot 5H_2O(c) = CuSO_4 \cdot 3H_2O(c) + 2H_2O(g).$$

This is in good agreement with the data given here, for which $\Delta G°$ = 5.46 kcal, $\Delta S°$ = 71.3 cal/mol•K, and $\Delta H°$ = 26.7 kcal at 298.15 K.

$Cu_2SO_4(c)$

The enthalpy of formation at 298.15 K is from Wagman (48). The entropy at 298.15 K was estimated by Nagamori and Habashi (35), using Latimer's method. The heat capacities were estimated by comparison with $K_2SO_4(c)$ (10).

$CuO \cdot CuSO_4(c)$

All data for $CuO \cdot CuSO_4(c)$ are from the compilation of King, Mah, and Pankratz (23).

Zinc

$ZnSO_4(c)$

CODATA (8) enthalpy of formation values for $SO_4^{2-}(aq)$ and ZnO(c) were used in recalculating the results of Adami and King (2) to obtain $\Delta Hf°[ZnSO_4(c)]$ = -234.26 kcal/mol. JANAF (12) reported the same value for $ZnSO_4(c)$. This value is adopted here. The enthalpy of solution at infinite dilution, $\Delta H°soln[ZnSO_4(c)]$ = -19.9 kcal/mol, was taken from Larson (29). Combining this result with the CODATA values for the heats of formation of the infinitely dilute ions yielded $\Delta Hf°[ZnSO_4(c)]$ = -234.16 kcal/mol.

Low-temperature heat capacities of $ZnSO_4(\alpha,c)$ have been measured by Weller (50) from 51.7 to 296.5 K. We adopt his entropy and heat capacity values in this region. High-temperature enthalpy data have been measured by Hosmer and Krikorian (16) as well as by Voskresenskaya and Patsukova (46) and Krestovnikov and Feigina (27). The enthalpy data of Hosmer and Krikorian (16) lie above those of 46 and 27. Hosmer and Krikorian reported that the low values of 46 and 27 may be due to decomposition to the oxysulfate during vacuum dehydration. Chemical analysis of the sample of Hosmer and Krikorian indicated pure $ZnSO_4(c)$. However, serious problems remain in matching the low-temperature heat capacity data with the high-temperature enthalpy data of Hosmer and Krikorian. JANAF (12) recognized this problem and arbitrarily assigned a transition at 540 K with $\Delta H°_{tr}$ = 1.20 kcal/mol. There is no evidence in the literature for such a transition and Brown (7) found none by DSC measurements in our laboratories. In addition, the data of Voskresenskaya and Patsukova (46) match nicely the low-temperature heat capacity data of Weller (50). Therefore, the high-temperature enthalpy data of 46 for $ZnSO_4(\alpha,c)$ are adopted.

The transition of $ZnSO_4(\alpha,c)$ to $ZnSO_4(\beta,c)$ occurs at 1,015 ±15 K with a $\Delta H°_{tr}$ given by Hosmer and Krikorian (16) as 4.87 kcal/mol, which is the adopted value. This value is in good agreement with that reported by Ingraham and Marier (17, 4.74 kcal/mol) from differential thermogravimetric analysis (DTA) measurements.

$ZnSO_4 \cdot H_2O(c)$

The enthalpy of solution at infinite dilution was calculated from Wagman (47) to be $\Delta H°soln\ [ZnSO_4 \cdot H_2O(c)] = -10.63$ kcal/mol. Combining this result with the heat of solution of $ZnSO_4(c)$ (27) and the heat of formation of $ZnSO_4(c)$ and $H_2O(\ell)$ (47) yielded $\Delta Hf°[ZnSO_4 \cdot H_2O(c)] = -311.85$ kcal/mol, which is the adopted value.

The entropy at 298.15 K is taken from Wagman (47), and the heat capacity at 282 K was reported by Kelley (21) to be 34.7 cal/mol•K. The high-temperature heat capacities were extrapolated as discussed earlier.

$ZnSO_4 \cdot 6H_2O(c)$

The enthalpy of solution at infinite dilution, $\Delta H°soln[ZnSO_4 \cdot 6H_2O(c)] = -0.15$ kcal/mol was reported by Larson (29). Combining this value with the enthalpy of solution of $ZnSO_4(c)$ (29) and the adopted enthalpy of formation of $ZnSO_4(c)$ and Wagman's $H_2O(\ell)$ (47) yielded $\Delta Hf°[ZnSO_4 \cdot 6H_2O(c)] = -663.90$ kcal/mol, which is the adopted value. The entropy and heat capacity at 298.15 K are taken from Barieau and Giauque (4). They also reported that $ZnSO_4 \cdot 6H_2O(c)$ decomposes to the monohydrate and saturated solution at 60.3° C. Heat capacities above 310 K, the highest temperature reported by Barieau and Giauque, were extrapolated by fitting the lower temperature data as discussed earlier.

$ZnSO_4 \cdot 7H_2O(c)$

The enthalpy of solution at infinite dilution, $\Delta H°soln[ZnSO_4 \cdot 7H_2O(c)] = 3.18$ kcal/mol, was reported by Larson (29). Combining this value with the heat of solution of $ZnSO_4(c)$ (29) and the enthalpies of formation of $ZnSO_4(c)$ and $H_2O(\ell)$ (47) gave $\Delta Hf°[ZnSO_4 \cdot 7H_2O(c)] = -735.55$ kcal/mol. The entropy and heat capacities are from Barieau and Giauque (4), who reported that the transition of $ZnSO_4 \cdot 7H_2O(c)$ to $ZnSO_4 \cdot 6H_2O(c)$ and $H_2O(\ell)$ occurs at 311.27 K with $\Delta H°_{tr} = 4.017$ kcal/mol.

$ZnO \cdot 2ZnSO_4(c)$

Ko and Brown (25), from hydrochloric acid solution calorimetry, determined $\Delta Hf°[ZnO \cdot 2ZnSO_4(c)] = -550.31$, which is the adopted value. High-temperature enthalpy data for $ZnO \cdot 2ZnSO_4(c)$ were reported by Hosmer and Krikorian (16). Their $S°_{298} = 68.19$ cal/mol•K and high-temperature enthalpy values are adopted.

THERMAL DECOMPOSITION OF ANHYDROUS METAL SULFATES

The thermodynamic properties for the thermal decomposition of anhydrous metal sulfates were calculated as a function of temperature. These data are given in the auxiliary tables 53-61 and are plotted in figures 1-3. These tables and figures enable the reader to make a ready comparison of the stabilities of these metal sulfates as a function of temperature. For $CuSO_4(c)$ and $ZnSO_4(c)$, the decomposition proceeds through the oxysulfates (22). The decomposition equations are:

$$2CuSO_4(c) = CuO \cdot CuSO_4(c) + SO_3(g);$$

$$CuO \cdot CuSO_4(c) = 2CuO(c) + SO_3(g);$$

$$3ZnSO_4(c) = ZnO \cdot 2ZnSO_4(c) + SO_3(g);$$

$$ZnO \cdot 2ZnSO_4(c) = 3ZnO(c) + 2SO_3(g).$$

The remaining systems all decompose directly to the metal oxide and $SO_3(g)$ (22). Recall that the equilibrium,

$$SO_2(g) + 0.5\ O_2(g) = SO_3(g),$$

becomes important at higher temperatures. That the $SO_2(g)$-$SO_3(g)$ equilibrium is attained is critical for the evaluation of the experimental decomposition data. However, recent work (24) indicates that attainment of equilibrium depends on the solids involved and whether or not a catalyst is present.

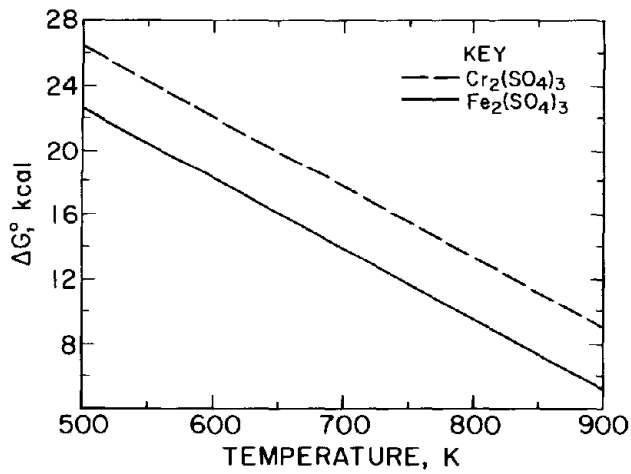

FIGURE 1. - Gibbs energy of decomposition for $Cr_2(SO_4)_3(c)$ and $Fe_2(SO_4)_3(c)$ according to the reactions given in tables 53 and 55.

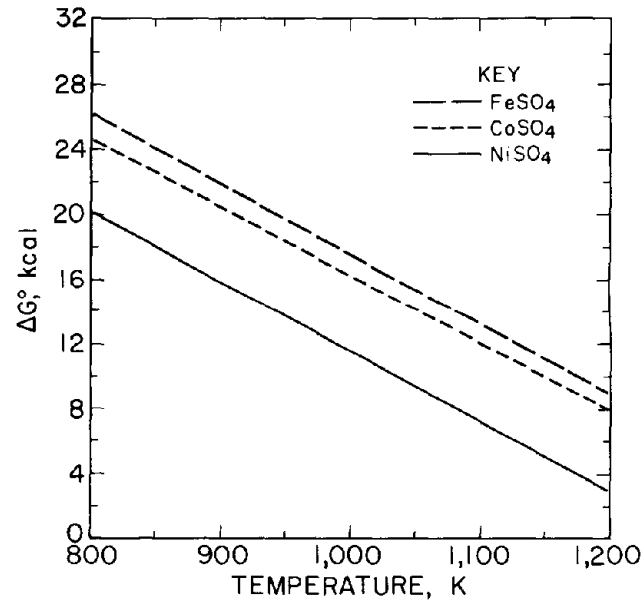

FIGURE 2. - Gibbs energy of decomposition for $FeSO_4(c)$, $CoSO_4(c)$, and $NiSO_4(c)$ according to the reactions given in tables 54, 56, and 57.

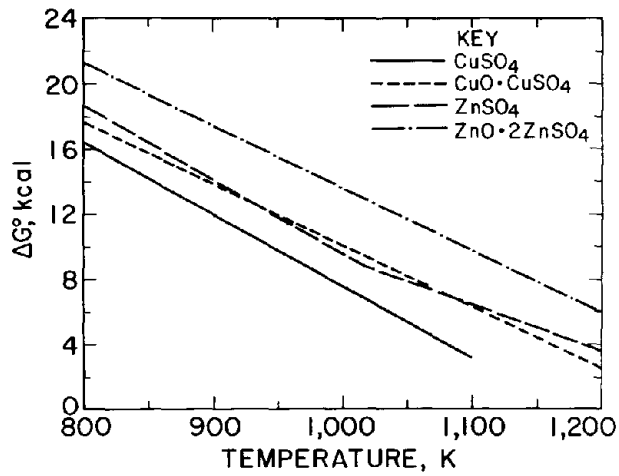

FIGURE 3. - Gibbs energy of decomposition for $CuSO_4(c)$, $CuO \cdot CuSO_4(c)$, $ZnSO_4(c)$, and $ZnO\ 2ZnSO_4(c)$ according to the reactions given in tables 58-61.

TABLE 1. - Thermodynamic properties of $VOSO_4$(c)
[Formation: V(c) + S(c,ℓ) + 2.5 O_2(g) = $VOSO_4$(c)]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	29.000	26.000	26.000	0	-312.900	-279.779	205.081
300	29.066	26.180	26.000	.054	-312.900	-279.573	203.666
368.30	31.305	32.373	26.619	2.119	-312.841	-271.990	161.397
368.30	31.305	32.373	26.619	2.119	-312.937	-271.990	161.397
388.36	31.962	34.051	26.961	2.754	-312.905	-269.760	151.806
388.36	31.962	34.051	26.961	2.754	-313.318	-269.760	151.806
400	32.344	35.001	27.181	3.128	-313.314	-268.455	146.675
432.02	33.250	37.527	27.855	4.178	-313.307	-264.865	133.988
500	35.174	42.531	29.515	6.508	-313.334	-257.234	112.436
600	37.555	49.161	32.248	10.148	-313.088	-246.032	89.616
700	39.487	55.101	35.095	14.004	-312.642	-234.890	73.335
717.82	39.751	56.097	35.604	14.710	-312.544	-232.911	70.912

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.

Sources: The enthalpy of formation at 298 K and entropy at 298 K are from Wagman (49). The heat capacities are estimates.

TABLE 2. - Thermodynamic properties of $VOSO_4 \cdot H_2O$(c)
[Formation: V(c) + S(c,ℓ) + 3 O_2(g) + H_2(g) = $VOSO_4 \cdot H_2O$(c)]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	38.000	35.500	35.500	0	-387.550	-340.652	249.701
300	38.167	35.736	35.503	.070	-387.553	-340.361	247.949
350	42.667	41.957	35.983	2.091	-387.518	-332.496	207.617
368.30	44.314	44.173	36.335	2.887	-387.458	-329.620	195.595
368.30	44.314	44.173	36.335	2.887	-387.554	-329.620	195.595
388.36	46.119	46.571	36.801	3.794	-387.460	-326.466	183.717
388.36	46.119	46.571	36.801	3.794	-387.873	-326.466	183.717
400	47.167	47.948	37.106	4.337	-387.823	-324.627	177.365
432.02	50.049	51.689	38.047	5.894	-387.649	-319.574	161.664
450	51.667	53.763	38.634	6.808	-387.590	-316.742	153.829
500	56.167	59.440	40.432	9.504	-387.121	-308.893	135.015
550	60.667	65.004	42.413	12.425	-386.432	-301.100	119.644

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 based on Reggiani (41). The entropy at 298 K and the heat capacities are estimates.

TABLE 3. - Thermodynamic properties of $VOSO_4 \cdot 3H_2O(c)$
[Formation: $V(c) + S(c,\ell) + 4\ O_2(g) + 3H_2(g) = VOSO_4 \cdot 3H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	57.000	54.500	54.500	0	-533.880	-459.427	336.765
300	57.244	54.853	54.500	.106	-533.886	-458.964	334.351
350	63.844	64.173	55.222	3.133	-533.890	-446.473	278.787
368.30	66.260	67.488	55.749	4.323	-533.819	-441.904	262.223
368.30	66.260	67.488	55.749	4.323	-533.915	-441.904	262.223
388.36	68.908	71.071	56.448	5.679	-533.796	-436.895	245.860
388.36	68.908	71.071	56.448	5.679	-534.209	-436.895	245.860
400	70.444	73.129	56.904	6.490	-534.137	-433.979	237.112
432.02	74.671	78.714	58.314	8.813	-533.875	-425.972	215.487
450	77.044	81.807	59.191	10.177	-533.750	-421.484	204.698
500	83.644	90.266	61.876	14.195	-533.026	-409.044	178.791
550	90.244	98.548	64.835	18.542	-531.985	-396.693	157.629

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 based on Reggiani (41). The entropy at 298 K and the heat capacities are estimates.

TABLE 4. - Thermodynamic properties of $VOSO_4 \cdot 5H_2O(\alpha,c)$
[Formation: $V(c) + S(c,\ell) + 5\ O_2(g) + 5H_2(g) = VOSO_4 \cdot 5H_2O(\alpha,c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	76.000	73.500	73.500	0	-676.690	-574.682	421.248
300	76.333	73.971	73.501	.141	-676.700	-574.049	418.189
350	85.333	86.414	74.463	4.183	-676.734	-556.931	347.759
368.30	88.627	90.847	75.167	5.775	-676.646	-550.669	326.764
368.30	88.627	90.847	75.167	5.775	-676.742	-550.669	326.764
388.36	92.238	95.641	76.102	7.588	-676.588	-543.806	306.023
388.36	92.238	95.641	76.102	7.588	-677.001	-543.806	306.023
400	94.333	98.396	76.711	8.674	-676.900	-539.816	294.938
432.02	100.097	105.879	78.595	11.787	-676.527	-528.855	267.533
450	103.333	110.026	79.768	13.616	-676.319	-522.714	253.861
500	112.333	121.379	83.363	19.008	-675.289	-505.697	221.037
550	121.333	132.508	87.328	24.849	-673.828	-488.805	194.231

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 based on Reggiani (41). The entropy at 298 K and the heat capacities are estimates.

TABLE 5. - Thermodynamic properties of $VOSO_4 \cdot 5H_2O(\beta,c)$
[Formation: $V(c) + S(c,\ell) + 5\ O_2(g) + 5H_2(g) = VOSO_4 \cdot 5H_2O(\beta,c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	76.000	73.500	73.500	0	-676.200	-574.192	420.889
300	76.333	73.971	73.501	.141	-676.210	-573.559	417.832
350	85.333	86.414	74.463	4.183	-676.244	-556.441	347.453
368.30	88.627	90.847	75.167	5.775	-676.156	-550.179	326.473
368.30	88.627	90.847	75.167	5.775	-676.253	-550.179	326.473
388.36	92.238	95.641	76.102	7.588	-676.098	-543.316	305.748
388.36	92.238	95.641	76.102	7.588	-676.511	-543.316	305.748
400	94.333	98.396	76.711	8.674	-676.410	-539.326	294.670
432.02	100.097	105.879	78.595	11.787	-676.037	-528.365	267.285
450	103.333	110.026	79.768	13.616	-675.829	-522.224	253.623
500	112.333	121.379	83.363	19.008	-674.799	-505.207	220.823
550	121.333	132.508	87.328	24.849	-673.338	-488.315	194.036

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 based on Reggiani (41). The entropy at 298 K and the heat capacities are estimates.

TABLE 6. - Thermodynamic properties of $VOSO_4 \cdot 6H_2O(c)$
[Formation: $V(c) + S(c,\ell) + 5.5\ O_2(g) + 6H_2(g) = VOSO_4 \cdot 6H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	85.000	83.000	83.000	0	-746.920	-631.135	462.628
300	85.388	83.527	83.000	.158	-746.932	-630.416	459.252
350	95.888	97.478	84.078	4.690	-746.998	-610.984	381.511
368.30	99.731	102.463	84.869	6.480	-746.905	-603.874	358.335
368.30	99.731	102.463	84.869	6.480	-747.001	-603.874	358.335
388.36	103.944	107.862	85.919	8.522	-746.830	-596.083	335.442
388.36	103.944	107.862	85.919	8.522	-747.243	-596.083	335.442
400	106.388	110.968	86.603	9.746	-747.127	-591.554	323.206
432.02	113.112	119.416	88.722	13.260	-746.691	-579.116	292.959
450	116.888	124.105	90.043	15.328	-746.437	-572.148	277.870
500	127.388	136.964	94.094	21.435	-745.225	-552.842	241.644
550	137.889	149.597	98.566	28.067	-743.510	-533.681	212.063

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 based on Reggiani (41). The entropy at 298 K and the heat capacities are estimates.

TABLE 7. - Thermodynamic properties of $Cr_2(SO_4)_3(c)$
[Formation: $2Cr(c) + 3S(c,\ell) + 6\ O_2(g) = Cr_2(SO_4)_3(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	67.250	61.850	61.850	0	-705.000	-625.554	458.538
300	67.458	62.267	61.850	0.125	-705.003	-625.061	455.351
311.50	68.655	64.827	61.913	0.908	-705.028	-621.996	436.390
368.30	74.565	76.844	63.301	4.988	-704.951	-606.857	360.106
368.30	74.565	76.844	63.301	4.988	-705.239	-606.857	360.106
388.36	76.653	80.855	64.106	6.505	-705.198	-601.498	338.489
388.36	76.653	80.855	64.106	6.505	-706.437	-601.498	338.490
400	77.864	83.137	64.627	7.404	-706.446	-598.354	326.921
432.02	80.675	89.241	66.228	9.942	-706.476	-589.702	298.314
500	86.643	101.485	70.199	15.643	-706.648	-571.292	249.708
600	93.796	117.939	76.807	24.679	-706.029	-544.264	198.245
700	99.322	132.834	83.765	34.348	-704.802	-517.391	161.535
717.82	100.017	135.340	85.015	36.124	-704.532	-512.622	156.073

Phase changes: 311.5 K, second-order transition for Cr; ΔH° = 0 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.

Sources: The enthalpy of formation at 298 K is based on Jacob (18). The entropy at 298 K is from Kubaschewski (28). The heat capacity at 298 K is from Vasileff (45). The high-temperature enthalpy values are estimates.

TABLE 8. - Thermodynamic properties of $Cr_2(SO_4)_3(c)$
[Formation: $2Cr(c) + 1.5S_2(g) + 6\ O_2(g) = Cr_2(SO_4)_3(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	67.250	61.850	61.850	0	-751.065	-654.095	479.458
300	67.458	62.267	61.850	.125	-751.059	-653.493	476.063
311.50	68.655	64.827	61.913	.908	-751.030	-649.753	455.864
400	77.864	83.137	64.627	7.404	-750.399	-621.051	339.322
500	86.643	101.485	70.199	15.643	-749.031	-588.852	257.384
600	93.796	117.939	76.807	24.679	-747.112	-556.986	202.880
700	99.322	132.834	83.765	34.348	-744.777	-525.476	164.059
800	103.222	146.369	90.758	44.489	-742.154	-494.329	135.043
900	105.495	158.674	97.632	54.938	-739.370	-463.517	112.556

Phase change: 311.5 K, second-order transition for Cr; ΔH° = 0 kcal/mol.

Sources: The enthalpy of formation at 298 K is based on Jacob (18). The entropy at 298 K is from Kubaschewski (28). The heat capacity at 298 K is from Vasileff (45). The high-temperature enthalpy values are estimates.

TABLE 9. - Thermodynamic properties of $[Cr_2(H_2O)_6(SO_4)_3]\cdot 2H_2O(c)$
[Formation: $2Cr(c) + 3S(c,\ell) + 10\ O_2(g) + 8H_2(g) = [Cr_2(H_2O)_6(SO_4)_3]\cdot 2H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	141.000	138.000	138.000	0	-1302.500	-1112.880	815.752
300	141.536	138.874	138.004	.261	-1302.523	-1111.705	809.866
311.50	144.871	144.261	138.136	1.908	-1302.642	-1104.387	774.833
350	156.036	161.781	139.778	7.701	-1302.907	-1079.863	674.288
368.30	161.343	169.869	141.074	10.605	-1302.707	-1068.215	633.873
368.30	161.343	169.869	141.074	10.605	-1302.995	-1068.215	633.873
388.36	167.160	178.577	142.786	13.900	-1302.867	-1055.428	593.935
388.36	167.160	178.577	142.786	13.900	-1304.106	-1055.428	593.936
400	170.536	183.563	143.901	15.865	-1304.033	-1047.977	572.581
432.02	179.822	197.047	147.341	21.474	-1303.706	-1027.492	519.780
450	185.036	204.486	149.477	24.754	-1303.633	-1015.995	493.428
500	199.536	224.732	155.994	34.369	-1302.486	-984.087	430.139
550	214.036	244.430	163.143	44.708	-1300.649	-952.329	378.416

Phase changes: 311.5 K, second-order transition for Cr; $\Delta H°$ = 0 kcal/mol.
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.

Sources: The enthalpy of formation at 298 K is from Wagman (48). The entropy at 298 K and heat capacities are estimates.

TABLE 10. - Thermodynamic properties of $[Cr(H_2O)_6]_2(SO_4)_3\cdot 2H_2O(c)$
[Formation: $2Cr(c) + 3S(c,\ell) + 13\ O_2(g) + 14H_2(g) = [Cr(H_2O)_6]_2(SO_4)_3\cdot 2H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	197.000	195.000	195.000	0	-1732.000	-1459.716	1069.987
300	197.925	196.221	195.004	.365	-1732.036	-1458.028	1062.159
311.50	203.675	203.774	195.190	2.674	-1732.212	-1447.520	1015.574
350	222.925	228.609	197.503	10.887	-1732.473	-1412.309	881.874
368.30	232.075	240.203	199.339	15.050	-1732.167	-1395.585	828.132
368.30	232.075	240.203	199.339	15.050	-1732.455	-1395.585	828.132
388.36	242.105	252.773	201.774	19.806	-1732.134	-1377.242	775.034
388.36	242.105	252.773	201.774	19.806	-1733.373	-1377.242	775.034
400	247.925	260.009	203.364	22.658	-1733.151	-1366.573	746.651
432.02	263.935	279.708	208.293	30.853	-1732.274	-1337.260	676.483
450	272.925	290.653	211.366	35.679	-1731.804	-1320.828	641.473
500	297.925	320.703	220.803	49.950	-1729.203	-1275.291	557.422
550	322.925	350.271	231.231	65.472	-1725.405	-1230.071	488.779

Phase changes: 311.5 K, second-order transition for Cr; $\Delta H°$ = 0 kcal/mol.
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.

Sources: The enthalpy of formation at 298 K is from Wagman (48). The entropy at 298 K and heat capacities are estimates.

TABLE 11. - Thermodynamic properties of $[Cr(H_2O)_6]_2(SO_4)_3 \cdot 3H_2O(c)$
[Formation: $2Cr(c) + 3S(c,\ell) + 13.5\ O_2(g) + 15H_2(g) = [Cr(H_2O)_6]_2(SO_4)_3 \cdot 3H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	206.000	204.000	204.000	0	-1802.100	-1515.889	1111.162
300	206.999	205.277	204.004	.382	-1802.139	-1514.115	1103.018
311.50	213.209	213.180	204.197	2.798	-1802.327	-1503.070	1054.547
350	233.999	239.214	206.623	11.407	-1802.595	-1466.057	915.436
368.30	243.881	251.391	208.547	15.780	-1802.272	-1448.478	859.518
368.30	243.881	251.391	208.547	15.780	-1802.560	-1448.478	859.519
388.36	254.713	264.608	211.100	20.781	-1802.205	-1429.198	804.272
388.36	254.713	264.608	211.100	20.781	-1803.444	-1429.198	804.272
400	260.999	272.223	212.768	23.782	-1803.195	-1417.986	774.741
432.02	278.290	292.978	217.944	32.416	-1802.218	-1387.186	701.739
450	287.999	304.523	221.174	37.507	-1801.675	-1369.922	665.316
500	314.999	336.264	231.100	52.582	-1798.804	-1322.089	577.877
550	341.999	367.553	242.086	69.007	-1794.640	-1274.606	506.475

Phase changes: 311.5 K, second-order transition for Cr; ΔH° = 0 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.

Sources: The enthalpy of formation at 298 K is from Wagman (48). The entropy at 298 K and heat capacities are estimates.

TABLE 12. - Thermodynamic properties of $[Cr(H_2O)_6]_2(SO_4)_3 \cdot 4H_2O(c)$
[Formation: $2Cr(c) + 3S(c,\ell) + 14\ O_2(g) + 16H_2(g) = [Cr(H_2O)_6]_2(SO_4)_3 \cdot 4H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	216.000	214.000	214.000	0	-1871.300	-1571.461	1151.897
300	217.073	215.339	214.002	.401	-1871.339	-1569.601	1143.439
311.50	223.743	223.630	214.206	2.936	-1871.529	-1558.031	1093.108
350	246.073	250.979	216.753	11.979	-1871.765	-1519.260	948.656
368.30	256.687	263.790	218.775	16.579	-1871.407	-1500.847	890.594
368.30	256.687	263.790	218.775	16.579	-1871.695	-1500.847	890.594
388.36	268.322	277.707	221.457	21.845	-1871.286	-1480.655	833.229
388.36	268.322	277.707	221.457	21.845	-1872.525	-1480.655	833.229
400	275.073	285.731	223.211	25.008	-1872.238	-1468.915	802.567
432.02	293.645	307.618	228.655	34.114	-1871.128	-1436.669	726.771
450	304.073	319.804	232.055	39.487	-1870.494	-1418.599	688.957
500	333.073	353.342	242.512	55.415	-1867.304	-1368.544	598.183
550	362.073	386.448	254.095	72.794	-1862.723	-1318.877	524.067

Phase changes: 311.5 K, second-order transtion for Cr; ΔH° = 0 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.

Sources: The enthalpy of formation at 298 K is from Wagman (48). The entropy at 298 K and heat capacities are estimates.

TABLE 13. - Thermodynamic properties of $[Cr(H_2O)_6]_2(SO_4)_3 \cdot 5H_2O(c)$
[Formation: $2Cr(c) + 3S(c,\ell) + 14.5\ O_2(g) + 17H_2(g) = [Cr(H_2O)_6]_2(SO_4)_3 \cdot 5H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	225.000	223.000	223.000	0	-1940.700	-1626.934	1192.560
300	226.128	224.395	223.005	.417	-1940.742	-1624.989	1183.789
311.50	233.143	233.033	223.217	3.058	-1940.946	-1612.881	1131.590
350	256.629	261.544	225.870	12.486	-1941.200	-1572.308	981.780
368.30	267.792	274.907	227.977	17.284	-1940.836	-1553.038	921.563
368.30	267.792	274.907	227.977	17.284	-1941.124	-1553.038	921.564
388.36	280.029	289.428	230.774	22.779	-1940.698	-1531.907	862.071
388.36	280.029	289.428	230.774	22.779	-1941.937	-1531.907	862.071
400	287.129	297.803	232.603	26.080	-1941.635	-1519.623	830.273
432.02	306.661	320.654	238.281	35.587	-1940.463	-1485.884	751.668
450	317.629	333.382	241.829	41.199	-1939.781	-1466.977	712.452
500	348.129	368.426	252.740	57.843	-1936.409	-1414.608	618.317
550	378.629	403.037	264.833	76.012	-1931.575	-1362.649	541.460

Phase changes: 311.5 K, second-order transition for Cr; ΔH° = 0 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.

Sources: The enthalpy of formation at 298 K is from Wagman (48). The entropy at 298 K and heat capacities are estimates.

TABLE 14. - Thermodynamic properties of $MnSO_4(c)$
[Formation: $Mn(c) + S(c,\ell) + 2\ O_2(g) = MnSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	24.020	26.790	26.790	0	-254.700	-228.901	167.787
300	24.110	26.939	26.789	.045	-254.703	-228.740	166.635
368.30	26.780	32.208	27.314	1.802	-254.735	-222.825	132.223
368.30	26.780	32.208	27.314	1.802	-254.831	-222.825	132.223
388.36	27.564	33.649	27.605	2.348	-254.826	-221.081	124.412
388.36	27.564	33.649	27.605	2.348	-255.239	-221.081	124.412
400	28.019	34.470	27.793	2.671	-255.249	-220.057	120.232
432.02	28.859	36.660	28.370	3.582	-255.283	-217.240	109.896
500	30.643	41.018	29.796	5.611	-255.406	-211.236	92.330
600	32.674	46.791	32.158	8.780	-255.346	-202.405	73.725
700	34.313	51.956	34.623	12.133	-255.131	-193.600	60.444
717.82	34.550	52.822	35.064	12.747	-255.079	-192.033	58.466

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.

Sources: The enthalpy of formation at 298 K is taken from Southard (42), corrected for sulfate ion CODATA (8) value. The entropy at 298 K and low-temperature heat capacities are from Moore (34). The high temperature enthalpy data are from Southard (42).

TABLE 15. - Thermodynamic properties of $MnSO_4$(c)
[Formation: $Mn(c) + 0.5S_2(g) + 2\ O_2(g) = MnSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	24.020	26.790	26.790	0	-270.055	-238.414	174.760
300	24.110	26.939	26.789	.045	-270.055	-238.217	173.539
400	28.019	34.470	27.793	2.671	-269.900	-227.623	124.366
500	30.643	41.018	29.796	5.611	-269.534	-217.089	94.888
600	32.674	46.791	32.158	8.780	-269.040	-206.646	75.270
700	34.313	51.956	34.623	12.133	-268.456	-196.295	61.285
800	35.642	56.627	37.086	15.633	-267.806	-186.032	50.821
900	36.702	60.889	39.498	19.252	-267.104	-175.853	42.703
980	37.350	64.044	41.374	22.216	-266.516	-167.763	37.412
980	37.350	64.044	41.374	22.216	-267.048	-167.763	37.412
1000	37.512	64.800	41.835	22.965	-266.901	-165.743	36.223
1100	38.085	68.404	44.089	26.747	-266.150	-155.653	30.925

Phase change: 980 K, α-β transition of Mn; ΔH° = 0.532 kcal/mol.

Sources: The enthalpy of formation at 298 K is from Southard (42), corrected for sulfate ion CODATA (8) value. The entropy at 298 K and low-temperature heat capacities are from Moore (34). The high-temperature enthalpy data are from Southard (42).

TABLE 16. - Thermodynamic properties of $MnSO_4 \cdot H_2O$(α,c)
[Formation: $Mn(c) + S(c,\ell) + 2.5\ O_2(g) + H_2(g) = MnSO_4 \cdot H_2O(\alpha,c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	33.000	35.000	35.000	0	-329.100	-289.139	211.942
300	33.167	35.205	35.002	.061	-329.107	-288.891	210.454
350	37.667	40.655	35.421	1.832	-329.161	-282.182	176.200
368.30	39.314	42.617	35.730	2.536	-329.135	-279.726	165.988
368.30	39.314	42.617	35.730	2.536	-329.231	-279.726	165.988
388.36	41.120	44.749	36.141	3.343	-329.176	-277.030	155.897
388.36	41.120	44.749	36.141	3.343	-329.589	-277.030	155.897
400	42.168	45.979	36.409	3.828	-329.561	-275.456	150.500
432.02	45.050	49.335	37.242	5.224	-329.448	-271.129	137.157
450	46.669	51.205	37.763	6.049	-329.423	-268.700	130.497
500	51.169	56.355	39.365	8.495	-329.055	-261.970	114.505
550	55.670	61.443	41.141	11.166	-328.472	-255.288	101.441

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 (48) corrected for sulfate ion CODATA (8) value. The entropy at 298 K and heat capacities are estimates.

TABLE 17. - Thermodynamic properties of $MnSO_4 \cdot 4H_2O(c)$
[Formation: $Mn(c) + S(c,\ell) + 4\ O_2(g) + 4H_2(g) = MnSO_4 \cdot 4H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	61.000	65.000	65.000	0	-539.800	-458.954	336.418
300	61.266	65.378	65.001	.113	-539.813	-458.452	333.978
350	68.467	75.363	65.774	3.356	-539.963	-444.877	277.790
368.30	71.103	78.920	66.340	4.633	-539.941	-439.905	261.037
368.30	71.103	78.920	66.340	4.633	-540.037	-439.905	261.037
388.36	73.992	82.766	67.087	6.089	-539.967	-434.452	244.485
388.36	73.992	82.766	67.087	6.089	-540.380	-434.452	244.485
400	75.668	84.976	67.576	6.960	-540.334	-431.278	235.636
432.02	80.280	90.978	69.089	9.456	-540.140	-422.555	213.759
450	82.869	94.304	70.031	10.923	-540.047	-417.662	202.842
500	90.069	103.408	72.914	15.247	-539.402	-404.093	176.627
550	97.270	112.330	76.094	19.930	-538.418	-390.609	155.212

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 (48), corrected for sulfate ion CODATA (8) value. The entropy at 298 K and heat capacities are estimates.

TABLE 18. - Thermodynamic properties of $MnSO_4 \cdot 5H_2O(c)$
[Formation: $Mn(c) + S(c,\ell) + 4.5\ O_2(g) + 5H_2(g) = MnSO_4 \cdot 5H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	78.000	75.000	75.000	0	-610.300	-515.826	378.105
300	78.333	75.484	75.001	.145	-610.300	-515.239	375.347
350	87.332	88.234	75.988	4.286	-610.075	-499.408	311.841
368.30	90.626	92.769	76.710	5.914	-609.894	-493.626	292.915
368.30	90.626	92.769	76.710	5.914	-609.990	-493.627	292.915
388.36	94.237	97.670	77.666	7.769	-609.732	-487.294	274.221
388.36	94.237	97.670	77.666	7.769	-610.145	-487.294	274.222
400	96.332	100.484	78.289	8.878	-609.984	-483.614	264.231
432.02	102.095	108.120	80.218	12.054	-609.449	-473.519	239.540
450.00	105.331	112.349	81.418	13.919	-609.151	-467.866	227.224
500	114.331	123.913	85.091	19.411	-607.871	-452.232	197.668
550	123.330	135.232	89.137	25.352	-606.166	-436.748	173.546

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 (48), corrected for sulfate ion CODATA (8) value. The entropy at 298 K is estimated. The heat capacity at 298 K is from Wagman (48).

TABLE 19. - Thermodynamic properties of $MnSO_4 \cdot 7H_2O(c)$
[Formation: $Mn(c) + S(c,\ell) + 5.5\ O_2(g) + 7H_2(g) = MnSO_4 \cdot 7H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	91.000	94.000	94.000	0	-750.400	-628.371	460.602
300	91.444	94.564	94.001	.169	-750.416	-627.613	457.210
350	103.443	109.562	95.159	5.041	-750.504	-607.132	379.105
368.30	107.835	114.946	96.010	6.974	-750.403	-599.638	355.822
368.30	107.835	114.946	96.010	6.974	-750.499	-599.638	355.822
388.36	112.649	120.790	97.138	9.186	-750.307	-591.425	332.820
388.36	112.649	120.790	97.138	9.186	-750.720	-591.425	332.820
400	115.442	124.158	97.875	10.513	-750.587	-586.653	320.528
432.02	123.127	133.339	100.164	14.332	-750.087	-573.548	290.142
450	127.442	138.448	101.592	16.585	-749.783	-566.206	274.984
500	139.441	152.496	105.982	23.257	-748.391	-545.877	238.599
550	151.440	166.349	110.842	30.529	-746.429	-525.717	208.898

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 (48), corrected for sulfate ion CODATA (8) value. The entropy at 298 K and heat capacities are estimates.

TABLE 20. - Thermodynamic properties of $FeSO_4(c)$
[Formation: $Fe(c) + S(c,\ell) + 2\ O_2(g) = FeSO_4(c)$]

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	∞	-4.008	-220.529	-220.529	∞
100	10.534	10.223	46.563	-3.634	-221.810	-214.108	467.926
200	18.845	20.319	30.964	-2.129	-222.512	-206.098	225.211
298.15	24.040	28.909	28.909	0	-222.800	-197.969	145.114
300	24.140	29.058	28.908	.045	-222.802	-197.814	144.106
368.30	26.694	34.282	29.430	1.787	-222.831	-192.122	114.004
368.30	26.694	34.282	29.430	1.787	-222.927	-192.122	114.004
388.36	27.445	35.718	29.718	2.330	-222.919	-190.443	107.171
388.36	27.445	35.718	29.718	2.330	-223.332	-190.444	107.171
400	27.880	36.535	29.905	2.652	-223.341	-189.458	103.514
432.02	28.818	38.718	30.478	3.560	-223.372	-186.745	94.469
500	30.810	43.085	31.899	5.593	-223.481	-180.968	79.100
600	32.990	48.904	34.257	8.788	-223.390	-172.469	62.821
700	34.570	54.113	36.727	12.170	-223.159	-163.998	51.202
717.82	34.773	54.985	37.170	12.788	-223.108	-162.492	49.472

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.

Sources: Enthalpy of formation at 298 K is based on Wagman (48). Heat capacities and entropy at 298 K are from JANAF (10).

TABLE 21. - Thermodynamic properties of $FeSO_4(c)$
[Formation: $Fe(c) + 0.5S_2(g) + 2\ O_2(g) = FeSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.008	-235.847	-235.847	∞
100	10.534	10.223	46.563	-3.634	-237.331	-227.598	497.408
200	18.845	20.319	30.964	-2.129	-237.995	-217.560	237.735
298.15	24.040	28.909	28.909	0	-238.155	-207.483	152.087
300	24.140	29.058	28.908	.045	-238.154	-207.292	151.010
400	27.880	36.535	29.905	2.652	-237.992	-197.023	107.647
500	30.810	43.085	31.899	5.593	-237.609	-186.821	81.658
600	32.990	48.904	34.257	8.788	-237.085	-176.710	64.366
700	34.570	54.113	36.727	12.170	-236.484	-166.693	52.043
800	35.710	58.808	39.199	15.687	-235.864	-156.768	42.826
900	36.510	63.061	41.618	19.299	-235.282	-146.916	35.676
1000	37.160	66.943	43.960	22.983	-234.831	-137.126	29.968
1043	37.396	68.512	44.940	24.586	-234.773	-132.926	27.853
1100	37.710	70.511	46.214	26.727	-234.544	-127.364	25.305
1185	38.126	73.333	48.058	29.951	-234.029	-119.100	21.965
1185	38.126	73.333	48.058	29.951	-234.244	-119.099	21.965
1200	38.200	73.813	48.377	30.523	-234.117	-117.644	21.426
1300	38.640	76.889	50.454	34.365	-233.261	-107.974	18.152
1400	39.040	79.767	52.446	38.250	-232.404	-98.367	15.356
1500	39.420	82.473	54.358	42.173	-231.544	-88.824	12.941
1600	39.780	85.029	56.196	46.133	-230.684	-79.337	10.837
1667	40.008	86.666	57.388	48.806	-230.108	-73.011	9.572
1667	40.008	86.666	57.388	48.806	-230.308	-73.011	9.572
1700	40.120	87.451	57.964	50.128	-230.050	-69.900	8.986
1800	40.460	89.754	59.667	54.157	-229.269	-60.500	7.346
1811	40.495	90.001	59.850	54.602	-229.186	-59.472	7.177
1811	40.495	90.001	59.850	54.602	-232.486	-59.472	7.177
1900	40.780	91.950	61.308	58.219	-231.864	-50.985	5.865
2000	41.100	94.050	62.894	62.313	-231.146	-41.484	4.533

Phase changes: 1043 K, Curie temperature of Fe; ΔH° = 0 kcal/mol.
1185 K, α-γ transition point of Fe; ΔH° = 0.215 kcal/mol.
1667 K, γ-δ transition point of Fe; ΔH° = 0.200 kcal/mol.
1811 K, melting point of Fe; ΔH° = 3.300 kcal/mol.

Sources: Enthalpy of formation at 298 K is based on Wagman (48). Heat capacities and entropy at 298 K are from JANAF (10).

TABLE 22. - Thermodynamic properties of $FeSO_4 \cdot H_2O(c)$
[Formation: $Fe(c) + S(c,\ell) + H_2(g) + 2.5\ O_2(g) = FeSO_4 \cdot H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	33.346	37.700	37.700	0	-297.400	-258.581	189.542
300	33.513	37.907	37.700	.062	-297.404	-258.339	188.198
350	38.015	43.411	38.125	1.850	-297.429	-251.825	157.244
368.30	39.663	45.390	38.438	2.561	-297.391	-249.441	148.017
368.30	39.663	45.390	38.438	2.561	-297.487	-249.441	148.017
388.36	41.469	47.541	38.853	3.374	-297.420	-246.825	138.899
388.36	41.469	47.541	38.853	3.374	-297.833	-246.825	138.899
400	42.517	48.781	39.123	3.863	-297.798	-245.297	134.022
432.02	45.400	52.165	39.964	5.271	-297.668	-241.099	121.965
450	47.019	54.049	40.489	6.102	-297.634	-238.745	115.949
500	51.521	59.236	42.106	8.565	-297.242	-232.221	101.502
550	56.023	64.357	43.895	11.254	-296.636	-225.744	89.701

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.

Sources: Enthalpy of formation at 298 K is based on Adami (1). The entropy at 298 K is from Pribylov (39). Heat capacities are estimates.

TABLE 23. - Thermodynamic properties of $FeSO_4 \cdot 4H_2O(c)$
[Formation: $Fe(c) + S(c,\ell) + 4H_2(g) + 4\ O_2(g) = FeSO_4 \cdot 4H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	65.924	67.500	67.500	0	-509.500	-429.736	315.001
300	66.190	67.909	67.502	.122	-509.503	-429.241	312.698
350	73.390	78.653	68.333	3.612	-509.392	-415.868	259.676
368.30	76.025	82.460	68.941	4.979	-509.276	-410.981	243.874
368.30	76.025	82.460	68.941	4.979	-509.372	-410.981	243.874
388.36	78.914	86.567	69.746	6.533	-509.198	-405.625	228.263
388.36	78.914	86.567	69.746	6.533	-509.612	-405.625	228.263
400	80.590	88.922	70.270	7.461	-509.506	-402.510	219.919
432.02	85.201	95.303	71.888	10.116	-509.147	-393.958	199.293
450	87.790	98.830	72.894	11.671	-508.963	-389.169	189.004
500	94.990	108.452	75.972	16.240	-508.066	-375.903	164.305
550	102.190	117.844	79.353	21.170	-506.830	-362.743	144.139

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.

Sources: Heat of formation at 298 K is based on Larson (29). Entropy at 298 K is based on Malinin (32). Heat capacity at 298 K is from Kelley (21).

TABLE 24. - Thermodynamic properties of $FeSO_4 \cdot 7H_2O(c)$
[Formation: $Fe(c) + S(c,\ell) + 7H_2(g) + 5.5\ O_2(g) = FeSO_4 \cdot 7H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	94.313	97.800	97.800	0	-720.440	-599.881	439.719
300	94.784	98.385	97.802	.175	-720.448	-599.133	436.462
350	107.210	113.937	99.003	5.227	-720.343	-578.913	361.485
368.30	111.543	119.511	99.884	7.229	-720.169	-571.523	339.138
368.30	111.543	119.511	99.884	7.229	-720.265	-571.523	339.138
388.36	116.293	125.557	101.053	9.516	-719.992	-563.427	317.065
388.36	116.293	125.557	101.053	9.516	-720.405	-563.427	317.065
400	119.049	129.032	101.817	10.886	-720.227	-558.724	305.269
432.02	126.254	138.478	104.185	14.816	-719.610	-545.819	276.115
450	130.300	143.709	105.660	17.122	-719.250	-538.595	261.574
500	140.964	157.995	110.183	23.906	-717.739	-518.598	226.676
550	151.040	171.907	115.163	31.209	-715.741	-498.775	198.192

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.

Sources: Enthalpy of formation at 298 K is based on Adami (1). The entropy and heat capacity at 298 K are from Lyon (30). The high-temperature heat capacities are estimates.

TABLE 25. - Thermodynamic properties of $Fe_2(SO_4)_3(c)$
[Formation: $2Fe(c) + 3S(c,\ell) + 6\ O_2(g) = Fe_2(SO_4)_3(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	64.950	67.550	67.550	0	-617.100	-538.835	394.971
300	65.207	67.953	67.553	.120	-617.110	-538.348	392.181
368.30	72.795	82.213	68.964	4.880	-617.242	-520.395	308.799
368.30	72.795	82.213	68.964	4.880	-617.530	-520.395	308.799
388.36	75.024	86.134	69.752	6.362	-617.523	-515.103	289.871
388.36	75.024	86.134	69.752	6.362	-618.762	-515.103	289.871
400	76.317	88.369	70.262	7.243	-618.799	-511.997	279.738
432.02	78.866	94.344	71.828	9.727	-618.918	-503.444	254.679
500	84.277	106.287	75.711	15.288	-619.315	-485.227	212.090
600	90.928	122.255	82.162	24.056	-619.122	-458.415	166.975
700	96.850	136.724	88.938	33.450	-618.386	-431.681	134.775
717.82	97.818	139.171	90.155	35.184	-618.204	-426.928	129.982

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.

Sources: Enthalpy of formation at 298 K is based on Barany (3). The entropy and high-temperature enthalpy values are from Pankratz (37).

TABLE 26. - Thermodynamic properties of $Fe_2(SO_4)_3$(c)
[Formation: $2Fe(c) + 1.5S_2(g) + 6\ O_2(g) = Fe_2(SO_4)_3(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	64.950	67.550	67.550	0	-663.165	-567.376	415.892
300	65.207	67.953	67.553	.120	-663.166	-566.780	412.893
400	76.317	88.369	70.262	7.243	-662.752	-534.693	292.139
500	84.277	106.287	75.711	15.288	-661.697	-502.787	219.765
600	90.928	122.255	82.162	24.056	-660.206	-471.138	171.610
700	96.850	136.724	88.938	33.450	-658.361	-439.766	137.299
800	102.282	150.015	95.753	43.410	-656.226	-408.687	111.647
800	102.720	150.643	95.753	43.912	-655.724	-408.687	111.647
900	102.720	162.742	102.538	54.184	-653.579	-377.939	91.775

Phase changes: 800 K, α-β transition point of $Fe_2(SO_4)_3$; $\Delta H° = 0.540$ kcal/mol.

Sources: Enthalpy of formation at 298 K is based on Barany (3). The entropy at 298 K and high-temperature enthalpy values are from Pankratz (37).

TABLE 27. - Thermodynamic properties of $CoSO_4$(c)
[Formation: $Co(c) + S(c,\ell) + 2\ O_2(g) = CoSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.120	-210.077	-210.077	∞
100	10.625	9.022	46.032	-3.701	-211.334	-203.474	444.686
200	19.188	19.309	30.144	-2.167	-212.042	-195.303	213.414
298.15	24.670	28.060	28.060	0	-212.300	-187.020	137.087
300	24.773	28.213	28.060	.046	-212.301	-186.861	136.126
368.30	27.404	33.608	28.596	1.846	-212.266	-181.076	107.449
368.30	27.404	33.608	28.596	1.846	-212.362	-181.076	107.449
388.36	28.177	35.082	28.894	2.403	-212.336	-179.372	100.940
388.36	28.177	35.082	28.894	2.403	-212.749	-179.372	100.940
400	28.625	35.921	29.086	2.734	-212.747	-178.372	97.457
432.02	29.345	38.153	29.676	3.662	-212.750	-175.621	88.842
500	30.874	42.568	31.134	5.717	-212.818	-169.763	74.202
600	32.466	48.344	33.531	8.888	-212.706	-161.159	58.701
700	33.746	53.447	36.018	12.200	-212.478	-152.585	47.639
700	33.746	53.447	36.018	12.200	-212.586	-152.585	47.639
717.82	33.945	54.298	36.462	12.803	-212.532	-151.061	45.992

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.
700 K, α-β transition for Co(c); $\Delta H° = 0.108$ kcal/mol.
717.824 K, boiling point of S to equilibrium mixture.

Sources: Enthalpy of formation at 298 K is based on Adami (1). Entropy and low-temperature heat capacities are from Weller (50). The high-temperature heat capacities are estimates.

TABLE 28. - Thermodynamic properties of $CoSO_4(c)$
[Formation: $Co(c) + 0.5S_2(g) + 2\ O_2(g) = CoSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.120	-225.395	-225.395	∞
100	10.625	9.022	46.032	-3.701	-226.855	-216.964	474.168
200	19.188	19.309	30.144	-2.167	-227.525	-206.764	225.939
298.15	24.670	28.060	28.060	0	-227.655	-196.533	144.061
300	24.773	28.213	28.060	.046	-227.653	-196.338	143.030
400	28.625	35.921	29.086	2.734	-227.398	-185.937	101.590
500	30.874	42.568	31.134	5.717	-226.946	-175.616	76.761
600	32.466	48.344	33.531	8.888	-226.400	-165.400	60.246
700	33.746	53.447	36.018	12.200	-225.803	-155.280	48.480
700	33.746	53.447	36.018	12.200	-225.911	-155.280	48.480
800	34.861	58.028	38.488	15.632	-225.262	-145.234	39.676
900	35.880	62.193	40.894	19.169	-224.593	-135.272	32.848
964	36.500	64.679	42.392	21.485	-224.156	-128.945	29.233
964	36.495	65.213	42.392	22.000	-223.641	-128.945	29.233
1000	36.837	66.557	43.237	23.320	-223.394	-125.413	27.409
1100	37.759	70.112	45.521	27.050	-222.706	-115.640	22.975
1200	38.653	73.436	47.710	30.871	-222.023	-105.938	19.294
1300	39.528	76.564	49.810	34.780	-221.372	-96.295	16.188
1394	40.336	79.352	51.709	38.534	-220.839	-87.278	
1400	40.388	79.525	51.828	38.776	-220.798	-86.703	13.535

Phase changes: 700 K, α-β transition for Co(c); ΔH° = 0.108 kcal/mol.
964 K, α-β transition of $CoSO_4(c)$; ΔH° = 0.515 kcal/mol.
1394 K, Curie temperature of Co(c); ΔH°= 0 kcal/mol.

Sources: Enthalpy of formation at 298 K is based on Adami (1). Entropy and low-temperature heat capacities are from Weller (50). High-temperature heat capacities are estimates.

TABLE 29. - Thermodynamic properties of $CoSO_4 \cdot H_2O(c)$
[Formation: $Co(c) + S(c,\ell) + 2.5\ O_2(g) + H_2(g) = CoSO_4 \cdot H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	34.000	42.000	42.000	0	-286.800	-239.762	175.748
300	34.170	42.211	42.001	.063	-286.816	-239.469	174.450
350	38.668	47.816	42.433	1.884	-287.150	-231.553	144.586
368.30	40.314	49.829	42.751	2.607	-287.225	-228.644	135.676
368.30	40.314	49.829	42.751	2.607	-287.321	-228.644	135.676
388.36	42.118	52.014	43.172	3.434	-287.377	-225.445	126.868
388.36	42.118	52.014	43.172	3.434	-287.790	-225.446	126.868
400	43.165	53.273	43.448	3.930	-287.827	-223.577	122.155
432.02	46.045	56.707	44.305	5.358	-287.893	-218.431	110.498
450	47.662	58.617	44.839	6.200	-287.970	-215.534	104.676
500	52.159	63.871	46.479	8.696	-287.878	-207.488	90.692
550	56.656	69.053	48.297	11.416	-287.572	-199.462	79.258

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: Enthalpy of formation at 298 K is based on Goldberg (15). The entropy at 298 K is from Goldberg (15). Heat capacities are estimates.

TABLE 30. - Thermodynamic properties of $CoSO_4 \cdot 6H_2O(c)$
[Formation: $Co(c) + S(c,\ell) + 5\ O_2(g) + 6H_2(g) = CoSO_4 \cdot 6H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-13.525	-630.143	-630.143	∞
100	33.674	26.822	146.552	-11.973	-636.651	-603.724	1319.420
200	61.028	58.923	94.848	-7.185	-640.057	-569.293	622.086
298.15	84.340	87.863	87.863	0	-641.330	-534.221	391.590
300	84.759	88.386	87.866	.156	-641.338	-533.556	388.690
337	92.978	98.715	88.489	3.446	-641.315	-520.260	337.393
350	95.794	102.287	88.936	4.673	-641.241	-515.596	321.948
368.30	99.630	107.267	89.724	6.461	-641.086	-509.030	302.055
368.30	99.630	107.267	89.724	6.461	-641.182	-509.030	302.055
388.36	103.834	112.667	90.769	8.504	-640.938	-501.837	282.406
388.36	103.834	112.667	90.769	8.504	-641.351	-501.837	282.406
400	106.274	115.769	91.451	9.727	-641.195	-497.658	271.904
432.02	112.631	124.200	93.567	13.234	-640.655	-486.188	245.949
450	116.200	128.865	94.885	15.291	-640.349	-479.762	233.001
500	125.572	141.598	98.924	21.337	-639.026	-461.986	201.931
550	134.389	153.984	103.368	27.839	-637.273	-444.363	176.571

Phase changes: 337 K $CoSO_4 \cdot 6H_2O(c)$ dissociates to $CoSO_4 \cdot H_2O(c)$ and saturated solution.
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: Enthalpy of formation at 298 K is from Ko (25). Entropy at 298 K and heat capacities are from Rao (40). The transition temperature is from Broers (6).

TABLE 31. - Thermodynamic properties of $CoSO_4 \cdot 7H_2O(c)$
[Formation: $Co(c) + S(c,\ell) + 5.5\ O_2(g) + 7H_2(g) = CoSO_4 \cdot 7H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-15.097	-699.423	-699.423	∞
100	37.564	28.644	162.704	-13.406	-706.857	-669.637	1463.471
200	69.109	64.777	104.832	-8.011	-710.647	-630.730	689.220
298.15	93.483	97.048	97.048	0	-712.100	-591.120	433.297
300	93.924	97.628	97.051	.173	-712.110	-590.369	430.078
317.78	98.144	103.156	97.237	1.881	-712.154	-583.151	401.051
350	105.746	112.996	98.236	5.166	-712.060	-570.078	355.968
368.30	110.019	118.494	99.107	7.140	-711.911	-562.658	333.878
368.30	110.019	118.494	99.107	7.140	-712.007	-562.658	333.878
388.36	114.703	124.452	100.263	9.394	-711.764	-554.529	312.057
388.36	114.703	124.452	100.263	9.394	-712.177	-554.529	312.057
400	117.421	127.880	101.018	10.745	-712.016	-549.806	300.396
432.02	124.804	137.204	103.354	14.624	-711.443	-536.842	271.574
450	128.949	142.377	104.810	16.905	-711.104	-529.579	257.195
500	140.331	156.554	109.278	23.638	-709.628	-509.483	222.692
550	151.565	170.457	114.210	30.936	-707.616	-489.562	194.531

Phase changes: 317.78 K $CoSO_4 \cdot 7H_2O(c)$ dissociates to $CoSO_4 \cdot 6H_2O(c)$ and saturated solution; ΔH° = 2.848 kcal/mol (heptahydrate).
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: Enthalpy of formation at 298 K is based on Ko (25) and Brodale (5). The entropy at 298.15 K is from Rao (40). Heat capacities are from Rao (40).

TABLE 32. - Thermodynamic properties of $NiSO_4(c)$
[Formation: $Ni(c) + S(c,\ell) + 2\ O_2(g) = NiSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-3.810	-206.172	-206.172	∞
100	9.020	6.760	40.960	-3.420	-207.455	-199.375	435.728
200	17.840	15.990	26.190	-2.040	-208.312	-190.929	208.635
298.15	23.330	24.210	24.210	0	-208.710	-182.294	133.623
300	23.420	24.350	24.217	.040	-208.718	-182.131	132.681
368.30	26.213	29.492	24.718	1.758	-208.788	-176.066	104.477
368.30	26.213	29.492	24.718	1.758	-208.884	-176.066	104.477
388.36	27.034	30.905	25.001	2.293	-208.890	-174.278	98.074
388.36	27.034	30.905	25.001	2.293	-209.303	-174.278	98.074
400	27.510	31.710	25.185	2.610	-209.320	-173.228	94.646
432.02	28.323	33.860	25.749	3.504	-209.374	-170.338	86.169
500	30.050	38.140	27.140	5.500	-209.539	-164.174	71.760
600	31.910	43.790	29.457	8.600	-209.588	-155.098	56.494
631	32.363	45.409	30.201	9.596	-209.591	-152.281	52.743
700	33.370	48.820	31.863	11.870	-209.472	-146.011	45.586
717.82	33.584	49.662	32.294	12.467	-209.425	-144.396	43.963

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.
631 K, Curie temperature of Ni.
717.824 K, boiling point of S to equilibrium mixture.

Sources: Enthalpy of formation is based on Adami (2). Low-temperature heat capacities are from Stuve (44) and Weller (50). High-temperature enthalpy data are from Stuve (44). Entropy at 298 K is from Stuve (44).

TABLE 33. - Thermodynamic properties of $NiSO_4(c)$
[Formation: $Ni(c) + 0.5\ S_2(g) + 2\ O_2(g) = NiSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-3.810	-221.490	-221.490	∞
100	9.020	6.760	40.960	-3.420	-222.976	-212.865	465.210
200	17.840	15.990	26.190	-2.040	-223.794	-202.390	221.159
298.15	23.330	24.210	24.210	0	-224.065	-191.807	140.597
300	23.420	24.350	24.217	.040	-224.070	-191.608	139.585
400	27.510	31.710	25.185	2.610	-223.971	-180.794	98.780
500	30.050	38.140	27.140	5.500	-223.667	-170.028	74.318
600	31.910	43.790	29.457	8.600	-223.283	-159.339	58.039
631	32.363	45.409	30.201	9.596	-223.166	-156.037	54.043
700	33.370	48.820	31.863	11.870	-222.797	-148.707	46.428
800	34.570	53.360	34.285	15.260	-222.176	-138.181	37.749
900	35.560	57.490	36.634	18.770	-221.482	-127.720	31.014
1000	36.380	61.280	38.910	22.370	-220.741	-117.343	25.645
1100	37.030	64.780	41.107	26.040	-219.975	-107.032	21.265
1200	37.530	68.020	43.212	29.770	-219.188	-96.795	17.629

Phase change: 631 K, Curie temperature of Ni.

Sources: Enthalpy of formation at 298 K is based on Adami (2). Low-temperature heat capacities are from Stuve (44) and Weller (50). High-temperature enthalpy data are from Stuve (44). Entropy at 298 K is from Stuve (44).

TABLE 34. - Thermodynamic properties of $NiSO_4 \cdot H_2O(c)$
[Formation: $Ni(c) + S(c,\ell) + 2.5\ O_2(g) + H_2(g) = NiSO_4 \cdot H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	32.597	32.700	32.700	0	-284.600	-244.105	178.932
300	32.763	32.902	32.702	.060	-284.608	-243.854	177.645
350	37.260	38.290	33.116	1.811	-284.681	-237.054	148.021
368.30	38.906	40.231	33.421	2.508	-284.663	-234.564	139.189
368.30	38.906	40.231	33.421	2.508	-284.759	-234.564	139.189
388.36	40.710	42.341	33.828	3.306	-284.712	-231.830	130.461
388.36	40.710	42.341	33.828	3.306	-285.125	-231.830	130.461
400	41.757	43.559	34.094	3.786	-285.103	-230.234	125.792
432.02	44.636	46.884	34.917	5.170	-285.005	-225.844	114.249
450	46.253	48.737	35.433	5.987	-284.989	-223.383	108.488
500	50.750	53.843	37.019	8.412	-284.650	-216.554	94.654
550	55.246	58.891	38.778	11.062	-284.099	-209.770	83.354

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: Enthalpy of formation at 298 K is based on Goldberg (15). Entropy at 298 K is from Mah (31). Heat capacities are estimates.

TABLE 35. - Thermodynamic properties of $NiSO_4 \cdot 4H_2O(c)$
[Formation: $Ni(c) + S(c,\ell) + 4\ O_2(g) + 4H_2(g) = NiSO_4 \cdot 4H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	60.500	61.000	61.000	0	-499.400	-417.513	306.042
300	60.767	61.375	61.002	.112	-499.414	-417.005	303.784
350	67.973	71.283	61.766	3.331	-499.587	-403.252	251.799
368.30	70.611	74.814	62.327	4.599	-499.574	-398.215	236.298
368.30	70.611	74.814	62.327	4.599	-499.670	-398.215	236.299
388.36	73.502	78.635	63.070	6.045	-499.610	-392.689	220.983
388.36	73.502	78.635	63.070	6.045	-500.023	-392.689	220.983
400	75.180	80.830	63.555	6.910	-499.984	-389.473	212.796
432.02	79.795	86.795	65.058	9.391	-499.807	-380.634	192.552
450	82.387	90.102	65.993	10.849	-499.725	-375.677	182.451
500	89.593	99.155	68.859	15.148	-499.113	-361.923	158.194
550	96.800	108.032	72.017	19.808	-498.163	-348.248	138.379

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: Enthalpy of formation at 298 K--see discussion in text. Heat capacities and entropy at 298 K are estimates.

TABLE 36. - Thermodynamic properties of $NiSO_4 \cdot 6H_2O(\alpha,c)$
[Formation: $Ni(c) + S(c,\ell) + 5\ O_2(g) + 6H_2(g) = NiSO_4 \cdot 6H_2O(\alpha,c)$]

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	∞	-12.391	-629.014	-629.014	∞
100	29.980	23.841	134.231	-11.039	-635.719	-602.500	1316.745
200	56.680	53.128	86.428	-6.660	-639.529	-567.626	620.265
298.15	78.361	79.935	79.935	0	-641.340	-531.879	389.873
300	78.730	80.421	79.938	.145	-641.360	-531.200	386.974
350	88.180	93.280	80.931	4.322	-641.620	-512.814	320.211
368.30	91.254	97.852	81.660	5.964	-641.618	-506.079	300.304
368.30	91.254	97.852	81.660	5.964	-641.714	-506.079	300.304
388.36	94.624	102.792	82.622	7.833	-641.653	-498.691	280.635
388.36	94.624	102.792	82.622	7.833	-642.066	-498.691	280.635
400	96.579	105.615	83.250	8.946	-642.025	-494.395	270.121
432.02	101.285	113.241	85.191	12.118	-641.836	-482.584	244.126
450	103.928	117.425	86.396	13.963	-641.749	-475.959	231.154
500	110.227	128.710	90.068	19.321	-641.146	-457.567	200
550	115.476	139.470	94.074	24.968	-640.283	-439.250	174.540

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: Enthalpy of formation is based on Goldberg (15). Low-temperature heat capacities and entropies are from Stout (43). Heat capacities above 300 K are estimates.

TABLE 37. - Thermodynamic properties of $NiSO_4 \cdot 7H_2O(c)$
[Formation: $Ni(c) + S(c,\ell) + 5.5\ O_2(g) + 7H_2(g) = NiSO_4 \cdot 7H_2O(c)$]

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	∞	-14.085	-697.707	-697.707	∞
100	34.700	26.549	152.079	-12.553	-705.296	-667.872	1459.615
200	64.800	60.327	97.867	-7.508	-709.432	-628.644	686.941
298.15	87.142	90.570	90.570	0	-711.400	-588.500	431.377
300	87.503	91.110	90.570	.162	-711.423	-587.737	428.161
304	88.277	92.274	90.587	.513	-711.466	-586.088	421.342
350	96.425	105.290	91.670	4.767	-711.777	-567.089	354.102
368.30	99.098	110.272	92.472	6.556	-711.820	-559.523	332.017
368.30	99.098	110.272	92.472	6.556	-711.916	-559.523	332.017
388.36	102.028	115.622	93.530	8.580	-711.912	-551.222	310.196
388.36	102.028	115.622	93.530	8.580	-712.325	-551.222	310.196
400	103.728	118.660	94.218	9.777	-712.323	-546.393	298.532
432.02	107.368	126.8	96.333	13.163	-712.258	-533.113	269.687
450	109.412	131.222	97.640	15.112	-712.260	-525.659	255.292
500	113.477	142.974	101.592	20.691	-711.969	-504.939	220.706
550	115.923	153.917	105.857	26.433	-711.548	-484.257	192.423

Phase changes: 304 K $NiSO_4 \cdot 7H_2O(c)$ dissociates to $NiSO_4 \cdot 6H_2O(c)$ and saturated solution.
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: Enthalpy of formation at 298 K is based on Goldberg (15). Heat capacities, entropies, and transition temperature are from Stout (43).

TABLE 38. - Thermodynamic properties of $CuSO_4(c)$
[Formation: $Cu(c) + S(c,\ell) + 2\ O_2(g) = CuSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.032	-181.932	-181.932	∞
100	10.454	7.865	43.425	-3.556	-183.168	-175.136	382.756
200	18.419	17.786	28.176	-2.078	-183.956	-166.762	182.227
298.15	23.632	26.173	26.173	0	-184.300	-158.235	115.988
300	23.710	26.319	26.172	.044	-184.303	-158.072	115.154
368.30	26.353	31.491	26.685	1.770	-184.330	-152.095	90.252
368.30	26.353	31.491	26.685	1.770	-184.426	-152.095	90.252
388.36	27.130	32.910	26.971	2.307	-184.416	-150.334	84.599
388.36	27.130	32.910	26.971	2.307	-184.829	-150.334	84.599
400	27.580	33.718	27.155	2.625	-184.836	-149.300	81.573
432.02	28.448	35.875	27.723	3.522	-184.859	-146.455	74.088
500	30.290	40.180	29.128	5.526	-184.946	-140.401	61.368
600	32.300	45.889	31.456	8.660	-184.805	-131.500	47.898
700	33.890	50.991	33.888	11.972	-184.488	-122.639	38.289
717.82	34.136	51.846	34.323	12.578	-184.416	-121.065	36.859

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.

Sources: The enthalpy of formation at 298 K and entropy at 298 K are from CODATA (8). Heat capacities are from King (23).

TABLE 39. - Thermodynamic properties of $CuSO_4(c)$
[Formation: $Cu(c) + 0.5S_2(g) + 2\ O_2(g) = CuSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.032	-197.250	-197.250	∞
100	10.454	7.865	43.425	-3.556	-198.689	-188.626	412.237
200	18.419	17.786	28.176	-2.078	-199.439	-178.224	194.751
298.15	23.632	26.173	26.173	0	-199.655	-167.749	122.962
300	23.710	26.319	26.172	.044	-199.655	-167.550	122.058
400	27.580	33.718	27.155	2.625	-199.487	-156.866	85.706
500	30.290	40.180	29.128	5.526	-199.074	-146.254	63.927
600	32.300	45.889	31.456	8.660	-198.499	-135.741	49.443
700	33.890	50.991	33.888	11.972	-197.813	-125.334	39.131
800	35.270	55.609	36.320	15.431	-197.036	-115.034	31.426
900	36.530	59.836	38.700	19.022	-196.176	-104.834	25.457
1000	37.700	63.747	41.013	22.734	-195.238	-94.736	20.704
1100	38.730	67.390	43.246	26.558	-194.232	-84.731	16.834

Sources: The enthalpy of formation at 298 K and entropy at 298 K are from CODATA (8). The heat capacities are from King (23).

TABLE 40. - Thermodynamic properties of $CuSO_4 \cdot H_2O(c)$
[Formation: $Cu(c) + S(c,\ell) + 2.5\ O_2(g) + H_2(g) = CuSO_4 \cdot H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	32.000	34.900	34.900	0	-259.520	-219.447	160.857
300	32.180	35.099	34.902	.059	-259.527	-219.199	159.684
350	36.678	40.397	35.308	1.781	-259.606	-212.468	132.669
368.30	38.324	42.308	35.609	2.467	-259.587	-210.003	124.615
368.30	38.324	42.308	35.609	2.467	-259.683	-210.003	124.615
388.36	40.129	44.387	36.009	3.254	-259.634	-207.298	116.656
388.36	40.129	44.387	36.009	3.254	-260.047	-207.298	116.656
400	41.176	45.588	36.271	3.727	-260.022	-205.718	112.397
432.02	44.057	48.869	37.084	5.091	-259.918	-201.375	101.870
450	45.674	50.698	37.591	5.898	-259.897	-198.940	96.617
500	50.172	55.743	39.153	8.295	-259.530	-192.183	84.002
550	54.670	60.736	40.889	10.916	-258.942	-185.474	73.699

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, entropy at 298 K, and heat capacity at 298 K are from Wagman (48). The high-temperature heat capacities are estimates.

TABLE 41. - Thermodynamic properties of $CuSO_4 \cdot 3H_2O(c)$
[Formation: $Cu(c) + S(c,\ell) + 3.5\ O_2(g) + 3H_2(g) = CuSO_4 \cdot 3H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G^\circ - H^\circ_{298})/T$	$H^\circ - H^\circ_{298}$	ΔHf°	ΔGf°	
298.15	49.000	52.900	52.900	0	-402.560	-334.634	245.290
300	49.244	53.204	52.901	.091	-402.574	-334.212	243.470
350	55.843	61.290	53.524	2.718	-402.793	-322.797	201.561
368.30	58.259	64.198	53.983	3.762	-402.801	-318.614	189.064
368.30	58.259	64.198	53.983	3.762	-402.897	-318.614	189.064
388.36	60.907	67.357	54.592	4.957	-402.862	-314.024	176.715
388.36	60.907	67.357	54.592	4.957	-403.275	-314.024	176.715
400	62.443	69.178	54.991	5.675	-403.251	-311.349	170.111
432.02	66.669	74.147	56.227	7.742	-403.122	-303.997	153.784
450	69.042	76.914	56.998	8.962	-403.071	-299.874	145.637
500	75.641	84.530	59.372	12.579	-402.552	-288.432	126.072
550	82.240	92.048	62.001	16.526	-401.712	-277.056	110.091

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, entropy at 298 K, and heat capacity at 298 K are from Wagman (48). High-temperature heat capacities are estimates.

TABLE 42. - Thermodynamic properties of $CuSO_4 \cdot 5H_2O(c)$
[Formation: $Cu(c) + S(c,\ell) + 4.5\ O_2(g) + 5H_2(g) = CuSO_4 \cdot 5H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	67.000	71.800	71.800	0	-544.870	-449.360	329.385
300	67.360	72.216	71.803	.124	-544.890	-448.767	326.923
350	76.354	83.275	72.655	3.717	-545.188	-432.717	270.197
368.30	79.646	87.250	73.282	5.144	-545.197	-426.836	253.282
368.30	79.646	87.250	73.282	5.144	-545.293	-426.836	253.282
388.36	83.254	91.567	74.113	6.779	-545.242	-420.383	236.568
388.36	83.254	91.567	74.113	6.779	-545.655	-420.383	236.568
400	85.348	94.057	74.657	7.760	-545.613	-416.629	227.633
432.02	91.108	100.848	76.347	10.585	-545.405	-406.312	205.542
450	94.342	104.629	77.402	12.252	-545.290	-400.526	194.520
500	103.336	115.035	80.647	17.194	-544.513	-384.479	168.053
550	112.330	125.305	84.240	22.586	-543.302	-368.529	146.438

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 based on Larson (29). The entropy and heat capacity at 298 K are from Wagman (48).

TABLE 43. - Thermodynamic properties of $Cu_2SO_4(c)$
[Formation: $2Cu(c) + S(c,\ell) + 2\ O_2(g) = Cu_2SO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	31.000	43.600	43.600	0	-179.600	-156.368	114.620
300	31.068	43.792	43.602	.057	-179.601	-156.224	113.808
368.30	33.489	50.411	44.262	2.265	-179.550	-150.905	89.546
368.30	33.489	50.411	44.262	2.265	-179.646	-150.905	89.546
388.36	34.200	52.206	44.627	2.944	-179.614	-149.339	84.040
388.36	34.200	52.206	44.627	2.944	-180.027	-149.339	84.040
400	34.613	53.222	44.862	3.344	-180.022	-148.420	81.092
432.02	35.657	55.928	45.583	4.469	-180.011	-145.891	73.802
500	37.872	61.301	47.361	6.970	-180.019	-140.518	61.420
600	40.846	68.473	50.291	10.909	-179.699	-132.640	48.314
700	43.535	74.975	53.361	15.130	-179.112	-124.840	38.976

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 (48). The entropy at 298 K is from Nagamori (35). The heat capacities are estimates.

TABLE 44. - Thermodynamic properties of $CuO^{\bullet}CuSO_4(c)$
[Formation: $2Cu(c) + S(c,\ell) + 2.5\ O_2(g) = CuO^{\bullet}CuSO_4(c)$]

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	0	-5.909	-216.376	-216.376	0
100	16.148	13.806	65.066	-5.126	-217.812	-208.065	454.719
200	26.484	28.410	43.205	-2.959	-218.740	-197.915	216.268
298.15	33.450	40.358	40.358	0	-219.100	-187.596	137.510
300	33.570	40.565	40.358	.062	-219.103	-187.400	136.519
368.30	36.659	47.790	41.078	2.472	-219.091	-180.180	106.918
368.30	36.659	47.790	41.078	2.472	-219.187	-180.181	106.918
388.36	37.566	49.759	41.476	3.217	-219.161	-178.056	100.200
388.36	37.566	49.759	41.476	3.217	-219.574	-178.056	100.200
400	38.092	50.876	41.734	3.657	-219.571	-176.812	96.604
432.02	39.144	53.850	42.523	4.894	-219.564	-173.390	87.713
500	41.376	59.750	44.470	7.640	-219.576	-166.119	72.610
600	43.701	67.511	47.678	11.900	-219.313	-155.448	56.621
700	45.332	74.378	51.011	16.357	-218.879	-144.835	45.219
717.82	45.547	75.520	51.605	17.167	-218.788	-142.951	43.523

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.

Source: All data are from King (23).

TABLE 45. - Thermodynamic properties of $CuO^{\bullet}CuSO_4(c)$
[Formation: $2Cu(c) + 0.5S_2(g) + 2.5\ O_2(g) = CuO^{\bullet}CuSO_4(c)$]

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	0	-5.909	-231.693	-231.693	0
100	16.148	13.806	65.066	-5.126	-233.332	-221.554	484.201
200	26.484	28.410	43.205	-2.959	-234.222	-209.376	228.793
298.15	33.450	40.358	40.358	0	-234.455	-197.110	144.484
300	33.570	40.565	40.358	.062	-234.455	-196.877	143.423
400	38.092	50.876	41.734	3.657	-234.222	-184.378	100.738
500	41.376	59.750	44.470	7.640	-233.704	-171.973	75.168
600	43.701	67.511	47.678	11.900	-233.007	-159.689	58.166
700	45.332	74.378	51.011	16.357	-232.204	-147.530	46.060
800	46.539	80.513	54.322	20.953	-231.340	-135.495	37.015
900	47.587	86.055	57.545	25.659	-230.435	-123.568	30.006
1000	48.744	91.127	60.653	30.474	-229.483	-111.745	24.421
1100	50.278	95.840	63.640	35.420	-228.466	-100.017	19.871
1200	52.455	100.303	66.511	40.551	-227.336	-88.387	16.097

Source: All data are from King (23).

TABLE 46. - Thermodynamic properties of $ZnSO_4(c)$
[Formation: $Zn(c,\ell) + S(c,\ell) + 2\ O_2(g) = ZnSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.120	-231.823	-231.823	∞
100	11.373	7.548	43.868	-3.632	-233.125	-224.907	491.527
200	18.655	17.979	28.429	-2.090	-233.902	-216.360	236.425
298.15	23.680	26.430	26.430	0	-234.260	-207.668	152.223
300	23.746	26.577	26.430	.044	-234.263	-207.502	151.163
368.30	25.885	31.681	26.938	1.747	-234.330	-201.400	119.509
368.30	25.885	31.681	26.938	1.747	-234.426	-201.400	119.510
388.36	26.513	33.071	27.220	2.272	-234.431	-199.600	112.324
388.36	26.513	33.071	27.220	2.272	-234.844	-199.600	112.324
400	26.878	33.859	27.402	2.583	-234.862	-198.544	108.478
432.02	27.719	35.961	27.959	3.457	-234.917	-195.635	98.966
500	29.506	40.144	29.336	5.404	-235.080	-189.437	82.802
600	31.945	45.741	31.611	8.478	-235.039	-180.307	65.676
692.73	34.124	50.486	33.825	11.541	-234.805	-171.866	54.222
692.73	34.124	50.486	33.825	11.541	-236.555	-171.866	54.222
700	34.295	50.843	34.000	11.790	-236.533	-171.187	53.446
717.82	34.705	51.710	34.429	12.405	-236.470	-169.524	51.613

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.
692.73 K, melting point of Zn; ΔH° = 1.750 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture.

Sources: Enthalpy of formation at 298 K is based on Adami (2). Heat capacities of α-$ZnSO_4$ are from Weller (50) and Voskresenskaya (46). Enthalpy and entropy values are taken from JANAF (12).

TABLE 47. - Thermodynamic properties of $ZnSO_4$(c)
[Formation: $Zn(c,\ell,g) + 0.5S_2(g) + 2\ O_2(g) = ZnSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-4.120	-247.141	-247.141	∞
100	11.373	7.548	43.868	-3.632	-248.645	-238.397	521.009
200	18.655	17.979	28.429	-2.090	-249.384	-227.822	248.949
298.15	23.680	26.430	26.430	0	-249.615	-217.181	159.196
300	23.746	26.577	26.430	.044	-249.615	-216.979	158.067
400	26.878	33.859	27.402	2.583	-249.513	-206.110	112.612
500	29.506	40.144	29.336	5.404	-249.207	-195.290	85.360
600	31.945	45.741	31.611	8.478	-248.734	-184.548	67.221
692.73	34.124	50.486	33.825	11.541	-248.156	-174.672	55.107
692.73	34.124	50.486	33.825	11.541	-249.906	-174.672	55.107
700	34.295	50.843	34.000	11.790	-249.858	-173.882	54.288
800	36.597	55.573	36.404	15.335	-249.094	-163.080	44.551
900	38.871	60.015	38.783	19.109	-248.139	-152.383	37.003
1000	41.128	64.227	41.118	23.109	-246.986	-141.804	30.991
1015	41.466	64.842	41.285	23.910	-246.615	-140.046	30.154
1015	34.700	69.640	41.285	28.780	-241.745	-140.046	30.154
1100	34.700	72.431	43.586	31.729	-241.241	-131.549	26.136
1180	34.700	74.867	45.625	34.505	-240.781	-123.584	22.889
1180	34.700	74.867	45.625	34.505	-268.346	-123.584	22.889
1200	34.700	75.450	46.117	35.199	-268.184	-121.134	22.061

Phase changes: 692.73 K, melting point of Zn; ΔH° = 1.750 kcal/mol.
1015 K, α-β transition point for $ZnSO_4$(c); ΔH° = 4.87 kcal/mol.
1180 K, boiling point of Zn; ΔH° = 27.565 kcal/mol.

Sources: Enthalpy of formation at 298 K is based on Adami (2). Heat capacities of α-$ZnSO_4$ are from Weller (50) and Voskresenskaya (46). Heat capacities of β-$ZnSO_4$ and ΔH for the α-β transition are from Hosmer (16). Enthalpy and entropy values are taken from JANAF (12).

TABLE 48. - Thermodynamic properties of $ZnSO_4 \cdot H_2O$(c)
[Formation: $Zn(c) + S(c,\ell) + 2.5\ O_2(g) + H_2(g) = ZnSO_4 \cdot H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	36.153	33.100	33.100	0	-311.850	-270.637	198.379
300	36.319	33.324	33.101	.067	-311.850	-270.380	196.969
350	40.819	39.261	33.561	1.995	-311.734	-263.476	164.520
368.30	42.466	41.383	33.897	2.757	-311.643	-260.955	154.849
368.30	42.466	41.383	33.897	2.757	-311.740	-260.955	154.849
388.36	44.272	43.682	34.341	3.628	-311.612	-258.190	145.295
388.36	44.272	43.682	34.341	3.628	-312.025	-258.190	145.295
400	45.320	45.005	34.632	4.149	-311.955	-256.578	140.186
432.02	48.202	48.605	35.536	5.646	-311.726	-252.155	127.558
450	49.820	50.603	36.099	6.527	-311.634	-249.678	121.258
500	54.320	56.085	37.823	9.131	-311.076	-242.820	106.135
550	58.820	61.473	39.729	11.959	-310.299	-236.030	93.788

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: Enthalpy of formation is based on Wagman (47). Entropy at 298 K is from Wagman (47). Heat capacity at 298 K is from Kelley (21), and high-temperature heat capacities are estimates.

TABLE 49. - Thermodynamic properties of $ZnSO_4 \cdot 6H_2O(c)$
[Formation: $Zn(c) + S(c,\ell) + 5\ O_2(g) + 6H_2(g) = ZnSO_4 \cdot 6H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	84.994	86.900	86.900	0	-663.900	-555.678	407.318
300	85.456	87.427	86.900	.158	-663.906	-555.006	404.316
333.40	93.988	96.887	87.430	3.153	-663.862	-542.882	355.865
350	98.362	101.559	87.988	4.750	-663.739	-536.860	335.226
368.30	103.380	106.700	88.791	6.596	-663.526	-530.231	314.636
368.30	103.380	106.700	88.791	6.596	-663.622	-530.231	314.636
388.36	108.880	112.317	89.861	8.721	-663.296	-522.973	294.300
388.36	108.880	112.317	89.861	8.721	-663.709	-522.973	294.300
400	112.072	115.580	90.563	10.007	-663.489	-518.759	283.433
432.02	121.367	124.555	92.749	13.741	-662.719	-507.201	256.579
450	126.586	129.610	94.121	15.970	-662.238	-500.740	243.189
500	141.904	143.733	98.375	22.679	-660.243	-482.895	211.071
550	158.026	158.008	103.146	30.174	-657.484	-465.287	184.886

Phase changes: $ZnSO_4 \cdot 6H_2O(c)$ dissociates to $ZnSO_4 \cdot H_2O(c)$ and saturated solution at 333.4 K.
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.

Sources: The enthalpy of formation at 298 K is based on Larson (29). The entropy and heat capacity at 298 K are from Barieau (4). The high-temperature heat capacity values are obtained by extrapolating the low-temperature values of Barieau (4).

TABLE 50. - Thermodynamic properties of $ZnSO_4 \cdot 7H_2O(c)$
[Formation: $Zn(c) + S(c,\ell) + 5.5\ O_2(g) + 7H_2(g) = ZnSO_4 \cdot 7H_2O(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
0	0	0	∞	-14.592	-722.154	-722.154	∞
100	36.630	26.991	156.231	-12.924	-729.724	-692.129	1512.627
200	66.139	61.789	100.464	-7.735	-733.798	-652.747	713.279
298.15	91.144	92.900	92.900	0	-735.550	-612.507	448.974
300	91.620	93.465	92.902	.169	-735.564	-611.743	445.649
311.27	94.590	96.898	92.982	1.219	-735.625	-607.090	426.246
350	103.820	108.512	94.063	5.057	-735.624	-591.093	369.090
368.30	108.143	113.913	94.917	6.996	-735.509	-583.539	346.268
368.30	108.143	113.913	94.917	6.996	-735.605	-583.539	346.268
388.36	112.881	119.776	96.048	9.215	-735.398	-575.260	323.724
388.36	112.881	119.776	96.048	9.215	-735.811	-575.260	323.724
400	115.631	123.150	96.788	10.545	-735.669	-570.450	311.676
432.02	122.962	132.336	99.083	14.366	-735.152	-557.244	281.894
450	127.078	137.434	100.514	16.614	-734.843	-549.847	267.039
500	138.163	151.400	104.906	23.247	-733.458	-529.360	231.380
550	148.885	165.074	109.756	30.425	-731.553	-509.038	202.270

Phase changes: 311.27 K, $ZnSO_4 \cdot 7H_2O(c)$ dissociates to $ZnSO_4 \cdot 6H_2O$ and saturated solution with ΔH of dissociation = 4.017 kcal/mol hydrate.
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.

Sources: The enthalpy of formation at 298 K is based on Larson (29). The entropy at 298 K and heat capacities are from Barieau (4). The ΔH of dissociation is from Barieau (4).

TABLE 51. - Thermodynamic properties of $ZnO \cdot 2ZnSO_4(c)$
[Formation: $3Zn(c,\ell) + 2S(c,\ell) + 4.5\ O_2(g) = ZnO \cdot 2ZnSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	56.686	68.190	68.190	0	-550.310	-491.424	360.219
300	56.939	68.541	68.191	.105	-550.317	-491.056	357.730
368.30	63.332	81.017	69.425	4.269	-550.352	-477.553	283.377
368.30	63.332	81.017	69.425	4.269	-550.544	-477.553	283.377
388.36	65.209	84.427	70.114	5.559	-550.514	-473.577	266.502
388.36	65.209	84.427	70.114	5.559	-551.340	-473.578	266.503
400	66.299	86.369	70.559	6.324	-551.346	-471.247	257.474
432.02	67.919	91.537	71.925	8.473	-551.373	-464.835	235.147
500	71.359	101.753	75.297	13.228	-551.526	-451.197	197.215
600	74.727	115.077	80.842	20.541	-551.323	-431.143	157.042
692.73	77.108	125.991	86.169	27.586	-550.943	-412.604	130.171
692.73	77.108	125.991	86.169	27.586	-556.193	-412.603	130.171
700	77.295	126.797	86.587	28.147	-556.168	-411.096	128.348
717.82	77.677	128.745	87.609	29.528	-556.095	-407.403	124.038

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.
692.73 K, melting point of Zn; ΔH° = 1.750 kcal/mol.
717.824 K, boiling point of S to equilibrium mixture.

Sources: The enthalpy at 298.15 K is from Ko (25). High-temperature enthalpies and the entropy at 298.15 K are from Hosmer (16).

TABLE 52. - Thermodynamic properties of $ZnO \cdot 2ZnSO_4(c)$
[Formation: $3Zn(c,\ell,g) + S_2(g) + 4.5\ O_2(g) = ZnO \cdot 2ZnSO_4(c)$]

T, K	cal/mol°K			kcal/mol			Log Kf
	Cp°	S°	$-(G°- H°_{298})/T$	$H°- H°_{298}$	ΔHf°	ΔGf°	
298.15	56.686	68.190	68.190	0	-581.020	-510.451	374.166
300	56.939	68.541	68.191	.105	-581.021	-510.011	371.538
400	66.299	86.369	70.559	6.324	-580.648	-486.378	265.741
500	71.359	101.753	75.297	13.228	-579.781	-462.903	202.332
600	74.727	115.077	80.842	20.541	-578.711	-439.625	160.131
692.73	77.108	125.991	86.169	27.586	-577.643	-418.216	131.941
692.73	77.108	125.991	86.169	27.586	-582.893	-418.214	131.941
700	77.295	126.797	86.587	28.147	-582.818	-416.486	130.031
800	79.438	137.261	92.279	35.986	-581.690	-392.802	107.307
900	81.333	146.729	97.811	44.026	-580.443	-369.266	89.669
1000	83.074	155.389	103.141	52.248	-579.080	-345.874	75.590
1100	84.714	163.385	108.260	60.638	-577.610	-322.622	64.098
1180	85.972	169.376	112.202	67.465	-576.354	-304.112	56.324
1180	85.972	169.376	112.202	67.465	-659.049	-304.112	56.324
1200	86.286	170.824	113.167	69.188	-658.574	-298.104	54.292

Phase changes: 692.73 K, melting point of Zn; ΔH° = 1.750 kcal/mol.
1015 K, α-β transition point for $ZnSO_4(c)$; ΔH° = 4.87 kcal/mol.
1180 K, boiling point of Zn; ΔH° = 27.565 kcal/mol.

Sources: The enthalpy at 298.15 K is from Ko (25). High-temperature enthalpies and the entropy at 298.15 K are from Hosmer (16).

TABLE 53. - Thermodynamic data for the reaction $1/3Cr_2(SO_4)_3(c) = 1/3Cr_2O_3(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
298.15	49.872	35.801	-26.242
300	49.870	35.713	-26.016
305	49.868	35.477	-25.421
400	49.636	31.025	-16.951
500	49.256	26.412	-11.545
600	48.754	21.891	-7.974
700	48.145	17.461	-5.452
800	47.459	13.122	-3.585
900	46.737	8.877	-2.156

Phase change: 305 K, second-order transition point of Cr_2O_3; ΔH° = 0 kcal/mol.

TABLE 54. - Thermodynamic data for the reaction $FeSO_4(c) = FeO(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
298.15	63.220	49.220	-36.079
300	63.219	49.133	-35.793
400	63.130	44.448	-24.285
500	62.892	39.802	-17.397
600	62.552	35.215	-12.827
700	62.144	30.689	-9.581
800	61.695	26.226	-7.165
900	61.226	21.820	-5.299
1000	60.748	17.468	-3.818
1100	60.262	13.162	-2.615
1200	59.769	8.902	-1.621
1300	59.270	4.686	- .788
1400	58.762	.504	- .079
1500	58.245	-3.641	.530
1600	57.718	-7.748	1.058

TABLE 55. - Thermodynamic data for the reaction $1/3Fe_2(SO_4)_3(c) = 1/3Fe_2O_3(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
298.15	45.439	31.786	-23.300
300	45.437	31.702	-23.094
400	45.268	27.146	-14.832
500	45.042	22.641	-9.896
600	44.760	18.186	-6.624
700	44.419	13.784	-4.303
800	44.022	9.433	-2.577
800	43.854	9.433	-2.577
900	43.495	5.154	-1.252

TABLE 56. - Thermodynamic data for the reaction $CoSO_4(c) = CoO(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
298.15	60.850	47.152	-34.563
300	60.850	47.066	-34.287
400	60.732	42.483	-23.211
500	60.466	37.950	-16.588
600	60.148	33.476	-12.193
700	59.787	29.058	-9.072
800	59.377	24.695	-6.746
900	58.918	20.387	-4.951
964	58.598	17.659	-4.003
964	58.083	17.659	-4.003
1000	57.894	16.152	-3.530
1100	57.336	12.005	-2.385
1200	56.732	7.910	-1.441
1300	56.086	3.868	- .650
1400	55.399	- .125	.020

Phase change: 964 K, α-β transition of $CoSO_4(c)$; ΔH° = 0.515 kcal/mol.

TABLE 57. - Thermodynamic data for the reaction $NiSO_4(c) = NiO(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
0	56.234	56.234	∞
100	56.752	52.203	-114.087
200	56.856	47.594	-52.008
298.15	56.830	43.051	-31.557
300	56.832	42.966	-31.301
400	56.712	38.362	-20.960
500	56.628	33.775	-14.763
525	56.661	32.636	-13.586
525	56.661	32.636	-13.586
565	56.597	30.804	-11.915
565	56.597	30.804	-11.915
600	56.498	29.211	-10.640
700	56.155	24.686	-7.707
800	55.757	20.236	-5.528
900	55.278	15.809	-3.839
1000	54.768	11.457	-2.504
1100	54.237	7.162	-1.423
1200	53.680	2.888	- .526

Phase changes: 525 K, α-β transition point of NiO; ΔH° = 0 kcal/mol.
565 K, β-δ transition point of NiO; ΔH° = 0 kcal/mol.

TABLE 58. - Thermodynamic data for the reaction $2CuSO_4(c) = CuO{\cdot}CuSO_4(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
0	54.279	54.279	∞
100	54.908	50.027	-109.333
200	55.023	45.071	-49.251
298.15	54.920	40.204	-29.470
300	54.916	40.112	-29.221
400	54.649	35.215	-19.240
500	54.276	30.397	-13.287
600	53.828	25.663	-9.348
700	53.308	21.009	-6.559
800	52.698	16.437	-4.490
900	51.983	11.944	-2.900
1000	51.174	7.540	-1.648
1100	50.301	3.215	- .639

TABLE 59.- Thermodynamic data for the reaction $CuO{\cdot}CuSO_4(c) = 2CuO(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
0	49.839	49.839	∞
100	50.166	46.006	-100.545
200	50.143	41.856	-45.738
298.15	50.120	37.787	-27.698
300	50.118	37.711	-27.472
400	49.965	33.595	-18.355
500	49.726	29.529	-12.907
600	49.426	25.516	-9.294
700	49.098	21.557	-6.730
800	48.752	17.646	-4.821
900	48.381	13.781	-3.347
1000	47.960	9.958	-2.176
1100	47.461	6.179	-1.228
1200	46.855	2.455	- .447

TABLE 60. - Thermodynamic data for the reaction $3ZnSO_4(c) = ZnO{\cdot}2ZnSO_4(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
298.15	57.890	42.910	-31.453
300	57.885	42.816	-31.191
400	57.787	37.812	-20.659
500	57.674	32.830	-14.350
600	57.325	27.887	-10.158
700	56.642	23.032	-7.191
800	55.558	18.300	-4.999
900	54.037	13.727	-3.333
1000	52.059	9.350	-2.043
1015	51.177	8.168	-1.759
1015	36.567	8.168	-1.759
1100	36.418	5.797	-1.152
1200	36.411	3.014	- .549

Phase change: 1015 K, α-β transition point for $ZnSO_4(c)$; ΔH°= 4.87 kcal/mol.

TABLE 61. - Thermodynamic data for the reaction $0.5ZnO{\cdot}2ZnSO_4(c) = 1.5ZnO(c) + SO_3(g)$

T, K	ΔH°, kcal	ΔG°, kcal	Log K
298.15	54.932	42.143	-30.891
300	54.928	42.063	-30.643
400	54.666	37.811	-20.659
500	54.300	33.638	-14.703
600	53.905	29.548	-10.763
700	53.495	25.514	-7.966
800	53.072	21.544	-5.885
900	52.633	17.627	-4.280
1000	52.173	13.762	-3.008
1100	51.688	9.951	-1.977
1200	51.175	6.175	-1.125

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