~~G. F. Worts~~

TEI-609

THERMODYNAMIC PROPERTIES OF SELECTED MINERALS AND OXIDES AT HIGH TEMPERATURES

By Richard A. Robie

Trace Elements Investigations Report 609

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

December 16, 1959

AEC-80/0

Dr. Joseph A. Lieberman
Chief, Environmental & Sanitary
Engineering Branch
Division of Reactor Development
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Joe:

Transmitted herewith are 50 copies of TEI-609, "Thermodynamic properties of selected minerals and oxides at high temperatures," by Richard A. Robie, September 1959.

We plan to publish this report as a Geological Survey bulletin.

Bull. 1259

Sincerely yours,

V. T. Stringfield
V. T. Stringfield
Chief, Radiohydrology Section
Water Resources Division

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

December 16, 1959

AEC-82/0

Dr. Daniel R. Miller
Chemistry Branch
Division of Research
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Dan:

Transmitted herewith is one copy of TEI-609, "Thermodynamic properties of selected minerals and oxides at high temperatures," by Richard A. Robie, September 1959.

This report is part of our Investigations of Geologic Processes project. We plan to publish this report as a Geological Survey bulletin.

Sincerely yours,

John H. Eric

for Montis R. Klepper
Assistant Chief Geologist

TEI-609

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THERMODYNAMIC PROPERTIES OF SELECTED MINERALS AND OXIDES AT HIGH TEMPERATURES *

By

Richard A. Robie

September 1959

Trace Elements Investigations Report 609

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done partly on behalf of the Division of Research and the Division of Reactor Development, U. S. Atomic Energy Commission.

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TABLES (Con't.)

THERMODYNAMIC PROPERTIES OF SELECTED MINERALS AND OXIDES AT HIGH TEMPERATURES

By Richard A. Robie

Introduction

Tables of the thermodynamic properties of several minerals have been constructed in a form convenient for calculation of chemical equilibria of minerals and of problems related to the heat content of rocks. Minerals selected are those for which reliable, modern thermal data exist, and which are commonly found in natural rocks. No attempt has been made to make this compilation exhaustive.

In order to insure internal consistency each table has been recalculated from original data. The tables of Stull and Sinke (1956) have been used exclusively for the thermodynamic properties of the elements. Choices for the standard states of the elements of those authors have also been adopted.

The unit of energy is the defined calorie, equal to 4.1840 absolute joules. Zero degrees Celsius has been taken as 273.15°K in accordance with the 1954 definition of the thermodynamic scale of temperature (see for example Cohen, Crowe, and Dumond, 1957). Values of other physical constants used and the symbols adopted may be found in table 1.

Two choices of reference temperature are in common use: 0°K and 298.15°K (25°C). Inasmuch as many of the entropy values used are based on heat capacity measurements extending downward only to 50°K for which no evaluation of $H^\circ_T - H^\circ_0$ was made, we have adopted 298.15°K as the reference temperature. This choice is also convenient, because it permits us to use directly the tables of Stull and Sinke (1956), who adopted the

Table 1. Symbols and constants

T	= Temperature in degrees Kelvin.
gfw	= Gram formula weight.
$H_T - H_{298.15}$	= Enthalpy at temperature T relative to 298.15°K in cal/gfw.
S_T	= Entropy at temperature T in cal/deg gfw.
$\frac{F_T - H_{298.15}}{T}$	= Free energy function in cal/deg gfw.
ΔH_f	= Heat of formation from reference state in cal/gfw.
ΔF_f	= Free energy of formation from reference state in cal/gfw.
ΔH_{melt}	= Heat of melting at one atmosphere in cal/gfw.
ΔH_{vap}	= Heat of vaporization to ideal gas at one atmosphere in cal/gfw.
M.P.	= Melting point at one atmosphere in degrees K.
B.P.	= Boiling point at one atmosphere in degrees K.
gfw. vol.	= Volume of one gram formula weight at one atmosphere and 298.15°K in cm^3.
°	= Superscript indicates the substance is in its standard state.
R	= Gas constant, 1.98726 cal/deg gfw (mole). 8.31469 joules/deg gfw (mole).
calorie	= Unit of energy, 4.1840 absolute joules. 41.2929 cm^3 atmosphere.
A	= Avogadro's number, 6.02380×10^{23} molecules/gfw (mole).
f	= Fugacity in atmospheres.
P	= Pressure, in atmospheres or bars.
Atm	= Atmosphere, 1,013,250 dynes/cm^2.
bar	= Bar, 1,000,000 dynes/cm^2.
log	= Logarithm to the base 10.
ln	= Logarithm to the base e = 2.718......

same reference temperatures. The 1955 scale of atomic weights (Wichers, 1956) has been used. Temperatures above 273.15°K are based on the International Temperature Scale of 1948. Where the accuracy of data have warranted it, temperatures measured on other scales have been corrected to I.T.S. 1948 using the curves given by Sosman (1952).

Methods of computation

The free energy function was calculated from the relation:

$$\frac{F^\circ_T - H^\circ_{298.15}}{T} = \frac{H^\circ_T - H^\circ_{298.15}}{T} - S^\circ_T$$

Values for the free energy functions of the elements were taken from Stull and Sinke (1956). The free energies of formation were obtained from:

$$\Delta F^\circ_{f,T} = \Delta H^\circ_{f,298.15} + T\Delta\left[\frac{(F^\circ_T - H^\circ_{298.15})}{T}\right]$$

The heats of formation were calculated from the expression:

$$\Delta H^\circ_f = \Delta H^\circ_{f,298.15} + \Delta(H^\circ_T - H^\circ_{298.15})$$

The equilibrium constant of formation K_f has not been tabulated. It may be obtained direction from $\Delta F^\circ_{f,T}$ using the expression:

$$\log_{10} K_f = \frac{\Delta F^\circ_{f,T}}{4.57584\ T}$$

Because it is common practice in mineral or ceramic equilibria to use oxides rather than elements as reference states, the thermodynamic properties of a number of oxides have been tabulated, and, wherever appropriate, the heats and free energies of formation of a compound from the oxides have been calculated. The heats and free energies of formation, using the oxides as reference states, were obtained by the relations:

$$\Delta H^\circ_f \text{ (compound from elements)} - \sum \Delta H^\circ_f \text{ (component oxides)} = \Delta H^\circ_f \text{ (compound from oxides)}$$

and

$$\Delta F^\circ_f \text{ (compound from elements)} - \sum \Delta F^\circ_f \text{ (component oxides)} = \Delta F^\circ_f \text{ (compound from oxides)}$$

Alternatively the heat of formation from the oxides at temperature T can be calculated from the heat of formation from the oxides at 298.15°K, and the difference between the heat contents of the compound and the sum of the oxides at the temperature T. This latter method was used to check the internal consistency of the tables. Values of ΔH_f° obtained by the two different paths should agree to ±2 calories. The free energy of formation from the oxides was checked by comparing the direct values of ΔS with those calculated from the relation:

$$\left[\frac{\Delta F_f^\circ - \Delta H_f^\circ}{T}\right]_{\text{oxides}} = \left[S_T^\circ,\ \text{compound} - \sum S_T^\circ,\ \text{oxides}\right]$$

The two values must check to 0.02 cal/deg gfw. The uncertainty above arises from the rounding error in the calculation of the free energy function. It corresponds to 6 calories at 300°K and 36 calories at 1800°K in the free energy of formation from the oxides. This method of checking also serves to eliminate numerical mistakes in the tables for the separate oxides.

A horizontal line in the columns ΔH_f° and ΔF_f° indicates a transition in one of the reference states. At the transition temperature ΔH_f° will be discontinuous and ΔF_f° will be continuous but its slope, $\frac{d\,\Delta F_f^\circ}{dT}$, is discontinuous. This must be borne in mind when interpolating in the tables. The temperatures of the transitions are listed at the left side of each table.

Treatment of data

Because of the extreme difficulty of making proper heat exchange corrections at high temperatures the thermal property most commonly measured is the heat content, or relative enthalpy;

$$H_T^\circ - H_{T_0}^\circ = \int_{T_0}^{T} C_p dT$$

not the true specific heat, C_p, and where T_0 is a fixed reference temperature, usually 298.15°K. The heat content is usually determined at intervals of 50° or 100°K. In order to obtain the specific heat it is necessary to differentiate the experimental curve of $H_T^\circ - H_{298.15}^\circ$ versus T. This process of differentiation gives rise to uncertainties in the derived values of C_p of the order of 10 times those in $H_T^\circ - H_{298.15}^\circ$ or about 2-3 percent. The entropy increments above the reference temperature may be derived from the heat capacity thus obtained, or directly from the heat content curve by the relation;

$$S_T^\circ - S_{298.15}^\circ = \int_{298.15}^{T} \frac{d\,(H_T^\circ - H_{298.15}^\circ)}{T} = \frac{H_T^\circ - H_{298.15}^\circ}{T} + \int_{298.15}^{T} \frac{H_T^\circ - H_{298.15}^\circ}{T^2}\, dT$$

For substances that exhibit heat capacity anomalies, measurements at 50° intervals are, of course, not sufficient. In the absence of heat content data at closer temperature intervals, or of true specific heat measurements through the anomalous region, we have treated the data in a fashion similar to that used by Kelley (1949). The transition is treated as a first order phase change at a specific temperature, with a latent heat. An anomaly in the heat capacity causes an abrupt change in the slope of the heat content versus temperature curve but not a discontinuity. This apparent "latent heat" is a rough measure of the excess heat capacity in the finite temperature interval above and below which the heat content curve is more or less normal. The "transition temperature" is generally taken as that temperature at which the abrupt change in slope of the heat content curve occurs. The thermodynamic properties obtained from this treatment of the data are less accurate in the immediate neighborhood of the transition, and this should be kept in mind in using these tables. Examples of this type of behavior are the $\alpha \rightarrow \beta$ transition in quartz (SiO_2) at 848°K, the antiferromagnetic transition in NiO at 525°K, and the Curie point in magnetite (Fe_3O_4) at 900°K.

Oxides as reference states

The use of oxides as reference states requires amplification in certain cases. The reference states for SiO_2 adopted for determining the heats and free energies of formation from the oxides of the silicates are α-quartz from 298.15° to 848°K and β-quartz between 848° and 1800°K. The α - β transition has been treated as a first order phase change with a latent heat of 290 calories at 848°K. The temperature of the α - β inversion was taken as 848°K, rather than the more commonly adopted value 846°K, to be consistent with the calorometric data (Kelley, 1949). β-quartz is not the most stable form of SiO_2 above 1140°K. However, the heats of transition of β-quartz to β-tridymite and β-tridymite to β-cristobalite are small (and quite uncertain). Moreover, the heat contents of the three forms above 1200°K, $H^\circ_T - H^\circ_{1200}$, are nearly equal, and consequently the free energy of formation of β-quartz is only slightly less negative, about 200 calories, than those of the true stable modifications, β-tridymite above 1140°K and β-cristobalite above 1743°K. This procedure effects a considerable simplification in calculation at very little expense to the absolute accuracy of the data.

Stoichiometric FeO is thermodynamically unstable at all temperatures. The maximum iron content corresponds to $Fe_{0.953}O$ (Darken and Gurry, 1946). Thermochemical data are available for $Fe_{0.947}O$ (Humphrey, King, and Kelley, 1952) and a table has been calculated for this "compound." Because of this complexity, values listed for the heat and free energy of formation from the oxides do not correspond to reactions involving FeO, but to ($Fe_{0.947}O$ + 0.053 Fe). As an example the free energy of formation of Fe_2SiO_4, fayalite, using the oxides as reference states refers to the reaction;

$$2Fe_{0.947}O + 0.106Fe + SiO_2 = Fe_2SiO_4.$$

This must be kept in mind when considering chemical equilibrium involving ferrous iron compounds, but only if the oxides are used as the reference states.

The tables are incomplete for several of the substances considered. Although heat capacities and entropy data for these are available, adequate information on heats of formation, ΔH_f°, does not exist. They are nonetheless included, because when such data become available one can determine F_f° by subtracting the values of $\frac{\Delta H_{f,\ 298.15}^\circ}{T}$ from the listed values of the free energy function.

Although the absolute value of ΔF_f° or ΔH_f° is rarely known to better than ± 500 calories these quantities are tabulated to the nearest calorie. This apparent anomaly disappears if we recall that

$$\left(\frac{d\ \ \Delta F_f^\circ}{dT}\right)_P = - \Delta S_f^\circ.$$

ΔS_f° is, of course, known independently of ΔF_f°. The practice of rounding tabulated values of ΔF_f° or ΔH_f° on the basis of the uncertainty in the absolute value (Coughlin, 1954) is to be deplored since it does not fully utilize the more accurate heat capacity information.

A similar argument holds for H_f° because of the relation

$$\left(\frac{d \quad \Delta H_f^\circ}{dT}\right)_P = \Delta C_p.$$

Whenever possible the molar volumes were obtained from precise determinations of the X-ray unit cell dimensions, corrected to 298.15°K. The principal source of these data have been Circular 539 of the National Bureau of Standards (Swanson and others, 1959).

Properties of CO_2 and H_2O at higher pressures

The properties of CO_2 in the ideal gas state and at 100 atmospheres were calculated from data in Circular 564 of the National Bureau of Standards (Hilsenrath and others, 1955). Values for higher pressures were obtained from Price's (1955) smoothing and reduction of the P-V-T data of Kennedy (1954). Price gives values of S and H as a function of P and T in bars and degrees C, and adopts the values of Woolley (1954) for the ideal gas. From Price's tables we have calculated the fugacity, f, from the relation:

$$\frac{F_{P,T} - F_T^\circ}{RT} = \ln \frac{f}{f^\circ}$$

where f° is the fugacity of the ideal gas at one atmosphere pressure or the real gas at unit activity.(i.e. when $\frac{f}{P} = 1$).

To obtain the fugacity of H_2O the recent P-V-T data of Holser and Kennedy (1958, 1959) were used. From their values of the specific volume of H_2O we have calculated the fugacity using the expression,

$$\ln f = \ln P - \frac{1}{RT}\int_0^P \left[\frac{RT}{P} - V\right] dP \; .$$

The function $\alpha = \left[\frac{RT}{P} - V\right]$ was plotted versus pressure on a large scale and smooth values were read from the curves at 10 or 50 atmosphere intervals. The integration was done graphically. As a check on the reliability of the specific volume data, the compressibility factor, $Z = \frac{PV}{RT}$, was calculated. The isotherms of Z were found to behave correctly, extrapolating to Z = 1 as the pressure approached zero. These compressibility factors also agreed within 0.3 percent with those given by Hilsenrath (1955) in the small overlap region where direct comparison is possible.

For convenience in calculation, the change in free energy with pressure for pressures in both bars and atmospheres have also been tabulated.

Acknowledgments

The task of preparing these tables has been greatly simplified by the extensive use of the excellent compilations of K. K. Kelley of the Berkeley Station, U. S. Bureau of Mines and the adoption of the thermodynamic properties of the elements tabulated by D. R. Stull and G. C. Sinke of the Thermal Laboratory of the Dow Chemical Company.

Professor E. F. Westrum, Jr. of the University of Michigan kindly permitted us to use his unpublished data on the heat capacities and entropies of quartz, cristobalite, silica glass, and hematite. Dr. Guy Waddington of the Critical Tables Office, National Research Council offered several useful suggestions as to the methods of presentation of the data.

This work is part of a program being conducted by the U. S. Geological Survey partly on behalf of the Division of Research and the Division of Reactor Development, U. S. Atomic Energy Commission.

C

Reference States: for elements from Stull and Sinke (1956).

GRAPHITE

GFW. 12.011 grams

GFW. VOL. 5.297 cm^3

M.P. °K

ΔH melt cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ 251.2 cal.

TRANSITIONS IN REFERENCE STATES

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0	1.37 (±.01)	1.37				
400	251	2.09	1.47				
500	569	2.80	1.67				
600	947	3.49	1.92				
700	1370	4.14	2.19				
800	1830	4.75	2.47				
900	2318	5.33	2.76				
1000	2823	5.86	3.04				
1100	3344	6.35	3.31				
1200	3874	6.82	3.60				
1300	4428	7.26	3.86				
1400	4990	7.67	4.11				
1500	5562	8.07	4.37				
1600	6142	8.44	4.61				
1700	6728	8.80	4.85				
1800	7320	9.14	5.08				

Entire table from Stull, D. R. and Sinke, G. C., American Chemical Soc., Advances in Chemistry Series 18, (1956).

March 10, 1959

C

Reference State: graphite from Stull and Sinke (1956).

DIAMOND

GFW.	12.011 grams
GFW. VOL.	3.417 cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^{\circ}_{298.15}-H^{\circ}_{0}$	124.8 cal.

TRANSITIONS IN REFERENCE STATES

T TEMPERATURE °K	$H^{\circ}_{T}-H^{\circ}_{298.15}$ HEAT CONTENT CAL/GFW	S°_{T} ENTROPY CAL/DEG GFW	$-\frac{(F^{\circ}-H^{\circ}_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_{f} CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_{f} CAL/GFW	FROM OXIDES: HEAT ΔH°_{f} CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_{f} CAL/GFW
298.15	0 (1)	0.568 (2) (±.005)	0.568	453 (3) (±5)	693 (±10)		
400	200	1.138	0.638	402	783		
500	465	1.728	0.798	349	885		
600	810	2.358	1.008	316	995		
700	1225	2.998	1.249	308	1107		
800	1675	3.598	1.504	298	1220		
900	2150	4.158	1.769	285	1340		
1000	2645	4.678	2.033	275	1457		
1100	3155	5.158	2.290	264	1565		
1200	3675	5.618	2.556	254	1696		

(1) Kelley, K. K., U. S. Bur. Mines Bull 476, (1949).
(2) DeSorbo, W., J. Chem. Phy. 21, 876, (1953).
(3) Rossini, F. D. et al., Cir. 500, Nat. Bur. Stds. (1952).

March 10, 1959

S

SULFUR

Reference States: the standard states for sulfur adopted are orthorhombic solid 298° to 368.6°K, monoclinic solid 368.6° to 392°K, liquid 392° to 717.75°K, ideal diatomic gas 717.75°K to 1800°K. Note that the gas in equilibrium with liquid at 717.75°K is a mixture of S_6, S_8 and S_2.

GFW.	32.066 grams
GFW. VOL.	15.37 cm^3
M.P.	392.0 °K
ΔH melt	337 cal.
B.P.	717.75 °K
ΔH vap.	2300 cal.
$H^\circ_{298.15}-H^\circ_0$	1053 cal.

TRANSITIONS IN REFERENCE STATES

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG/GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	7.62 (±.04)	7.62				
368.6 orth	400	8.82	7.73				
368.6 mon	490	9.06	7.73				
392.0 mon	635	9.44	7.82				
392.0 liq	972	10.30	7.82				
400	1033	10.45	7.87				
500	1948	12.48	8.58				
600	2798	14.03	9.37				
700	3655	15.35	10.13				
717.75 liq	3825	15.58	10.25				
717.75 gas	17168	30.92	7.00				
800	17530	31.37	9.46				
900	17970	31.88	11.92				
1000	18400	32.34	13.94				
1100	18850	32.76	15.63				
1200	19290	33.15	17.08				
1300	19740	33.51	18.33				
1400	20190	33.84	19.42				
1500	20630	34.15	20.40				
1600	21080	34.44	21.27				
1700	21530	34.71	22.05				
1800	21980	34.97	22.76				

(1) Table modified from Stull and Sinke (1956) and Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).

March 10, 1959

Al_2O_3

CORUNDUM

Reference States: for elements from Stull and Sinke (1956); for corundum, crystals 298° to 2318°K

GFW. 101.96 grams

GFW. VOL. 25.57 cm^3

M.P. (3) 2318 °K

ΔH melt (3) 26000 cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ 2335 cal.

TRANSITIONS IN REFERENCE STATES

Al M.P. 932°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1) (4)	12.17 (1) (±.02)	12.17	-400400(2) (±300)	-378073 (±330)		
400	2151	18.35	12.97	-400533	-370416		
500	4576	23.75	14.60	-400465	-362878		
600	7193	28.52	16.53	-400301	-355379		
700	9939	32.75	18.55	-400102	-347907		
800	12777	36.54	20.57	-399921	-340456		
900	15684	39.96	22.53	-399731	-333044		
1000	18643	43.08	24.44	-404558	-325270		
1100	21663	45.94	26.25	-404195	-317351		
1200	24675	48.58	28.02	-403856	-309476		
1300	27735	51.03	29.70	-403480	-301658		
1400	30825	53.32	31.30	-403086	-293825		
1500	33915	55.45	32.84	-402703	-286062		
1600	37005	57.45	34.32	-402328	-278272		
1700	40045	59.29	35.73	-402011	-270520		
1800	43055	61.01	37.12	-401735	-262853		

(1) Furakawa, G. T., et al, J. Research NBS 57, 67, (1956).

(2) Mah, A. D., J. Phy. Chem. 61, 1572, (1957).
(3) Kelley, K. K., U. S. Bur. Mines Bull. 393, (1936).

(4) Shomate, C. H. and Naylor, B. F., J.A.C.S. 67, 72 (1945).

March 10, 1959

CaO

CALCIUM OXIDE (LIME)

Reference States: for elements Stull and Sinke (1956); for oxide, crystals 298° to 2843°K.

GFW.	56.08 grams
GFW. VOL.	16.77 cm^3
M.P.	(4) 2843 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713 °K
Ca_{II}	M.P.	1123 °K
Ca	B.P.	1765 °K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	9.5 (2) (±.20)	9.50	-151790 (3) (±300)	-144350 (±350)		
400	1100	12.67	9.92	-151711	-141814		
500	2230	15.19	10.73	-151627	-139350		
600	3400	17.32	11.65	-151549	-136898		
700	4600	19.17	12.60	-151486	-134472		
800	5820	20.80	13.52	-151710	-132006		
900	7040	22.23	14.41	-151741	-129542		
1000	8270	23.53	15.26	-151839	-127070		
1100	9520	24.72	16.07	-151990	-124576		
1200	10800	25.84	16.84	-154012	-121958		
1300	12110	26.88	17.56	-153870	-119296		
1400	13430	27.86	18.27	-153722	-116636		
1500	14760	28.78	18.94	-153567	-114005		
1600	16100	29.64	19.58	-153406	-111358		
1700	17440	30.46	20.20	-153247	-108746		
1800	18780	31.22	20.79	-188846	-105422		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Huber, E. J. and Holley, C. E., Jr., Jr., J. Phy. Chem. 60, 498, (1956).
(4) Ricker, R. W. and Osborn, E. F., J. Am. Ceram. Soc. 37, 137 (1954).

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CO_2

Reference States: for elements from Stull and Sinke (1956); for CO_2, ideal gas 298° to 1800°K.

GFW.	44.011 grams
GFW. VOL.	24342 cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	51.073(1) (±.05)	51.073	-94052(2) (±10)	-94259 (±30)		
400	956.9	53.824	51.432	-94069	-94317		
500	1985.3	56.116	52.145	-94090	-94374		
600	3085.1	58.119	52.997	-94123	-94440		
700	4243.7	59.904	53.842	-94165	-94480		
800	5451.3	61.516	54.702	-94216	-94526		
900	6699.9	62.986	55.541	-94269	-94558		
1000	7982.7	64.337	56.354	-94319	-94586		
1100	9293.9	65.587	57.138	-94367	-94622		
1200	10630	66.748	57.890	-94410	-94616		
1300	11986	67.835	58.615	-94464	-94656		
1400	13360	68.854	59.311	-94516	-94683		
1500	14748	69.812	59.980	-94571	-94682		
1600	16150	70.714	60.620	-94626	-94676		
1700	17563	71.571	61.240	-94681	-94681		
1800	18985	72.383	61.836	-94740	-94675		

(1) Calculated from Circular 564, National Bureau of Standards (1955).

(2) Coughlin, J. P., U. S. Bur. Mines Bull 542, (1954).

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CO

Reference States: for elements from Stull and Sinke (1956); for CO ideal gas 298° to 1600°K.

GFW.	28.011 grams
GFW. VOL.	24456. cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^o_{298.15}-H^o_0$	cal.

TRANSITIONS IN REFERENCE STATES

T TEMPERATURE °K	$H^o_T-H^o_{298.15}$ HEAT CONTENT CAL/GFW	S^o_T ENTROPY CAL/DEG GFW	$-\frac{(F^o-H^o_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH^o_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF^o_f CAL/GFW	FROM OXIDES: HEAT ΔH^o_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF^o_f CAL/GFW
298.15	0 (1)	47.30 (2) (±.02)	47.30	-26416(2) (±10)	-32773 (±50)		
400	711	49.35	47.57	-26318	-34996		
500	1418	50.93	48.09	-26294	-37171		
600	2137	52.24	48.68	-26330	-39346		
700	2874	53.37	49.26	-26415	-41501		
800	3628	54.38	49.85	-26510	-43664		
900	4400	55.29	50.40	-26634	-45793		
1000	5186	56.12	50.93	-26766	-47916		
1100	5985	56.88	51.44	-26907	-50038		
1200	6798	57.58	51.92	-27049	-52108		
1300	7619	58.24	52.38	-27210	-54204		
1400	8450	58.86	52.82	-27373	-56285		
1500	9291	59.44	53.25	-27540	-58344		
1600	10134	59.98	53.65	-27715	-60384		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Coughlin, J. P., U. S. Bur. Mines Bull. 542, (1954).

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CoO

Reference States: for elements from Stull and Sinke (1956); for cobaltous oxide, crystals 298° to 1800°K.

GFW.	74.94 grams
GFW. VOL.	11.5 cm^3
M.P.	(4) 2080 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Co_I - Co_{II} 720°K

Co_{II} Curie Temp. 1395°K

Co_{II} M.P. 1768°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-(F^\circ-H^\circ_{298.15})/T$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	12.66 (2) (±.08)	12.66	-57100 (3) (±300)	-51428 (±350)		
400	1290	16.38	13.16	-56794	-49536		
500	2570	19.24	14.10	-56537	-47752		
600	3860	21.59	15.16	-56324	-46021		
700	5160	23.59	16.22	-56144	-44311		
800	6470	25.34	17.25	-56032	-42620		
900	7790	26.90	18.24	-55915	-40963		
1000	9120	28.30	19.18	-55854	-39310		
1100	10460	29.58	20.07	-55862	-37658		
1200	11820	30.76	20.91	-55927	-35980		
1300	13210	31.87	21.71	-56065	-34330		
1400	14640	32.93	22.47	-56397	-32649		
1500	16100	33.94	23.21	-56332	-30962		
1600	17600	34.91	23.91	-56231	-29276		
1700	19140	35.84	24.58	-56092	-27588		
1800	20730	36.75	25.23	-59496	-25843		

(1) King, E. G. and Christensen, A. U., J.A.C.S. 80, 1800, (1958)
(2) King, E. C., J.A.C.S. 79, 2399, (1957).
(3) Boyle, B. J., King, E. G. and Conway, K. C., J.A.C.S. 76, 3835, (1954).
(4) Asanti, P. and Kohlmeyer, E. J., Zeit. Anorg. Chem. 265, 96, (1951).

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$Fe_{0.947}O$

WUSTITE

Reference States: for elements from Stull and Sinke (1956); for wustite, crystals 298° to 1650°K, liquid oxide 1650° to 1800°K.

GFW.	68.89 grams
GFW. VOL.	12.0 cm^3
M.P.	(1) 1650 °K
ΔH melt	(2) 7490 cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Fe (Curie Point)	1033°K
Fe_{I} - Fe_{II}	1183°K
Fe_{II} - Fe_{III}	1673°K
Fe_{III} M. P.	1812°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	13.74 (2) (±.20)	13.74	-63800(2) (±400)	-58760 (±450)		
400	1220	17.22	14.17	-63547	-57056		
500	2440	19.97	15.09	-63334	-55472		
600	3700	22.27	16.10	-63138	-53921		
700	4980	24.24	17.13	-62994	-52404		
800	6280	25.97	18.12	-62916	-50888		
900	7590	27.52	19.09	-62955	-49391		
1000	8920	28.92	20.00	-63164	-47870		
1100	10280	30.21	20.86	-63498	-46304		
1200	11670	31.42	21.70	-63678	-44744		
1300	13080	32.55	22.49	-63480	-43175		
1400	14520	33.62	23.25	-63275	-41631		
1500	15980	34.62	23.97	-63071	-40078		
1600	17460	35.58	24.67	-62870	-38552		
1650 cry	18210	36.04	25.00	-62764	-37793		
1650 liq	25700	40.58	25.00	-55264	-37793		
1700	26510	41.06	25.47	-55285	-37263		
1800	28140	42.00	26.37	-55001	-36215		

(1) Coughlin, J. P., King, E. G. and Bonnickson, K. R., J.A.C.S. 73, 3891 (1951).
(2) Humphrey, G. L., King, E. G. and Kelley, K. K., U. S. Bur Mines Rept. of Investigation 4870 (1952).

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Fe_2O_3

HEMATITE

Reference State: for elements Stull and Sinke (1956); for hematite crystals I 298° to 950°, crystals II 950° to 1050°, crystals III 1050° to 1800°K.

GFW. 159.70 grams

GFW. VOL. 30.30 cm^3

M.P. (4) 1895 °K

ΔH melt cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ 3718.9 cal.

TRANSITIONS IN REFERENCE STATES

Fe_I (Curie Point) 1033°K

Fe_I - Fe_{II} 1183°K

Fe_{II} - Fe_{III} 1673°K

Fe_{III} M.P. 1812°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE, FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	20.889(2) (±.05)	20.889	-196750(3) (±1100)	-177190 (±1200)		
400	2750	28.80	21.925	-196362	-170548		
500	5770	35.53	23.990	-195795	-164165		
600	9010	41.43	26.413	-195138	-157902		
700	12460	46.74	28.940	-194431	-151754		
800	16130	51.64	31.478	-193698	-145708		
900	20030	56.23	32.973	-193006	-139747		
950 I	22060	58.43	35.208	-192785	-136795		
950 II	22220	58.60	35.209	-192625	-136795		
1000	24020	60.44	36.420	-192635	-133860		
1050 II	25820	62.20	37.609	-192812	-130907		
1050 III	25820	62.20	37.609	-192812	-130907		
1100	27500	63.76	38.760	-193106	-127934		
1200	30870	66.69	40.965	-193427	-121984		
1300	34250	69.40	43.054	-192987	-116064		
1400	37650	71.92	45.027	-192579	-110184		
1500	41070	74.28	46.900	-192200	-104320		
1600	44540	76.52	48.682	-191819	- 98433		
1700	48100	78.68	50.386	-191744	- 92635		
1800	51880	80.84	52.018	-191204	- 86802		

(1) Coughlin, J. P., King. E. G. and Bonnickson, K. R., J.A.C.S. 73, 3891 (1951).
(2) Westrum, E. F., Jr., private communication 1958.
(3) Calculated from data in; Darken, L. S. and Gurry, R. W., J.A.C.S. 68, 799 (1946) and Humphrey, G. L., King. E. G. and Kelley, K. K., U. S. Bur. Mines Rept. of Invest. 4870 (1952).
(4) Muan, A. F., Jour. Amer. Ceramic Soc. 40, 420 (1957).

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Fe_3O_4

MAGNETITE

Reference States: for elements from Stull and Sinke (1956); for magnetite, crystals I 298 to 900° (Curie point), crystals II 900° to 1870°K; for oxides, this compilation.

GFW. 231.55 grams	
GFW. VOL. 44.53 cm^3	
M.P. (4) 1870 °K	
ΔH melt(4) 33,000 cal.	
B.P. °K	
ΔH vap. cal.	
$H^\circ_{298.15}-H^\circ_0$ cal.	

TRANSITIONS IN REFERENCE STATES

Fe_I	Curie point	1033°K
Fe_I - Fe_{II}		1183°K
Fe_{II} - Fe_{III}		1673°K
Fe_{III}	M.P.	1812°K
$Fe_{.947}O$	M.P.	1650°K
Fe_2O_3 I - II		950°K
Fe_2O_3 II - III		1050°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	35.00 (2)	35.00	-267400(3) (±500)	-242806 (±700)	- 6850 (±1500)	-6856 (±1500)
400	3990	46.48	36.50	-266773	-234472	- 6864	-6868
500	8320	56.12	39.48	-265939	-226495	- 6772	-6858
600	13060	64.75	42.98	-264884	-218704	- 6608	-6881
700	18340	72.88	46.68	-263524	-211127	- 6099	-6969
800	24260	80.77	50.44	-261810	-203744	- 5196	-7148
900 I	30550	88.18	54.24	-260130	-196597	- 4169	-7459
900 II	30550	88.18	54.24	-260130	-196597	- 4169	-7459
1000	35350	93.24	57.89	-260550	-189520	- 4751	-7790
1100	40150	97.81	61.31	-261467	-182315	- 4863	-8077
1200	44950	101.99	64.53	-261992	-175096	- 4887	-8368
1300	49750	105.83	67.56	-261388	-167898	- 4921	-8659
1400	54550	109.39	70.43	-260860	-160748	- 5006	-8933
1500	59350	112.70	73.13	-260403	-153610	- 5132	-9212
1600	64150	115.80	75.71	-260018	-146472	- 5329	-9487
1700	68950	118.71	78.15	-260225	-139407	-13196	-9509
1800	73750	121.45	80.48	-260062	-132292	-13857	-9275

(1) Coughlin, J. P., King, E. G. and Bonnickson, K. R., J.A.C.S. 73, 3891, (1951).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Humphrey, G. L., King, E. G. and Kelley, K. K., U. S. Bur. Mines Rept. of Investigations 4870, (1952).
(4) Darken, L. S. and Gurry, R. W., J.A.C.S. 68, 799, (1946).

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H_2O

WATER

Reference States: for elements from Stull and Sinke (1956); for water, liquid 298° to 373.15°; ideal gas 373.15° to 1800°K.

GFW.	18.016 grams
GFW. VOL.	18.069 cm^3
M.P.	273.15 °K
ΔH melt	(3) 1436 cal.
B.P.	373.15 °K
ΔH vap.	(4) 9717 cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

T	$H^\circ_T-H^\circ_{298.15}$	S°_T	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$	FORMATION FROM REFERENCE STATE			
				FROM ELEMENTS		FROM OXIDES	
TEMPERATURE °K	HEAT CONTENT CAL / GFW	ENTROPY CAL/DEG GFW	FREE ENERGY FUNCTION CAL/DEG GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0(1)(2)	16.75 (3) (±.03)	16.75	-68317 (4) (±10)	-56700 (±20)		
373.15	1352	20.79	17.17	-67749	-53826		
373.15	11069	46.830	17.167	-58032	-53826		
400	11288	47.482	19.263	-58097	-53566		
500	12118	49.333	25.096	-58332	-52407		
600	12972	50.890	29.270	-58554	-51202		
700	13853	52.248	32.458	-58766	-49962		
800	14763	53.462	35.009	-58960	-48692		
900	15703	54.568	37.120	-59138	-47392		
1000	16673	55.590	38.917	-59300	-46084		
1100	17673	56.543	40.477	-59446	-44746		
1200	18703	57.439	41.853	-59578	-43397		
1300	19761	58.286	43.085	-59695	-42057		
1400	20846	59.090	44.200	-59799	-40702		
1500	21957	59.857	45.219	-59891	-39328		
1600	23092	60.589	46.156	-59972	-37959		
1700	24249	61.290	47.026	-60042	-36588		
1800	25426	61.963	47.837	-60105	-35224		

(1) Liquid water, Kelley, K. K., U. S. Bur. Mines Bull 476, (1949).
(2) Hilsenrath, J. et al, Circular 564, Nat. Bur. Stds., (1955).
(3) Giauque, W. F. and Stout, J. W., J.A.C.S. 58, 1144, (1936).
(4) Rossini, F. D. et al, Circular 500, Nat. Bur. Stds. (1952).

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MgO

PERICLASE

Reference States: for elements from Stull and Sinke (1956); for periclase, crystals 298° to 3073°K.

GFW.	40.32 grams
GFW. VOL.	11.25 cm^3
M.P.	(4) 3073 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Mg M. P. 923°K

Mg B. P. 1390°K

T	$H^\circ_T-H^\circ_{298.15}$	S°_T	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$	Formation from Reference State: From Elements		From Oxides	
TEMPERATURE °K	HEAT CONTENT CAL/GFW	ENTROPY CAL/DEG GFW	FREE ENERGY FUNCTION CAL/DEG GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	6.50 (2) (±.15)	6.50	-143800(3) (±90)	-136103 (±150)		
400	965	9.28	6.87	-143817	-133468		
500	1975	11.53	7.58	-143808	-130875		
600	3020	13.44	8.41	-143808	-128299		
700	4100	15.10	9.24	-143804	-125705		
800	5225	16.60	10.07	-143797	-123120		
900	6390	17.97	10.87	-143805	-120544		
1000	7580	19.23	11.65	-145944	-117780		
1100	8800	20.39	12.39	-145942	-114947		
1200	10050	21.48	13.10	-145947	-112132		
1300	11310	22.48	13.78	-145965	-109324		
1400	12570	23.42	14.44	-176721	-106280		
1500	13830	24.29	15.07	-176392	-101290		
1600	15090	25.10	15.67	-176071	- 96280		
1700	16350	25.86	16.24	-175742	- 91287		
1800	17610	26.58	16.80	-175426	- 86344		
1900	18870	27.26	17.33	-175114	- 81366		
2000	20130	27.91	17.84	-174804	- 76460		
2100	21390	28.52	18.33	-174486	- 71539		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Coughlin, J. P., U. S. Bur. Mines Bull. 542, (1954).
(4) Ricker, R. W. and Osborn, E. F., J. Am. Ceram. Soc. 37, 134, (1954).

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$Mg(OH)_2$

BRUCITE

Reference States: for elements, from Stull and Sinke (1956); for brucite, crystals 298° to 600°K, for oxides, this compilation.

GFW.	58.336 grams
GFW. VOL.	24.64 cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

H_2O B.P. 373.15°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	15.09 (2) (±.05)	15.09	-221917 (±500)	-200170 (±550)	-9800 (3) (±400)	-7367 (±450)
400	1890	20.53	15.80	-222076	-192701	-20162	-5667
500	3890	24.99	17.21	-222143	-185352	-20003	-2070
600	6080	28.98	18.85	-222071	-178003	-19709	+1498

(1) Kelley, K. K., U. S. Bur. of Mines Bull. 476, (1949).
(2) Giauque, W. F. and Archibald, R. C., J.A.C.S. 59, 561, (1937).
(3) Taylor, L. S. and Wells, K., J. Res. Nat. Bur. Stds. 21, 133 (1938).

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MnO

MANGANOSITE

Reference States: for elements from Stull and Sinke (1956); for manganosite, crystals 298° to 1800°K.

GFW.	70.94 grams
GFW. VOL.	13.22 cm^3
M.P.	(4) 2123 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^o_{298.15}-H^o_0$	cal.

TRANSITIONS IN REFERENCE STATES

Mn_I - Mn_{II}	1000°K
Mn_{II} - Mn_{III}	1374°K
Mn_{III} - Mn_{IV}	1410°K
Mn_{IV} M.P.	1517°K

T TEMPERATURE °K	$H^o_T-H^o_{298.15}$ HEAT CONTENT CAL/GFW	S^o_T ENTROPY CAL/DEG GFW	$-\frac{(F^o-H^o_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH^o_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF^o_f CAL/GFW	FROM OXIDES: HEAT ΔH^o_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF^o_f CAL/GFW
298.15	0 (1)	14.27 (2) (±.10)	14.27	-92040 (3) (±110)	-86708 (±150)		
400	1130	17.53	14.70	-91935	-84898		
500	2280	20.09	15.53	-91847	-83148		
600	3470	22.26	16.48	-91774	-81423		
700	4680	24.13	17.44	-91724	-79699		
800	5900	25.76	18.38	-91702	-77980		
900	7150	27.23	19.29	-91700	-76272		
1000	8430	28.58	20.15	-92244	-74540		
1100	9750	29.83	20.97	-92272	-72762		
1200	11100	31.01	21.76	-92277	-70992		
1300	12470	32.10	22.51	-92265	-69218		
1400	13840	33.12	23.23	-92837	-67435		
1500	15210	34.07	23.93	-93462	-65602		
1600	16590	34.96	24.59	-97121	-63352		
1700	17970	35.79	25.22	-97282	-61236		
1800	19350	36.58	25.83	-97446	-59109		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Todd, S. S. and Bonnickson, K. R., J.A.C.S. 73, 3894, (1951).
(3) Coughlin, J. P., U. S. Bur. Mines. Bull. 542, (1954).
(4) Glasser, F. P., Am. J. Sci. 256, 398, (1958).

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MnO_2

PYROLUSITE

Reference States: for elements from Stull and Sinke (1956); for pyrolusite, crystals 298° to 900°K.

GFW.	86.94 grams
GFW. VOL.	16.5 cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

$Mn_I - Mn_{II}$ 1000°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	12.7 (2) (±.10)	12.70	-124450(3) (±200)	-111343 (±250)		
400	1445	16.86	13.25	-124392	-106866		
500	3020	20.37	14.33	-124244	-102500		
600	4685	23.40	15.59	-124074	- 98170		
700	6415	26.06	16.90	-123892	- 93867		
800	8185	28.43	18.20	-123720	- 89586		
900	9990	30.58	19.48	-123569	- 85354		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., and Moore, G. E., J.A.C.S. 65, 782, (1943).
(3) Coughlin, J. P., U. S. Bur. Mines Bull. 542, (1954).

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NiO

BUNSENITE

Reference States: for elements, from Stull and Sinke (1956); for bunsenite, crystals 298° to 1800°K.

GFW.	74.71 grams
GFW. VOL.	10.97 cm^3
M.P.	(4) 2230 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Ni M.P. 1728°K

Ni Curie Point 630°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL / GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	9.08 (2) (±.04)	9.08	-57300 (3) (±100)	-50572 (±150)		
400	1165	12.43	9.52	-57158	-48288		
500	2535	15.47	10.40	-56865	-46092		
525	2940	16.26	10.66	-56744	-45558		
565	3495	17.28	11.09	-56665	-44531		
600	3940	18.05	11.48	-56629	-43971		
700	5220	20.02	12.56	-56514	-41872		
800	6500	21.73	13.61	-56382	-39796		
900	7780	23.24	14.60	-56265	-37725		
1000	9070	24.60	15.53	-56154	-35670		
1100	10370	25.84	16.41	-56047	-33622		
1200	11700	26.99	17.24	-55937	-31584		
1300	13060	28.08	18.03	-55825	-29552		
1400	14450	29.11	18.79	-55717	-27543		
1500	15860	30.08	19.51	-55612	-25538		
1600	17300	31.01	20.20	-55501	-23540		
1700	18770	31.90	20.86	-55372	-21532		
1800	20260	32.76	21.50	-59446	-19383		

(1) King, E. G. and Christensen, AU, J.A.C.S. 80, 1800 (1958).
(2) King, E. G., J.A.C.S. 79, 2399, (1957).
(3) Boyle, B. J., King, E. G. and Conway, K. C., J.A.C.S. 76, 3835, (1954).
(4) Brewer, L., Chem. Reviews 52, (1953).

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SiO_2

QUARTZ

Reference States: for elements from Stull and Sinke (1956); for quartz, α-quartz 298° to 848°K, β-quartz 848° to 1900°K.

GFW. 60.09 grams

GFW. VOL. 22.692 cm^3

M.P. °K

ΔH melt cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ 1652.7 cal.

TRANSITIONS IN REFERENCE STATES

Si M.P. 1683°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-(F^\circ-H^\circ_{298.15})/T$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	9.88 (2) (±.01)	9.88	-210168(3) (±400)	-197151 (±450)		
400	1200	13.33	10.33	-210209	-192688		
500	2560	16.36	11.24	-210132	-188318		
600	4040	19.05	12.32	-209977	-183966		
700	5630	21.50	13.46	-209755	-179648		
800	7320	23.76	14.61	-209473	-175376		
848 α	8170	24.79	15.16	-209288	-173339		
848 β	8460	25.13	15.16	-208998	-173339		
900	9300	26.09	15.76	-208922	-171144		
1000	10920	27.80	16.88	-208755	-166948		
1100	12570	29.37	17.94	-208583	-162769		
1140	13247	29.97	18.35	-208503	-161102		
1200	14250	30.83	18.96	-208402	-158616		
1300	15940	32.18	19.92	-208228	-154476		
1400	17640	33.44	20.84	-208062	-150359		
1500	19360	34.63	21.72	-207893	-146253		
1600	21100	35.76	22.57	-207720	-142136		
1700	22860	36.82	23.37	-218632	-137918		
1800	24630	37.84	24.16	-218451	-133200		
1900	26420	38.81	24.90	-218256	-128430		

(1) Kelley, K. K., U. S. Bur. Mines. Bull. 476, (1949).
(2) Westrum, E. F., Jr., Private communication, Nov. 1958.
(3) Calculated from heat of formation of cristobalite and high temperature data for quartz and tridymite.
(4) Frondel, C. and Hurlburt, C. S., J. Chem. Phys. 23, 1215 (1955).

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SiO_2

CRISTOBALITE

Reference States: for elements from Stull and Sinke (1956); for cristobalite, α cristobalite 298° to 523°K, β - cristobalite 523° to 1983°K.

GFW.	60.09 grams
GFW. VOL.	25.8 cm^3
M.P.	(4) 1996 °K
ΔH melt	(4) 1835 cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	1682.5 cal.

TRANSITIONS IN REFERENCE STATES

Si M.P. 1683°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL / GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	10.38 (2) (±.01)	10.38	-209450 (3) (±250)	-196582 (±300)		
400	1210	13.86	10.84	-209481	-192174		
500	2560	16.86	11.74	-209414	-187850		
523 α	2910	17.54	11.97	-209362	-186856		
523 β	3110	17.92	11.97	-209162	-186856		
600	4310	20.06	12.88	-208989	-183584		
700	5850	22.43	14.07	-208817	-179357		
800	7460	24.58	15.26	-208615	-175178		
900	9090	26.50	16.40	-208414	-171002		
1000	10730	28.23	17.50	-208227	-166850		
1100	12390	29.81	18.55	-208045	-162722		
1200	14080	31.28	19.55	-207854	-158606		
1300	15790	32.65	20.50	-207660	-154512		
1400	17510	33.92	21.41	-207474	-150440		
1500	19240	35.12	22.29	-207295	-146390		
1600	20990	36.25	23.13	-207112	-142314		
1700	22750	37.31	23.93	-218024	-138152		
1743	23513	37.75	24.26	-217942	-136122		
1800	24530	38.33	24.70	-217833	-133454		
1900	26320	39.30	25.45	-217638	-128751		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Westrum, E. F., Jr., Private Communication, Nov. 1958.
(3) Humphrey, G. L. and King, E. G., J.A.C.S. 74, 2041 (1952).
(4) Kracek, F. C., J.A.C.S. 52, 1436, (1930).

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SiO_2

TRIDYMITE

Reference States: for elements from Stull and Sinke (1956); for tridymite, crystals of α tridymite 298° to 390°K, β - tridymite 390° to 1900°K.

GFW.	60.09 grams
GFW. VOL.	27.3 cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Si M.P. 1683°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG. GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	10.50 (2) (±.10)	10.50	-209415 (3) (±400)	-196583 (±450)		
350	585	12.31	10.64	-209453	-194323		
390 α	1085	13.66	10.88	-209446	-192610		
390 β	1125	13.76	10.88	-209406	-192610		
400	1270	14.13	10.96	-209386	-192187		
500	2710	17.34	11.92	-209229	-187905		
600	4170	20.00	13.05	-209094	-183651		
700	5710	22.37	14.21	-208922	-179420		
800	7320	24.52	15.37	-208720	-175231		
900	8950	26.44	16.50	-208519	-171057		
1000	10590	28.17	17.58	-208332	-166895		
1100	12250	29.75	18.61	-208150	-162753		
1140	12928	30.35	19.01	-208015	-161102		
1200	13940	31.22	19.60	-207959	-158631		
1300	15650	32.59	20.55	-207765	-154542		
1400	17370	33.87	21.46	-207579	-150475		
1500	19100	35.06	22.33	-207400	-146415		
1600	20850	36.19	23.16	-207217	-142327		
1700	22610	37.25	23.95	-218129	-138151		
1743	23373	37.69	24.28	-218047	-136122		
1800	24390	38.27	24.72	-217938	-133455		
1900	26180	39.24	25.46	-217733	-128741		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Calculated from data in, Tuttle, O. F. and England, J. L., Carnegie Inst. of Washington Yearbook 52, 61, (1953).
(3) Calculated from cristobalite data and tridymite-cristobalite transition temperature 1743°K.

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SO_2

Reference States: for elements from Stull and Sinke (1956); for SO_2 ideal gas at one atmosphere 298° to 1500°K.

GFW.	64.066 grams
GFW. VOL.	23892 cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	2519 cal.

TRANSITIONS IN REFERENCE STATES

S_{rhomb} - S_{mon}		368.6°K
S_{mon}	M.P.	392°K
S	B.P.	717.75°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	59.29 (1) (±.02)	59.29	-70947 (1) (±50)	-71740 (±100)		
400	1017	62.22	59.68	-71686	-71951		
500	2091	64.62	60.44	-72258	-71957		
600	3241	66.71	61.31	-72713	-71853		
700	4439	68.55	62.21	-73150	-71675		
800	5673	70.20	63.11	-86589	-72555		
900	6940	71.69	63.98	-86576	-70803		
1000	8231	73.05	64.82	-86543	-69047		
1100	9548	74.31	65.63	-86514	-67306		
1200	10873	75.46	66.40	-86478	-65547		
1300	12223	76.54	67.13	-86434	-63810		
1400	13581	77.54	67.84	-86390	-62085		
1500	14941	78.48	68.52	-86341	-60342		

(1) Evans, W. H. and Wagman, D. D., J. Res. N.B.S. 49, 141 (1952).

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SO_3

Reference States: for elements from Stull and Sinke (1956); for SO_3, ideal gas 298° to 1500°K.

GFW.	80.066 grams
GFW. VOL.	cm^3
M.P.	290.0 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	2773 cal.

TRANSITIONS IN REFERENCE STATES

S_{rhomb} - S_{mon}		368.6° K
S_{mon}	M.P.	392° K
S	B.P.	717.75°K

T	$H^\circ_T-H^\circ_{298.15}$	S°_T	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$	FORMATION FROM REFERENCE STATE			
				FROM ELEMENTS		FROM OXIDES	
TEMPERATURE °K	HEAT CONTENT CAL/GFW	ENTROPY CAL/DEG GFW	FREE ENERGY FUNCTION CAL/DEG GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0(1)(2)	61.20 (3) (±1.0)	61.20	-94470 (2) (±70)	-88526 (±100)		
400	1330	65.03	61.70	- 95257	-86422		
500	2830	68.37	62.71	- 95769	-84160		
600	4450	71.32	63.90	- 96132	-81804		
700	6190	74.00	65.16	- 96416	-79399		
800	8010	76.43	66.42	-109668	-78070		
900	9900	78.65	67.65	-109438	-74130		
1000	11860	80.72	68.86	-109151	-70220		
1100	13860	82.62	70.02	-108858	-66343		
1200	15900	84.40	71.15	-108531	-62478		
1300	17976	86.05	72.22	-108189	-58662		
1400	20090	87.61	73.26	-107821	-54871		
1500	22233	89.07	74.25	-107425	-51068		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Evans, W. H. and Wagman, D. C., J. Research N.B.S. 49, 141, (1952).
(3) Kelley, K. K., U. S. Bur. of Mines Bull. 477, (1950).

March 10, 1959

ThO_2

THORIANITE

Reference States: for elements from Stull and Sinke (1956); for thorianite, crystals 298° to 1800°K.

GFW.	264.05 grams
GFW. VOL.	26.38 cm^3
M.P.	(4) 3573 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	2524.4 cal.

TRANSITIONS IN REFERENCE STATES

Th_I - Th_{II}	1673°K
Th_{II} M.P.	1968°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	15.59(2) (±.02)	15.59	-293200(3) (±400)	-279431 (±500)		
400	1600	20.20	16.20	-293013	-274752		
500	3210	23.79	17.37	-292854	-270205		
600	4890	26.85	18.70	-292699	-265690		
700	6620	29.51	20.05	-292557	-261196		
800	8390	31.88	21.39	-292445	-256728		
900	10200	34.01	22.68	-292359	-252277		
1000	12050	35.96	23.91	-292287	-247830		
1100	13940	37.76	25.09	-292225	-243381		
1200	15860	39.43	26.21	-292194	-238924		
1300	17800	40.98	27.29	-292200	-234518		
1400	19760	42.43	28.32	-292234	-230074		
1500	21740	43.80	29.31	-292295	-225640		
1600	23740	45.09	30.25	-292402	-221168		
1700	25750	46.31	31.16	-293154	-216700		
1800	27770	47.46	32.03	-293123	-212200		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Osborne, D. W. and Westrum, E. F., Jr., J. Chem. Phy. 21, 1884 (1953).
(3) Huber, E. J. and Holley, C. E. Jr., J.A.C.S. 74, 3406 (1952).
(4) Lambertson, W. A., Mueller, M. H. and Gunzel, E. H., J. Am. Ceram. Soc. 36, 399 (1953).

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TiO_2

RUTILE

Reference States: for elements from Stull and Sinke (1956); for rutile, crystals 298° to 2103°K.

GFW.	79.90 grams
GFW. VOL.	18.80 cm^3
M.P. (4)	2103 °K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Ti_I - Ti_{II}	1155°K
Ti_{II} M.P.	1950°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	12.01 (2) (±.07)	12.01	-225760(3) (±100)	-212543 (±150)		
400	1540	16.44	12.59	-225572	-208044		
500	3100	19.92	13.72	-225394	-203685		
600	4735	22.90	15.01	-225184	-199366		
700	6440	25.52	16.32	-224947	-195072		
800	8160	27.82	17.62	-224740	-190824		
900	9900	29.87	18.87	-224539	-186592		
1000	11650	31.71	20.06	-224357	-182380		
1100	13420	33.40	21.20	-224180	-178196		
1200	15200	34.95	22.28	-224964	-173980		
1300	17000	36.39	23.31	-224800	-169756		
1400	18820	37.74	24.30	-224634	-165532		
1500	20660	39.01	25.24	-224465	-161335		
1600	22540	40.22	26.13	-224272	-157104		
1700	24440	41.37	26.99	-224074	-152915		
1800	26340	42.46	27.83	-223903	-148738		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Shomate, C. H., J.A.C.S. 69, 218 (1947).
(3) Mah, A. D. et al, U. S. Bur. Mines Rept. of Investigations 5316, (1957).
(4) De Vries, R. C., Roy, R. and Osborn, E. F., J. Am. Ceram. Soc. 38, 165, (1955).

March 10, 1959

UO_2

URANINITE

Reference States: for elements from Stull and Sinke (1956); for Uraninite, crystals 298° to 1500°K.

GFW.	270.07 grams
GFW. VOL.	24.62 cm^3
M.P.	(4) 3148°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

$U_I - U_{II}$	941°K
$U_{II} - U_{III}$	1047°K
U_{III} M.P.	1406°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	18.63 (2) (±.10)	18.63	-259200(3) (±600)	-246556 (±700)		
400	1680	23.47	19.27	-258943	-242272		
500	3470	27.46	20.52	-258614	-238140		
600	5340	30.86	21.96	-258289	-234066		
700	7280	33.85	23.45	-257987	-230059		
800	9250	36.48	24.92	-257755	-226080		
900	11250	38.83	26.33	-257619	-222129		
1000	13280	40.97	27.69	-258157	-218150		
1100	15340	42.94	28.99	-258985	-214111		
1200	17420	44.75	30.23	-258664	-210036		
1300	19510	46.42	31.41	-258350	-206017		
1400	21620	47.98	32.54	-258014	-201996		
1500	23750	49.45	33.62	-261370	-197805		

(1) Moore, G. E. and Kelley, K. K., J.A.C.S. 69, 2105, (1947).
(2) Jones, Wm., Gordon, J., and Long, E. A., J. Chem. Phy. 20, 695, (1952).
(3) Huber, E. J. and Holley, C. E. Jr., J.A.C.S. 74, 3406, (1952).
(4) Lambertson, W. A., Mueller, M. H., and Gunzel, E. H., J. Am. Ceram. Soc. 36, 399, (1953).

March 10, 1959

NaCl

HALITE

Reference States: for elements from Stull and Sinke (1956); for halite, crystals 298° to 1073°K, liquid 1073° to 1738°K.

GFW.	58.448 grams
GFW. VOL.	27.01 cm^3
M.P.	(1) 1073 °K
ΔH melt	(1) 6850 cal.
B.P.	(4) 1738 °K
ΔH vap.	(4) 40808 cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Na M.P. 371°K

Na B.P. 1163°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	17.3 (2) (±.3)	17.30	-98230 (3) (±200)	-91803 (±250)		
400	1240	20.88	17.78	-98767	-89570		
500	2510	23.71	18.69	-98665	-87285		
600	3830	26.12	19.74	-98503	-85024		
700	5190	28.21	20.80	-98284	-82802		
800	6590	30.08	21.84	-98024	-80598		
900	8020	31.76	22.85	-97729	-78430		
1000	9480	33.30	23.82	-97405	-76310		
1073 cry.	10580	34.36	24.50	-97141	-74474		
1073 liq.	17430	40.74	24.50	-90291	-74474		
1100	17860	41.14	24.90	-90169	-74382		
1200	19460	42.53	26.31	-113106	-72538		
1300	21060	43.81	27.61	-112455	-69201		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Rossini, F. D. et al, Circular 500, Nat. Bur. Stds. (1952).
(4) Kelley, K. K., U. S. Bur. Mines Bull. 383, (1935).

March 10, 1959

KCl

SYLVITE

Reference States: for elements from Stull and Sinke (1956); for sylvite, crystals 298° to 1043°K, liquid 1043° to 1680°K.

GFW.	74.557 grams
GFW. VOL.	37.532 cm^3
M.P.	(1) 1043 °K
ΔH melt	(1) 6100 cal.
B.P.	(4) 1680 °K
ΔH vap.	(4) 38840 cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

K	M.P.	336.4 °K
K	B.P.	1039 °K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$\frac{-(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	19.76 (2) (±.07)	19.76	-104180 (3) (±200)	-97539 (±250)		
400	1260	23.40	20.25	-104666	-95176		
500	2520	26.21	21.17	-104576	-92810		
600	3810	28.56	22.21	-104447	-90470		
700	5150	30.62	23.26	-104262	-88150		
800	6550	32.49	24.30	-104016	-85860		
900	8000	34.20	25.31	-103724	-83615		
1000	9500	35.78	26.28	-103392	-81400		
1043 cry	10150	36.42	26.69	-122401	-80441		
1043 liq	16250	42.27	26.69	-116301	-80441		
1100	17160	43.12	27.52	-115931	-78572		
1200	18760	44.51	28.88	-115277	-75200		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Rossini, F. D. et al, Circular 500, Nat. Bur. Stds. (1952).
(4) Kelley, K. K., U. S. Bur. Mines Bull. 383, (1935).

March 10, 1959

MgF_2

SELLAITE

Reference States: for elements, Stull and Sinke (1956); for sellaite, crystals 298° to 1536°K, liquid 1536° to 1800°K.

GFW. 62.32 grams

GFW. VOL. 19.62 cm^3

M.P. (1) 1536 °K

ΔH melt (1) 13,900 cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ cal.

TRANSITIONS IN REFERENCE STATES

Mg M.P. 923°K

Mg B.P. 1390°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	13.68 (2) (±.07)	13.68	-263500(3) (±300)	-250805 (±350)		
400	1645	18.42	14.31	-263258	-246500		
500	3320	22.15	15.51	-263024	-242335		
600	5080	25.36	16.89	-262758	-238228		
700	6890	28.15	18.31	-262488	-234156		
800	8720	30.60	19.70	-262240	-230132		
900	10590	32.80	21.03	-262008	-226132		
1000	12510	34.82	22.31	-263882	-221980		
1100	14450	36.67	23.53	-263632	-217795		
1200	16430	38.39	24.70	-263373	-213640		
1300	18440	40.00	25.82	-263109	-209511		
1400	20460	41.50	26.89	-293575	-205176		
1500	22490	42.90	27.91	-292944	-198895		
1536 cry	23220	43.38	28.26	-292360	-197237		
1536 liq	37120	52.43	28.26	-278460	-197237		
1600	38560	53.35	29.25	-278279	-193244		
1700	40820	54.72	30.71	-277420	-187935		
1800	43080	56.01	32.08	-276573	-182698		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Todd, S. S., J. A. C. S. 71, 4115, (1949).
(3) Rossini, F. D. et. al, Circular 500, U. S. Nat. Bur. Stds. (1952).

March 10, 1959

CaF_2

FLUORITE

Reference States: for elements, Stull and Sinke (1956); for fluorite, crystals I 298° to 1424°K, crystals II 1424° to 1691°K, liquid 1691° to 1800°K.

GFW.	78.08		grams
GFW. VOL.	24.55		cm^3
M.P.	(1)	1691	°K
ΔH melt	(1)	7100	cal.
B.P.			°K
ΔH vap.			cal.
$H^\circ_{298.15}-H^\circ_0$			cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Ca	B.P.	1765°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	16.46 (2) (±.08)	16.46	-290300(3) (±400)	-277796 (±450)		
400	1755	21.52	17.13	-289987	-273564		
500	3540	25.50	18.42	-289688	-269500		
600	5400	28.89	19.89	-289372	-265496		
700	7320	31.85	21.39	-289050	-261537		
800	9280	34.47	22.87	-288998	-257604		
900	11300	36.84	24.28	-288694	-253679		
1000	13380	39.04	25.66	-288407	-249820		
1100	15550	41.10	26.96	-288110	-245959		
1200	17850	43.10	28.22	-289578	-242012		
1300	20230	45.01	29.45	-288834	-238105		
1400	22680	46.82	30.62	-288026	-234202		
1424 I	23280	47.25	30.90	-287821	-233297		
1424 II	24420	48.05	30.90	-286681	-233297		
1500	26660	49.58	31.81	-285689	-230480		
1600	29620	51.49	32.98	-284374	-226844		
1691 cry	32350	53.15	34.02	-283146	-223590		
1691 liq	39450	57.35	34.02	-276046	-223590		
1700	39670	57.48	34.14	-275975	-223303		
1800	42050	58.84	35.48	-311000	-219524		

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Todd, S. S., J. A. C. S. 71, 4115, (1949).
(3) Rossini, F. D. et al, Circular 500, U. S. Nat. Bur. Stds., (1952).

March 10, 1959

$CaCO_3$

CALCITE

Reference States: for elements Stull and Sinke (1956); for calcite crystals 298° to 1200°K; for oxides this compilation. Note, at about 1167°K the partial pressure of CO_2 in equilibrium with calcite reaches one atmosphere.

GFW.	100.09	grams
GFW. VOL.	36.93	cm^3
M.P.		°K
ΔH melt		cal.
B.P.		°K
ΔH vap.		cal.
$H^\circ_{298.15}-H^\circ_0$		cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II} 713°K

Ca_{II} M.P. 1123°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	22.20 (2) (±.20)	22.20	-288342 (±350)	-269667 (±400)	-42500(3) (±100)	-31058 (200)
400	2122	28.30	23.00	-288214	-263290	-42434	-27159
500	4442	33.47	24.59	-287988	-257087	-42271	-23363
600	6966	38.07	26.46	-287689	-250929	-42017	-19591
700	9671	42.23	28.41	-287322	-244830	-41671	-15878
800	12528	46.05	30.39	-287168	-238766	-41242	-12234
900	15491	49.54	32.33	-286756	-232740	-40746	- 8640
1000	18517	52.72	34.20	-286392	-226742	-40234	- 5086
1100	21583	55.64	36.01	-286087	-220786	-39730	- 1588

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949) and Kobayashi, K. Sci. Rept. Tohoku Univ. 1st Series XXXV 101, (1951).

(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).

(3) Rossini, F. D. et al., U. S. Bur. Stds. Cir. 500, (1952).

March 10, 1959

$MgCO_3$

MAGNESITE

Reference States: for elements from Stull and Sinke (1956); for magnesite, crystals 298° to 1100°K; for oxides this compilation. At about 680°K the partial pressure of CO_2 in equilibrium with magnesite reaches 1 atmosphere.

GFW. 84.33	grams
GFW. VOL. 28.02	cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Mg M.P. 923°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	15.7 (2) (±.20)	15.70	-266052 (±400)	-246077 (±450)	-28200 (3) (±300)	-15715 (±360)
400	2028	21.52	16.45	-265979	-239244	-28093	-11459
500	4301	26.58	17.98	-265757	-232582	-27859	- 7333
600	6786	31.11	19.80	-265447	-225978	-27516	- 3242
700	9449	35.21	21.71	-265064	-219425	-27095	+ 760
800	12269	38.97	23.63	-264621	-212932	-26608	+ 4714
900	15217	42.44	25.53	-264146	-206508	-26072	+ 8594
1000	18243	45.63	27.39	-265783	-199952	-25520	+12414
1100	21308	48.55	29.18	-265296	-193397	-24987	+16172

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Anderson, C. T., J. A. C. S. 56, 849, (1934).
(3) Robie, R. A., Ph.D. Thesis U. of Chicago (1957).

March 10, 1959

$CaMg(CO_3)_2$

DOLOMITE

Reference States: for elements from Stull and Sinke (1956); for dolomite, crystals 298° to 1000°K; for oxides this compilation. At about 750 °K the partial pressure of CO_2 in equilibrium with dolomite reaches 1 atmosphere.

GFW. 184.42 grams	
GFW. VOL. 64.33 cm^3	
M.P. °K	
ΔH melt cal.	
B.P. °K	
ΔH vap. cal.	
$H^\circ_{298.15}-H^\circ_0$ 6210 cal.	

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Mg	M.P.	923°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	37.09 (2) (±.07)	37.09	-557567 (±800)	-518676 (±900)	-73873(2) (±400)	-49706 (±500)
400	4150	49.01	38.64	-557367	-505383	-73701	-41467
500	8743	59.24	41.75	-556920	-492427	-73305	-33454
600	13752	68.37	45.45	-556310	-479591	-72707	-25514
700	19121	76.63	49.31	-555559	-466861	-71939	-17723
800	24797	84.21	53.21	-554963	-454223	-71024	-10045
900	30709	91.17	57.05	-554158	-441692	-70074	- 2492
1000	36760	97.53	60.77	-555349	-429047	-68928	+ 4975

(1) Heat capacity above 298°K estimated.
(2) Robie, R. A., PhD. Thesis, U. of Chicago, (1957).

March 10, 1959

$CaSO_4$

ANHYDRITE

Reference States: for elements from Stull and Sinke (1956); for anhydrite, crystals I 298° to 1466°K, crystals II 1466° to 1723°K, liquid 1723° to 2000°K; for oxides, this compilation.

GFW. 136.146 grams	
GFW. VOL. 45.95 cm^3	
M.P. (4) 1723 °K	
ΔH melt (5) 6700 cal.	
B.P. °K	
ΔH vap. cal.	
$H^\circ_{298.15}-H^\circ_0$ cal.	

TRANSITIONS IN REFERENCE STATES

$S_{rhomb} - S_{mon}$ 368.6 °K

S_{mon} M.P. 392 °K

S B.P. 717.75°K

$Ca_I - Ca_{II}$ 713 °K

Ca_{II} M.P. 1123 °K

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T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE — FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	25.5 (2) (±.40)	25.50	-342330 (±1350)	-315470 (±1500)	-96073(3) (±1000)	-82594 (±1200)
400	2600	32.99	26.41	-342868	-306222	-95900	-77986
500	5200	38.78	28.38	-343326	-297050	-95930	-73540
600	8050	43.97	30.55	-343550	-287772	-95869	-69070
700	11250	48.90	32.83	-343636	-278490	-95734	-64619
800	14850	53.70	35.14	-356428	-270306	-95050	-60230
900	18800	58.35	37.46	-355389	-259602	-94210	-55930
1000	22850	62.61	39.76	-354339	-249000	-93349	-51710
1100	27000	66.57	42.02	-353298	-238512	-92430	-47593
1200	31300	70.31	44.23	-354013	-227994	-91470	-43558
1300	35800	73.91	46.37	-352415	-217595	-90356	-39630
1400	40500	77.39	48.46	-350633	-207286	-89090	-35779

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., Southard, J. C. and Anderson, C. T., U. S. Bur. Mines Tech Paper 625, (1941).
(3) National Bureau of Standards Circular 500, (1952).
(4) Palache, C., Berman, H. and Frondel, C., Dana's System of Mineralogy II, John Wiley and Sons, (1951).
(5) Kelley, K. K., U. S. Bur. Mines 393, (1936).

$Ca_{10}(PO_4)_6(OH)_2$

HYDROXYAPATITE

Reference States: for elements, from Stull and Sinke (1956); for hydroxyapatite, crystals 298° to 1500°K.

GFW. 1004.666 grams

GFW. VOL. 334 cm^3

M.P. °K

ΔH melt cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ 30710 cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Ca	B.P.	1765°K
P.	S.P.	704°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0(1)	186.6 (1) (±.30)	186.60				
400	20340	245.3	194.45				
500	42690	294.6	209.22				
600	66000	337.1	227.10				
700	90010	374.1	245.51				
800	114710	407.1	263.71				
900	140090	436.9	281.24				
1000	166130	464.4	298.27				
1100	192780	498.8	314.54				
1200	220050	513.5	330.12				
1300	247890	535.8	345.12				
1400	276280	556.8	359.46				
1500	305180	576.7	373.25				

(1) Egan, E. P., Wakefield, Z. T., and Elmore, K. L., J.A.C.S. 73, 5579, (1951).

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$CaTiO_3$

PEROVSKITE

Reference States: for elements from Stull and Sinke (1956); for perovskite, crystals I 298° to 1530°K, crystals II 1530° to 1800°K; for oxides, this compilation.

GFW. 135.98 grams	
GFW. VOL. 33.52 cm^3	
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Ca	B.P.	1765°K
Ti_I - Ti_{II}		1155°K
Ti_{II}	M.P.	1950°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	22.4 (2) (±.10)	22.4	-396900 (±700)	-376508 (±800)	-19350(3) (±250)	-19615 (±300)
400	2680	30.11	23.41	-396592	-369578	-19309	-19720
500	5430	36.24	25.38	-396271	-362855	-19250	-19820
600	8300	41.47	27.64	-395918	-356208	-19180	-19944
700	11260	46.03	29.94	-395563	-349608	-19130	-20064
800	14270	50.05	32.21	-395511	-243036	-19060	-20206
900	17310	53.63	34.40	-395259	-336492	-18979	-20358
1000	20380	56.87	36.49	-395086	-329970	-18890	-20520
1100	23490	59.84	38.49	-394971	-323475	-18781	-20703
1200	26640	62.58	40.38	-397686	-316800	-18710	-20862
1300	29820	65.12	42.18	-397310	-310099	-18640	-21040
1400	33030	67.50	43.91	-396926	-303408	-18570	-21240
1500	36270	69.74	45.56	-396533	-296775	-18501	-21435
1530 I	37260	70.39	46.04	-396402	-294788	-18472	-21487
1530 II	37810	70.75	46.04	-395852	-294788	-17922	-21487
1600	40050	72.18	47.15	-395618	-290116	-17940	-21654
1700	43250	74.12	48.68	-395301	-282544	-17980	-21883
1800	46460	75.96	50.15	-430760	-276246	-18011	-22086

(1) Naylor, B. F. and Cook, O. A., J.A.C.S. 68, 1003, (1946).
(2) Shomate, C. H., J.A.C.S. 68, 964, (1946).
(3) Kelley, K. K., Todd, S. S. and King, E. G., U. S. Bur. Mines Rept. of Investigations 5059, (1954).

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$FeTiO_3$

ILMENITE

Reference States: for elements from Stull and Sinke (1956); for ilmenite, crystals 298° to 1640°K, liquid, 1640° to 1800°K; for oxides this compilation.

GFW. 151.75 grams

GFW. VOL. 31.5 cm^3

M.P. (3) 1640 °K

ΔH melt (3) 21670 cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ cal.

TRANSITIONS IN REFERENCE STATES

Fe_I - Fe_{II}	1183°K
Fe_{II} - Fe_{III}	1673°K
Fe_{III} M.P.	1812°K
Ti_I - Ti_{II}	1155°K
Ti_{II} M.P.	1950°K
$Fe_{.947}O$ M.P.	1650°K
Fe Curie point	1033°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	25.3 (2) (±.30)	25.30	-295560 (±800)	-277064 (±900)	-6000 (3) (±300)	-5761 (±400)
400	2595	32.77	26.28	-295320	-270764	-6201	-5664
500	5330	38.87	28.21	-295008	-264670	-6280	-5513
600	8200	44.10	30.43	-294666	-258636	-6344	-5349
700	11130	48.61	32.71	-294381	-252650	-6440	-5174
800	14150	52.65	34.96	-294143	-246712	-6487	-5000
900	17250	56.30	37.13	-293982	-240786	-6488	-4803
1000	20430	59.65	39.22	-293973	-234880	-6452	-4630
1100	23650	62.72	41.22	-294112	-228955	-6434	-4455
1200	26900	65.54	43.12	-295059	-222972	-6417	-4248
1300	30200	68.18	44.95	-294651	-217027	-6371	-4096
1400	33540	70.66	46.70	-294245	-211056	-6336	-3893
1500	36920	72.99	48.38	-293839	-205155	-6303	-3742
1600	40360	75.21	49.98	-293411	-199208	-6269	-3552
1640 cry	41750	76.07	50.61	-293237	-196881	-6258	-3510
1640 liq	63420	89.28	50.61	-271567	-196881	+15410	-3510
1700	66280	90.99	52.00	-270715	-194155	+8644	-3977
1800	71040	93.72	54.25	-269082	-189684	+9822	-4731

(1) Naylor, B. F., and Cook, O. A., J. A. C. S. 68, 1003, (1946).
(2) Shomate, C. H., J. A. C. S. 68, 964, (1946).
(3) Kelley, K. K., Todd, S. S. and King, E. G., U. S. Bur. Mines Rept. Investigations 5059, (1954).

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$MgTiO_3$

GEIKIELITE

Reference States: for elements from Stull and Sinke (1956); for geikielite, crystals 298° to 1903°K; for oxides, this compilation.

GFW. 120.22 grams	
GFW. VOL. 30.87 cm^3	
M.P. (4) 1903 °K	
ΔH melt cal.	
B.P. °K	
ΔH vap. cal.	
$H^\circ_{298.15}-H^\circ_0$ cal.	

TRANSITIONS IN REFERENCE STATES

Mg	M.P.	923°K
Mg	B.P.	1390°K
Ti_I - Ti_{II}		1155°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	17.8 (2) (±.10)	17.80	-375900 (±500)	-354775 (±600)	-6340 (3) (±220)	-6128 (±300)
400	2500	24.99	18.74	-375733	-374564	-6344	-6052
500	5130	30.85	20.59	-375487	-340550	-6285	-5990
600	7900	35.90	22.73	-375184	-333594	-6174	-5932
700	10790	40.35	24.94	-374841	-326683	-6090	-5906
800	13740	44.29	27.12	-374523	-319828	-5986	-5884
900	16750	47.83	29.22	-374223	-313008	-5879	-5872
1000	19800	51.05	31.25	-376071	-306040	-5770	-5880
1100	22900	54.00	33.18	-375783	-299043	-5661	-5900
1200	26030	56.73	35.04	-376471	-292044	-5560	-5932
1300	29190	59.25	36.80	-376225	-285030	-5460	-5950
1400	32390	61.65	38.51	-406695	-277844	-5340	-6032
1500	35660	63.90	40.13	-406028	-268695	-5171	-6070
1600	39010	66.06	41.68	-405303	-259532	-4960	-6148
1700	42450	68.15	43.18	-404496	-250457	-4680	-6255
1800	45980	70.17	44.63	-403640	-241404	-4311	-6322

(1) Naylor, B. F. and Cook, O. A., J.A.C.S. 68, 1003, (1946).
(2) Shomate, C. H., J.A.C.S. 68, 964, (1946).
(3) Kelley, K. K., Todd, S. S. and King, E. G., U. S. Bur. Mines Rept. of Investigations 5059, (1954).
(4) Coughanour, L. W. and De Prosse, V. A., J. Research, Nat. Bur. Stds. 51, 87, (1953).

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$MgAl_2O_4$

SPINEL

Reference States: for elements from Stull and Sinke (1956); for spinel, crystals 298° to 1800°K.

GFW. 142.28 grams	
GFW. VOL. 39.72 cm^3	
M.P. (3) 2408 °K	
ΔH melt cal.	
B.P. °K	
ΔH vap. cal.	
$H^\circ_{298.15}-H^\circ_0$ cal.	

TRANSITIONS IN REFERENCE STATES

Mg	M.P.	923°K
Mg	B.P.	1390°K
Al	M.P.	932°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	19.26(2) (±.10)	19.26				
400	3150	28.31	20.44				
500	6650	36.11	22.81				
600	10350	42.85	25.60				
700	14190	48.77	28.50				
800	18150	54.05	31.36				
900	22220	58.85	34.16				
1000	26390	63.66	37.27				
1100	30660	67.73	39.86				
1200	35030	71.53	42.34				
1300	39490	75.10	44.72				
1400	44030	78.46	47.01				
1500	48620	81.63	49.22				
1600	52230	84.60	51.96				
1700	57850	87.40	53.37				
1800	62480	90.05	55.34				

(1) Bonnickson, K. R., J. Phy. Chem. 59, 220, (1955).
(2) King, E. G., J. Phy. Chem. 59, 218, (1955).
(3) Palache, C., Berman, H. and Frondel, C., Dana's System of Mineralogy II, John Wiley and Son (1944).

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Al_2SiO_5

ANDALUSITE

Reference States: for elements from Stull and Sinke (1956); for andalusite, crystals from 298° to 1700°K; for oxides, this tabulation.

GFW. 162.05		grams
GFW. VOL. 51.6		cm^3
M.P.		°K
ΔH melt		cal.
B.P.		°K
ΔH vap.		cal.
$H^\circ_{298.15}-H^\circ_0$		cal.

TRANSITIONS IN REFERENCE STATES

Al	M.P.	932°K
Si		1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	22.28 (2) (±.10)	22.28				
400	3720	32.98	23.68				
500	7620	41.67	26.43				
600	11800	49.29	29.62				
700	16200	56.06	32.92				
800	20700	62.07	36.20				
900	25200	67.36	39.36				
1000	29600	72.00	42.40				
1100	34000	76.20	45.29				
1200	38500	80.12	48.04				
1300	43000	83.71	50.63				
1400	47600	87.13	53.13				
1500	52200	90.31	55.51				
1600	56800	93.27	57.77				

(1) Kelley, K. K., U. S. Bur. Mines Bull 476, (1949).

(2) Todd, S. S., J.A.C.S. 72, 4742 (1950).

March 10, 1959

Al_2SiO_5

KYANITE

Reference States: for elements from Stull and Sinke (1956); for kyanite crystals from 298° to 1700°K; for oxides, this tabulation.

GFW. 162.05	grams
GFW. VOL. 43.6	cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Al	M. P.	932°K
Si	M. P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FORMATION FROM REFERENCE STATE: FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	20.02 (2) (±.08)	20.02				
400	3600	30.35	21.35				
500	7400	38.82	24.02				
600	11300	45.92	27.09				
700	15600	52.54	30.25				
800	20000	58.42	33.42				
900	24500	63.71	36.49				
1000	29000	68.46	39.46				
1100	33600	72.84	42.29				
1200	38300	76.93	45.01				
1300	43000	80.69	47.61				
1400	47800	84.25	50.11				
1500	52700	87.63	52.50				
1600	57700	90.85	54.79				
1700	62800	93.94	57.00				

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).

(2) Todd, S. S., J.A.C.S. 72, 4742 (1950).

March 10, 1959

Al_2SiO_5

SILLIMANITE

Reference States: for elements from Stull and Sinke (1956); for sillimanite, crystals from 298° to 1700°K; for oxides, this tabulation.

GFW. 162.05	grams
GFW. VOL. 49.1	cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Al	M.P.	932°K
Si	M.P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	22.97 (2) (±.10)	22.97				
400	3300	32.46	24.21				
500	6940	40.57	26.69				
600	10900	47.79	29.62				
700	15300	54.57	32.71				
800	19900	60.71	35.84				
900	24400	66.00	38.89				
1000	28900	70.74	41.84				
1100	33400	75.03	44.67				
1200	37900	78.95	47.37				
1300	42500	82.63	49.94				
1400	47000	85.96	52.39				
1500	51600	89.14	54.74				
1600	56300	92.17	56.98				

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).

(2) Todd, S. S., J.A.C.S. 72, 4742, (1950).

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$CaSiO_3$

WOLLASTONITE

Reference States: for elements from Stull and Sinke (1956); for wollastonite, crystals I (wollastonite) 298° to 1400°K, crystals II (pseudo-wollastonite) 1400° to 1817°K; for oxides this compilation.

GFW. 116.17 grams

GFW. VOL. 39.8 cm^3

M.P. (4) 1817 °K

ΔH melt (5) 13400 cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II} 713°K

Ca_{II} M.P. 1123°K

$SiO_2\alpha$ - $SiO_2\beta$ 848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG. GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	19.6 (2) (±.20)	19.60	-383208 (±600)	-362816 (±700)	-21250(3) (±130)	-21315 (±160)
400	2300	26.21	20.46	-383169	-355836	-21241	-21334
500	4780	31.74	22.18	-383019	-349028	-21260	-21360
600	7390	36.49	24.17	-382826	-342240	-21300	-21376
700	10140	40.72	26.23	-382581	-335489	-21322	-21369
800	13000	44.54	28.29	-382574	-328760	-21391	-21378
900	15890	47.94	30.28	-382362	-322035	-21699	-21349
1000	18810	51.02	32.21	-382224	-315338	-21630	-21320
1100	21770	53.84	34.05	-382144	-308650	-21571	-21305
1200	24800	56.48	35.81	-383914	-301836	-21500	-21262
1300	27880	58.94	37.49	-383518	-295029	-21420	-21250
1400	31000	61.25	39.11	-383104	-288260	-21320	-21264

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Torgeson, D. R. and Sahama, Th. G., J.A.C.S. 70, 2156, (1948).
(4) Osborn, E. F., Am. J. Sci. 240, 761, (1942).
(5) Kelley, K. K., U. S. Bur. Mines Bull. 393, (1936).

March 10, 1959

β-Ca_2SiO_4

LARNITE

Reference States: for elements, Stull and Sinke (1956); for oxides this compilation. The stable forms of Ca_2SiO_4 are γ-Ca_2SiO_4 (calcium olivine) 298° to 1120°K, α'-Ca_2SiO_4 (bredigite) 1120° to 1710°K, α-Ca_2SiO_4 1710° to 2403°K (melting point). β-Ca_2SiO_4 is metastable from 298° to 2403°K.

GFW. 172.25 grams

GFW. VOL. 52.0 cm³

M.P. (4) 2403 °K

ΔH melt cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ cal.

T	$H^\circ_T-H^\circ_{298.15}$	S°_T	$-(F^\circ-H^\circ_{298.15})/T$	FORMATION FROM REFERENCE STATE			
				FROM ELEMENTS		FROM OXIDES	
TEMPERATURE °K	HEAT CONTENT CAL/GFW	ENTROPY CAL/DEG GFW	FREE ENERGY FUNCTION CAL/DEG. GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	30.5 (2) (±.20)	30.50	-543938 (±1500)	-516523 (±1650)	-30190(3) (±250)	-30672 (±350)
400	3335	40.09	31.75	-543885	-507138	-30254	-30822
500	6940	48.13	34.25	-543656	-497988	-30270	-30970
600	10790	55.14	37.16	-543314	-488882	-30239	-31120
700	14810	61.34	40.18	-542936	-479846	-30209	-31254
800	18940	66.85	43.18	-543104	-470802	-30211	-31414
900	23140	71.79	46.08	-542833	-461768	-30429	-31540
970 β	26120	74.98	48.06	-542711	-455455	-30301	-31654
970 α'	26560	75.44	48.06	-542271	-455455	-29861	-31652
1000	27860	76.76	48.90	-542212	-452778	-29779	-31690
1100	32250	80.94	51.62	-542114	-443816	-29551	-31895
1120	33140	81.74	52.15	-542101	-442029	-29502	-31932
1200	36720	84.83	54.23	-545746	-434630	-29320	-32098
1300	41290	88.49	56.73	-545028	-425456	-29060	-32374
1400	45970	91.95	59.11	-544226	-416258	-28720	-32627
1500	50780	95.27	61.42	-543318	-407198	-28291	-32935
1600	55710	98.45	63.63	-542312	-398082	-27780	-33230
1700	60780	101.53	65.78	-552276	-389017	-27150	-33607
1710 α'	61290	101.83	65.99	-552160	-388037	-27085	-33615
1710 α	64680	103.81	65.99	-548770	-388037	-23695	-33615
1800	69090	106.32	67.94	-619434	-378176	-23291	-34132

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Ca	B.P.	1765°K
Si	M.P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

(1) Coughlin, J. P., and O'Brien, C. J., J. Phy. Chem. 61, 767, (1957).
(2) Tood, S. S., J.A.C.S. 73, 3277, (1951).
(3) King, E. G., J. A. C. S. 73, 656, (1951)
(4) Bredig, M. A., J. Am. Ceram. Soc. 33, 191, (1950).

March 10, 1959

γ-Ca_2SiO_4

CALCIUM OLIVINE

Reference States: for elements Stull and Sinke (1956); for oxides this compilation. The stable forms of Ca_2SiO_4 are γ-Ca_2SiO_4 (calcium Olivine) 298° to 1120°K, α'-Ca_2SiO_4 (bredigite) 1120° to 1710°K, α-Ca_2SiO_4, 1710° to 2403°K the melting point, (4).

GFW. 172.25	grams
GFW. VOL. 58.3	cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Ca	B.P.	1765°K
Si	M.P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	28.80(2) (±.20)	28.80	-546491(3) (±1850)	-518569 (±2000)	-32743 (±600)	-32718 (±700)
400	3270	38.21	30.04	-546503	-509007	-32872	-32691
500	6760	45.99	32.47	-546389	-499651	-33003	-32633
600	10480	52.76	35.29	-546177	-490313	-33102	-32551
700	14380	58.77	38.23	-545919	-481034	-33192	-32442
800	18420	64.17	41.15	-546177	-471731	-33284	-32343
900	22590	69.08	43.98	-545936	-462431	-33532	-32203
1000	26890	73.61	46.72	-545745	-453211	-33312	-32123
1100	31320	77.83	49.36	-545597	-443883	-33034	-31962
1120	32220	78.64	49.87	-545574	-442029	-32975	-31932

(1) Coughlin, J. P. and O'Brien, C. J., J. Phy. Chem. 61, 767, (1957).
(2) King, E. G., J.A.C.S. 79, 5437, (1957).
(3) Calculated from free energy of formation of β-Ca_2SiO_4.
(4) Bredig, M. A., J. Am. Ceram. Soc. 33, 191, (1950).

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$CaMg(SiO_3)_2$

DIOPSIDE

Reference States: for elements from Stull and Sinke (1956); for diopside, crystals 298° to 1644.5°K; for oxides, this compilation.

GFW. 216.58 grams

GFW. VOL. 66.13cm³

M.P. (4) 1664.5 °K

ΔH melt (3,5)18500 cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ cal.

TRANSITIONS IN REFERENCE STATES

Mg	M.P.	923°K
Mg	B.P.	1390°K
Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Ca	B.P.	1765°K
Si	M.P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

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T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL / GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS, HEAT ΔH°_f CAL/GFW	FROM ELEMENTS, FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES, HEAT ΔH°_f CAL/GFW	FROM OXIDES, FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	34.2 (2) (±.20)	34.20	-753686 (±1500)	-712049 (±1600)	-37760(3) (±250)	-37293(3) (±400)
400	4320	46.61	35.81	-753850	-697762	-37904	-37104
500	8940	56.90	39.02	-753844	-683741	-38145	-36880
600	14060	66.24	42.81	-753507	-669758	-38196	-36629
700	19540	74.66	46.75	-752979	-655826	-38179	-36353
800	25420	82.52	50.74	-752479	-641982	-38026	-36104
900	31340	89.58	54.76	-751839	-628298	-38449	-35924
1000	37280	95.74	58.46	-753462	-614296	-38169	-35550
1100	43250	101.43	62.11	-753069	-600379	-37971	-35318
1200	49250	106.65	65.61	-754623	-586382	-37860	-35060
1300	55300	111.49	68.95	-754051	-572427	-37760	-34848
1400	61440	116.04	72.15	-784167	-558274	-37600	-34638
1500	67660	120.34	75.23	-783156	-542231	-37411	-34430
1600	73980	124.41	78.17	-782087	-526118	-37170	-34208

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) King, E. G., J.A.C.S. 79, 5437, (1957).
(3) Kracek, F. C., Carnegie Institution of Washington yearbook 52, (1953).
(4) Osborn, E. F., Am. J. Sci. 240, 761, (1942).
(5) Kelley, K. K., U. S. Bur. Mines Bull. 393, (1936).

$Ca_2Mg_5Si_8O_{22}(OH)_2$

TREMOLITE

Reference States: for elements from Stull and Sinke (1956); for tremolite, crystals 298° to 1100°K; for oxides, this compilation.

GFW. 812.496	grams
GFW. VOL. 270.7	cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^o_{298.15}-H^o_0$ 23338	cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Mg	M.P.	923°K
Mg	B.P.	1390°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K
H_2O	B.P.	373.15°K

T TEMPERATURE °K	$H^o_T-H^o_{298.15}$ HEAT CONTENT CAL/GFW	S^o_T ENTROPY CAL/DEG GFW	$-\frac{(F^o-H^o_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH^o_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF^o_f CAL/GFW	FROM OXIDES: HEAT ΔH^o_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF^o_f CAL/GFW
298.15	0(1)	131.19(2) (±.30)	131.19	-2893081 (±8000)	-2719161 (±8300)	-120840(3) (±2000)	-116036(3) (±2300)
400	17375	181.14	137.70	-2893650	-2659521	-131374	-113483
500	36516	223.75	150.72	-2892940	-2601056	-131258	-109030
600	57054	261.13	166.04	-2891468	-2542783	-130960	-104577
700	78638	294.44	182.10	-2889589	-2484848	-130791	-100233
800	101089	324.43	198.07	-2887992	-2427185	-130843	- 95873
900	124309	351.74	213.62	-2885681	-2369713	-132660	- 91365
1000	148241	376.93	228.69	-2893806	-2311511	-131068	- 86803
1100	172847	400.35	243.22	-2891069	-2253310	-129269	-82525

(1) Heat capacity above 298°K estimated.
(2) Robie, R. A., PhD. Thesis, U.of Chicago (1957).
(3) Weeks, W. F., J. Geol. 64, 456, (1956).

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$CaAl_2Si_2O_8$

ANORTHITE

Reference States: for elements, Stull and Sinke (1956); for anorthite, crystals 298° to 1826°K; for oxides this compilation.

GFW. 278.22 grams	
GFW. VOL. 100.8 cm^3	
M.P. (4) 1825 °K	
ΔH melt (5) 29400 cal.	
B.P. °K	
ΔH vap. cal.	
$H^\circ_{298.15}-H^\circ_0$ cal.	

TRANSITIONS IN REFERENCE STATES

Al	M.P.	932°K
Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1163°K
Ca	B.P.	1765°K
Si	M.P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0(1)	48.4 (2) (±.40)	48.40	-1001856 (±3000)	-948132 (±3200)	-29330(3) (±1500)	-31407(3) (±1700)
400	5570	64.42	50.50	-1002073	-929716	-29411	-32110
500	11750	78.18	54.68	-1001862	-911631	-29506	-32767
600	18450	90.39	59.64	-1001356	-893634	-29552	-33425
700	25410	101.11	64.81	-1000816	-875723	-29718	-34048
800	32570	110.67	69.96	-1000574	-857864	-29997	-34650
900	39910	119.30	74.96	-1000063	-840054	-30747	-35180
1000	47430	127.23	79.80	-1004559	-821906	-30652	-35670
1100	55130	134.57	84.45	-1003874	-803680	-30523	-36215
1200	62970	141.39	88.92	-1005007	-785364	-30335	-36698
1300	70930	147.75	93.19	-1003931	-767154	-30125	-37241
1400	79050	153.77	97.31	-1002747	-749002	-29815	-37821
1500	87450	159.57	101.27	-1001331	-730986	-29275	-38413
1600	96170	165.19	105.08	- 999639	-712896	-28465	-38994
1700	105230	170.68	108.78	-1019827	-694819	-27305	-39734

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) King, E. G., J.A.C.S. 79, 5437, (1957).
(3) Kracek, F. C., Carnegie Institution of Washington Yearbook 52, (1953).
(4) Osborn, E. F., Am. J. Sci. 240, 761, (1942).
(5) Kelley, K. K., U. S. Bur. Mines Bull. 393, (1936).

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$CaTiSiO_5$

SPHENE

Reference States: For elements from Stull and Sinke (1956); for sphene, crystals 298° to 1670°K, liquid 1670° to 1800°K; for oxides this compilation.

GFW. 196.07	grams
GFW. VOL. 55.7	cm^3
M.P. (1) 1670	°K
ΔH melt (1) 29590	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Ca_I - Ca_{II}		713°K
Ca_{II}	M.P.	1123°K
Ca	B.P.	1765°K
Ti_I - Ti_{II}		1155°K
Ti_{II}	M.P.	1950°K
Si	M.P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0(1)	30.9 (1) (±.20)	30.90	-614568 (±700)	-580747 (±900)	-26850(2) (±250)	-26703 (±350)
400	3750	41.68	32.30	-614432	-569180	-26940	-26634
500	7690	50.46	35.08	-614203	-557898	-27050	-26545
600	11860	58.06	38.29	-613874	-546666	-27164	-26436
700	16230	64.79	41.60	-613478	-535496	-27290	-26304
800	20750	70.83	44.89	-613323	-524368	-27400	-26162
900	25380	76.28	48.08	-612912	-513264	-27710	-25986
1000	30070	81.22	51.15	-612571	-502198	-27620	-25800
1100	34800	85.73	54.09	-612313	-491159	-27560	-25618
1200	39580	89.89	56.91	-614898	-480000	-27520	-25446
1300	44430	93.77	59.59	-614368	-468812	-27470	-25284
1400	49350	97.41	62.16	-613808	-457628	-27390	-25100
1500	54340	100.86	64.63	-613215	-442538	-27290	-24945
1600	59400	104.12	67.00	-612588	-435400	-27190	-24802
1670 cry	62980	106.31	68.60	-612130	-427645	-27109	-24688
1670 liq	92570	124.03	68.60	-582540	-427645	+ 2481	-24688
1700	94570	125.22	69.59	-592973	-424780	+ 2980	-25201
1800	101250	129.04	72.79	-626550	-414219	+ 4650	-26859

(1) King, E. G., Orr, R. L. and Bonnickson, K. R., J.A.C.S. 76, 4320, (1954).
(2) Todd, S. S. and Kelley, K. K., U. S. Bur. Mines Rept. of Investigations 5193, (1956).

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Fe_2SiO_4

FAYALITE

Reference States: for elements from Stull and Sinke (1956); for fayalite, crystals 298° to 1478°K; for oxides this compilation.

GFW. 203.79	grams
GFW. VOL. 46.40	cm^3
M.P. (4) 1478	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Fe (Curie Point)	1033°K
Fe_I - Fe_{II}	1183°K
Fe_{II} - Fe_{IV}	1673°K
Fe_{III} M.P.	1812°K
Si M.P.	1683°K
SiO_2 - SiO_2	848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL / GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	34.70 (2) (±.40)	34.70	-346050(3) (±1100)	-321951 (±1300)	-8282 (±1100)	-7280 (±1200)
400	3440	44.95	36.35	-345852	-313866	-8549	-7066
500	7210	52.99	28.57	-345452	-305740	-8652	-6478
600	11190	60.24	41.59	-345002	-297840	-8749	-6032
700	15320	66.61	44.72	-344594	-290022	-8851	-5566
800	19560	72.27	47.82	-344300	-282258	-8995	-5106
900	23890	77.37	50.83	-344201	-274509	-9369	-4583
1000	28310	82.03	53.72	-344438	-266750	-9355	-4062
1100	32850	86.35	56.49	-344908	-258919	-9329	-3542
1200	37510	90.41	59.15	-345014	-251094	-9256	-2990
1300	42290	94.23	61.70	-344262	-243331	-9074	-2505
1400	47190	97.87	64.16	-343456	-235604	-8844	-1983

(1) Orr, R. L., J.A.C.S. 75, 528, (1953).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) King, E. G., J.A.C.S. 74, 4446, (1952).
(4) Bowen, N. L. And Schairer, J. F., Am. J. Sci., 5th Series 29, 163, (1935).

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$MgSiO_3$

CLINO-ENSTATITE

Reference States: for elements from Stull and Sinke (1956); for clino-enstatite, crystals 298° to 1600°K; for oxides, this compilation.

GFW. 100.41	grams
GFW. VOL. 31.5	cm^3
M.P. (4) incon. 1830	°K
ΔH melt (5) 14700	cal.
B.P.	°K
ΔH vap.	cal.
$H^o_{298.15}-H^o_0$	cal.

TRANSITIONS IN REFERENCE STATES

Mg	M.P.	923°K
Mg	B.P.	1390°K
Si	M.P.	1683°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^o_T-H^o_{298.15}$ HEAT CONTENT CAL/GFW	S^o_T ENTROPY CAL/DEG GFW	$-\frac{(F^o-H^o_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH^o_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF^o_f CAL/GFW	FROM OXIDES: HEAT ΔH^o_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF^o_f CAL/GFW
298.15	0 (1)	16.22 (2) (±.10)	1622	-362658 (±700)	-341896 (±800)	-8690 (3) (±150)	-8642 (±160)
400	2140	22.38	17.03	-362740	-334778	-8714	-8622
500	4480	27.59	18.63	-362685	-327793	-8745	-8600
600	6980	32.14	20.51	-362552	-320826	-8767	-8561
700	9600	36.17	22.46	-362379	-313875	-8820	-8522
800	12300	39.77	24.40	-362206	-306962	-8936	-8466
900	15090	43.06	26.29	-362016	-300072	-9289	-8384
1000	17970	46.09	28.12	-363919	-293008	-9220	-8280
1100	20910	48.89	29.88	-363676	-385922	-9151	-8206
1200	23890	51.49	31.58	-363449	-278862	-9100	-8114
1300	26890	53.88	33.20	-363243	-271834	-9050	-8034
1400	29910	56.12	34.76	-393773	-264609	-8990	-7970
1500	32940	58.22	36.26	-393226	-255430	-8941	-7887
1600	35970	60.17	37.69	-392701	-246226	-8910	-7810

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Kelley, K. K., J.A.C.S. 65, 339, (1943).
(3) Torgeson, D. R. Sahama, Th. G., J.A.C.S. 70, 2156, (1948).
(4) Keith, M. L. and Schairer, J. F., J. Geol. 60, 182, (1952).
(5) Kelley, K. K., U. S. Bur. Mines Bull. 393, (1936).

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Mg_2SiO_4

FORSTERITE

Reference States: For elements from Stull and Sinke (1956); for forsterite, crystals 298° to 2163°K; for oxides, this compilation.

GFW. 149.73 grams

GFW. VOL. 43.67 cm^3

M.P. (4) 2163 °K

ΔH melt (4) 14000 cal.

B.P. °K

ΔH vap. cal.

$H^\circ_{298.15}-H^\circ_0$ cal.

TRANSITIONS IN REFERENCE STATES

Mg M.P. 923°K

Mg B.P. 1390°K

Si M.P. 1683°K

$SiO_2\alpha$ - $SiO_2\beta$ 848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	22.75 (2) (±.20)	22.75	-512888 (±1000)	-484439 (±1100)	-15120(3) (±210)	-15082 (±230)
400	3100	31.66	23.91	-512992	-474680	-15149	-15056
500	6520	39.28	26.24	-512858	-465113	-15110	-15045
600	10180	45.94	28.97	-512606	-455582	-15013	-15018
700	14010	51.85	31.84	-512302	-446108	-14939	-15050
800	17960	57.12	34.67	-511998	-436672	-14931	-15056
900	22000	61.88	37.44	-511731	-427298	-15199	-15066
1000	26130	66.23	40.10	-515712	-417548	-15069	-15040
1100	30340	70.24	42.66	-515418	-407728	-14951	-15065
1200	34630	73.97	45.11	-515136	-397940	-14840	-15060
1300	39000	77.47	47.47	-514838	-388218	-14680	-15094
1400	43450	80.77	49.73	-575954	-378068	-14450	-15149
1500	47950	83.87	51.90	-574868	-363998	-14191	-15165
1600	52470	86.79	54.00	-573792	-349960	-13930	-15264
1700	57000	89.54	56.01	-583796	-335884	-13680	-15392
1800	61540	92.13	57.94	-582734	-321314	-13431	-15426

(1) Orr, R. L., J.A.C.S. 75, 528, (1953).
(2) Kelley, K. K., J.A.C.S. 65, 339, (1943).
(3) Torgeson, D. R. and Sahama, Th. G., J.A.C.S. 70, 2156, (1948).
(4) Bowen, N. L. and Schairer, J. F., Am. J. Sci., 5th Ser. 29, 174, (1935).

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$Mg_3Si_4O_{10}(OH)_2$

TALC

Reference States: for elements from Stull and Sinke (1956); for talc, crystals, 298° to 1100°K; for oxides this compilation.

GFW. 379.336	grams
GFW. VOL. 131.1	cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Mg	M.P.	923°K
Mg	B.P.	1390°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K
H_2O	B.P.	373.15°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH°_f CAL/GFW	FROM ELEMENTS: FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES: HEAT ΔH°_f CAL/GFW	FROM OXIDES: FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	62.34 (2) (±.14)	62.34	-1383989 (±4000)	-1293208 (±4100)	-43600 (2) (±2000)	-39594 (±2200)
400	8561	86.94	65.54	-1384404	-1262061	-54020	-37339
500	17997	107.97	71.98	-1384170	-1231504	-53886	-33200
600	28148	126.46	79.55	-1383520	-1201025	-53634	-29071
700	38889	143.01	87.45	-1382580	-1170671	-53382	-25002
800	50152	158.03	95.34	-1381411	-1140501	-53168	-20945
900	61903	171.87	103.09	-1380009	-1110488	-53768	-16888
1000	74121	184.75	110.63	-1384722	-1080059	-52570	-12843
1100	86793	196.81	117.91	-1382765	-1049633	-51161	- 8970

(1) Heat capacity above room temperature estimated.

(2) Robie, R. A., PhD thesis, U. of Chicago (1957).

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$MnSiO_3$

RHODONITE

Reference States: for elements from Stull and Sinke (1956); for rhodonite, crystals 298° to 1564°K; for oxides, this compilation.

GFW. 131.03 grams	
GFW. VOL. 35.4 cm^3	
M.P. (4) incon. 1564 °K	
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Mn_I - Mn_{II}	1000°K
Mn_{II} - Mn_{III}	1374°K
Mn_{III} - Mn_{IV}	1410°K
Mn_{IV} M.P.	1517°K
$SiO_2\alpha$ - $SiO_2\beta$	848°K

T	$H^\circ_T-H^\circ_{298.15}$	S°_T	$-(F^\circ-H^\circ_{298.15})/T$	FORMATION FROM REFERENCE STATE			
				FROM ELEMENTS		FROM OXIDES	
TEMPERATURE °K	HEAT CONTENT CAL/GFW	ENTROPY CAL/DEG GFW	FREE ENERGY FUNCTION CAL/DEG GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	24.5 (2) (±.40)	24.50	-308128 (±800)	-289883 (±900)	-5920 (3) (±200)	-6024 (±350)
400	2300	31.12	25.37	-308094	-283640	-5950	-6054
500	4800	36.69	27.09	-307939	-277546	-5960	-6080
600	7430	41.48	29.10	-307751	-271489	-6000	-6100
700	10200	45.75	31.18	-307509	-265463	-6030	-6116
800	13070	49.58	33.24	-307245	-259472	-6070	-6116
900	15970	52.99	35.25	-307022	-253516	-6400	-6100
1000	18890	56.07	37.18	-307379	-247558	-6380	-6070
1100	21850	58.90	39.04	-307245	-241594	-6390	-6063
1200	24870	61.52	40.80	-307079	-235624	-6400	-6016
1300	27950	63.98	42.48	-306873	-229680	-6380	-5986
1400	31090	66.31	44.10	-307209	-223757	-6310	-5963
1500	34300	68.53	45.66	-307545	-217790	-6190	-5935

(1) Kelley, K. K., U. S. Bur. Mines Bull. 476, (1949).
(2) Estimated: to the value of Kelley, K. K., J.A.C.S. 63, 2750, (1941). 21.3 e.u. we have added .9 (Rln 6) which we estimate as the unextracted magnetic entropy below 50°K.
(3) King, E. G., J.A.C.S. 74, 4446, (1952).
(4) Glasser, F. P., Am. J. Sci. 256, 398 (1958).

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$KAlSi_3O_8$

ORTHOCLASE

Reference States: for elements from Stull and Sinke (1956); for orthoclase, crystals 298° to 1423°K; for oxides this compilation

GFW. 278.35 grams

GFW. VOL. 106 cm^3

M.P. (3) incon. 1423°K

ΔH melt cal.

B.P. °K

ΔH vap. cal.

$H^o_{298.15}-H^o_0$ cal.

TRANSITIONS IN REFERENCE STATES

K	M.P.	336.4°K
K	B.P.	1039 °K
Al	M.P.	932 °K
$SiO_2\alpha$ - $SiO_2\beta$		848 °K

T TEMPERATURE °K	$H^o_T-H^o_{298.15}$ HEAT CONTENT CAL / GFW	S^o_T ENTROPY CAL/DEG GFW	$-\frac{(F^o-H^o_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS: HEAT ΔH^o_f CAL/GFW	FREE ENERGY ΔF^o_f CAL/GFW	FROM OXIDES: HEAT ΔH^o_f CAL/GFW	FREE ENERGY ΔF^o_f CAL/GFW
298.15	0 (1)	52.5 (2) (±.50)	52.50				
400	5500	68.31	54.56				
500	11550	81.79	58.69				
600	17950	93.45	63.53				
700	24800	104.00	68.57				
800	32000	113.61	73.61				
900	39400	122.32	78.54				
1000	46900	130.22	83.32				
1100	54500	137.47	87.92				
1200	62200	144.17	92.34				
1300	70000	150.40	96.55				
1400	77900	156.26	100.62				

(1) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(2) Kelley, K. K., et al, U. S. Bur. Mines Rept. of Investigation 4955, (1953).
(3) Schairer, J. F., J. Geol. 58, 512, (1950).

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$NaAlSi_3O_8$

ALBITE

Reference States: for elements, Stull and Sinke (1956); for albite, crystals 298° to 1391°K; for oxides this compilation.

GFW. 262.241	grams
GFW. VOL. 100.1	cm^3
M.P. (2) 1391	°K
ΔH melt (3) 13150	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Na	M.P.	371°K
Na	B.P.	1163°K
Al	M.P.	932°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	50.20(1) (±.40)	50.20				
400	5410	65.75	52.22				
500	11390	79.07	56.29				
600	17900	90.93	61.10				
700	24690	101.40	66.13				
800	31690	110.74	71.13				
900	38870	119.19	76.00				
1000	46220	126.94	80.72				
1100	53720	134.08	85.24				
1200	61340	140.71	89.59				
1300	69060	146.89	93.77				
1400	76860	152.67	97.77				

(1) Kelley, K. K. et al., U. S. Bur. of Mines Rept. of Invest. 4955, (1953).
(2) Schairer, J. F., J. Geol. 58, 512, (1950).
(3) Kelley, K. K., U. S. Bur. Mines Bull. 393, (1936).

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$NaAlSi_2O_6$

JADEITE

Reference States: for elements from Stull and Sinke (1956); for jadeite, crystals 298° to 1200°K; for oxides, this compilation.

GFW. 202.151	grams
GFW. VOL. 60.7	cm^3
M.P.	°K
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Na	M.P.	371°K
Na	B.P.	1163°K
Al	M.P.	932°K
$SiO_2\alpha$ - $SiO_2\beta$		848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-\frac{(F^\circ-H^\circ_{298.15})}{T}$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS		FROM OXIDES	
				HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW	HEAT ΔH°_f CAL/GFW	FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	31.9 (1) (±.30)	31.90				
400	4250	44.10	33.47				
500	8970	54.62	36.68				
600	14040	63.86	40.46				
700	19360	72.05	44.39				
800	24860	77.39	48.32				
900	30490	86.02	52.14				
1000	36240	92.08	55.84				
1100	42120	97.68	59.39				
1200	48160	102.94	62.81				

(1) Kelley, et al., U.S. Bur. Mines Rept. of Investigation 4955, (1953).

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$ZrSiO_4$

ZIRCON

Reference States: for elements from Stull and Sinke (1956); for zircon, crystals 298° to 1948°K; for oxides this compilation.

GFW. 183.31	grams
GFW. VOL. 39.27	cm^3
M.P. (3) incon. 1948°K	
ΔH melt	cal.
B.P.	°K
ΔH vap.	cal.
$H^\circ_{298.15}-H^\circ_0$	cal.

TRANSITIONS IN REFERENCE STATES

Zr_I - Zr_{II}	1143°K
SiO_2 - SiO_2	848°K

T TEMPERATURE °K	$H^\circ_T-H^\circ_{298.15}$ HEAT CONTENT CAL/GFW	S°_T ENTROPY CAL/DEG GFW	$-(F^\circ-H^\circ_{298.15})/T$ FREE ENERGY FUNCTION CAL/DEG GFW	FORMATION FROM REFERENCE STATE: FROM ELEMENTS HEAT ΔH°_f CAL/GFW	FROM ELEMENTS FREE ENERGY ΔF°_f CAL/GFW	FROM OXIDES HEAT ΔH°_f CAL/GFW	FROM OXIDES FREE ENERGY ΔF°_f CAL/GFW
298.15	0 (1)	20.2 (2) (±.20)	20.20				
400	2620	27.73	21.18				
500	5460	34.06	23.14				
600	8550	39.68	25.43				
700	11800	44.70	27.84				
800	15180	49.21	30.24				
900	18640	53.28	32.57				
1000	22140	56.97	34.83				
1100	25670	60.33	36.99				
1200	29220	63.42	38.97				
1300	32790	66.28	41.06				
1400	36380	68.74	42.95				
1500	39990	71.43	44.77				
1600	43630	73.78	46.51				
1700	47290	76.00	48.18				
1800	50980	78.11	49.79				

(1) Coughlin, J. P. and King, E. G., J. A. C. S. 72, 2262, (1950).
(2) Kelley, K. K., U. S. Bur. Mines Bull. 477, (1950).
(3) Levin, E. M., McMurdie, H. F. and Hall, F. P., Phase Diagrams for Ceramists, Am. Ceram. Soc. (1956).

CO_2

FUGACITY OF CO_2, Atmospheres

PRESSURE ATM.	TEMPERATURE °K												
	400	450	500	550	600	650	700	750	800	900	1000	1100	1200
100(1)	82.99	89.32	93.79	96.66	98.83	100.4	101.5	102.3	102.5	103.6	104.0	104.5	104.6
150(2)	117.8	135.9	145.4	150.6	154.4	157.3	159.4	160.8	161.6	163.0	163.8	164.1	163.6
200	147.2	173.7	188.3	197.8	205.0	210.5	214.2	216.4	218.0	220.0	221.1	221.3	221.5
250	173.2	208.9	230.4	245.3	255.7	263.7	269.3	272.7	274.8	277.6	278.8	280.4	280.8
300	195.9	242.1	270.9	279.5	305.9	316.4	324.4	329.7	332.7	336.4	339.5	341.2	341.2
350	219.4	275.5	311.8	338.1	357.0	370.9	380.9	387.3	391.8	396.8	400.8	403.0	403.2
400	242.9	309.0	353.4	385.0	408.9	426.4	439.2	447.9	453.8	459.1	464.8	465.6	465.9
450	266.6	342.5	394.4	432.2	461.2	483.3	499.6	509.5	516.0	523.6	528.6	530.7	530.7
500	294.1	377.9	437.5	482.8	516.2	542.0	560.9	573.2	580.4	588.4	593.4	595.5	595.8
600	347.4	451.8	526.5	584.5	629.7	662.9	686.7	703.5	713.5	725.7	732.4	733.1	733.1
700	410.0	533.1	623.4	692.9	748.4	790.2	821.0	842.7	856.9	870.8	877.4	877.4	876.5
800	479.9	621.6	729.8	815.2	880.9	931.1	966.4	991.5	1008	1025	1032	1032	1030
900	555.0	723.2	848.3	945.6	1021	1080	1123	1151	1168	1185	1194	1193	1188
1000	643.8	834.7	977.1	1086	1173	1240	1289	1321	1340	1357	1367	1363	1350
1100	741.3	958.6	1118	1242	1341	1416	1468	1504	1524	1542	1552	1546	1521
1200	850.8	1095	1276	1414	1521	1604	1663	1706	1726	1742	1739	1727	1710
1300	970.3	1247	1448	1602	1720	1811	1874	1913	1931	1946	1949	1933	1900
1400	1107	1422	1641	1809	1940	2034	2102	2147	2172	2177	2163	2139	2107

(1) Hilsenrath, J. et al., Cir. 564 N.B.S., (1955).
(2) Recalculated from Price, D., Ind. and Eng. Chem. 47, 1649, (1955).

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CO_2

CHANGE IN FREE ENERGY WITH PRESSURE, $F_{P,T} - F^{\circ}_{T}$, calories

PRESSURE ATM.	TEMPERATURE °K												
	400	450	500	550	600	650	700	750	800	900	1000	1100	1200
100	3513	4017	4512	4996	5477	5954	6426	6898	7361	8300	9230	10162	11088
150	3791	4393	4948	5481	6009	6533	7055	7572	8084	9110	10132	11149	12156
200	3968	4612	5205	5779	6347	6910	7466	8014	8560	9647	10728	11803	12879
250	4097	4777	5405	6014	6610	7201	7784	8359	8928	10062	11189	12320	13444
300	4195	4909	5566	6202	6824	7436	8043	8642	9232	10406	11580	12749	13908
350	4285	5024	5706	6365	7008	7642	8267	8882	9492	10701	11910	13114	14307
400	4366	5127	5830	6507	7170	7822	8465	9099	9726	10962	12200	13429	14651
450	4440	5219	5939	6633	7314	7984	8644	9291	9930	11197	12460	13715	14962
500	4518	5307	6042	6754	7448	8132	8805	9466	10117	11406	12690	13967	15238
600	4651	5467	6226	6963	7685	8392	9086	9771	10445	11781	13108	14422	15733
700	4782	5615	6394	7149	7891	8619	9335	10041	10736	12107	13468	14814	16159
800	4907	5752	6551	7327	8085	8831	9562	10283	10995	12399	13790	15168	16544
900	5023	5888	6700	7489	8261	9022	9770	10506	11229	12659	14080	15486	16885
1000	5141	6016	6841	7640	8427	9201	9962	10710	11447	12900	14349	15778	17188
1100	5253	6140	6975	7787	8586	9372	10143	10904	11652	13130	14600	16053	17473
1200	5363	6259	7106	7929	8736	9533	10317	11091	11850	13348	14828	16305	17752
1300	5467	6374	7231	8065	8883	9690	10483	11262	12028	13546	15054	16541	18003
1400	5572	6492	7356	8198	9027	9840	10642	11434	12215	13746	15261	16762	18250

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CO_2

FREE ENERGY CHANGE WITH PRESSURE, $F_{P,T} - F^{\circ}_{T}$, calories

PRESSURE BARS.	TEMPERATURE °K 400	450	500	550	600	650	700	750	800	900	1000	1100	1200
100	3503	4002	4495	4977	5456	5937	6408	6878	7391	8269	9190	10137	11058
150	3780	4383	4932	5465	5993	6512	7030	7053	8060	9083	10102	11123	12118
200	3959	4602	5203	5777	6337	6898	7447	8000	8542	9622	10701	11782	12844
250	4085	4763	5395	6002	6595	7185	7762	8340	8902	10038	11163	12290	13407
300	4188	4902	5557	6191	6810	7422	8021	8622	9205	10385	11551	12720	13874
350	4277	5014	5694	6351	6992	7625	8247	8865	9471	10678	11882	13083	14270
400	4357	5115	5818	6494	7155	7803	8445	9080	9700	10938	12176	13397	14616
450	4436	5207	5928	6622	7299	7966	8623	9273	9908	11169	12431	13683	14927
500	4510	5295	6033	6741	7430	8113	8785	9448	10095	11380	12668	13935	15203
600	4643	5453	6214	6949	7670	8372	9065	9751	10422	11755	13080	14388	15698
700	4773	5602	6379	7133	7875	8598	9312	10022	10711	12082	13441	14787	16126
800	4895	5740	6538	7305	8069	8807	9541	10263	10969	12370	13758	15131	16502
900	5010	5871	6683	7472	8242	9002	9747	10482	11202	12629	14049	15451	16846
1000	5128	5998	6827	7623	8406	9180	9942	10685	11420	12871	14317	15743	17147
1100	5236	6122	6958	7764	8563	9348	10117	10878	11624	13098	14567	16019	17430
1200	5346	6241	7086	7909	8714	9507	10288	11063	11822	13316	14795	16268	17703
1300	5451	6355	7213	8046	8861	9666	10455	11233	12001	13516	15018	16503	18961
1400	5557	6470	7340	8171	9001	9813	10614	11404	12184	13710	15225	16723	18200

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H_2O

FUGACITY OF STEAM, Atmospheres

PRESSURE ATM.	TEMPERATURE °K 650	700	750	800	850	900	950	1000	1100	1200	1300
50	46.03	46.99	47.70	48.26	48.66	48.92	49.15	49.30	49.53	49.71	49.82
100	84.68	88.18	90.99	93.15	94.67	95.73	96.61	97.24	98.15	98.83	99.30
150	115.5	123.8	130.1	134.8	138.1	140.5	142.5	143.9	145.9	147.4	148.5
200	138.0	154.0	165.1	173.2	179.0	183.3	186.7	189.2	192.8	195.4	197.3
250	150.8	178.7	196.1	208.6	217.5	224.1	229.5	233.4	238.9	242.9	245.9
300	155.7	197.6	223.2	241.2	253.7	263.2	270.8	276.4	284.2	290.0	294.2
350	160.3	211.1	246.6	270.6	287.6	300.4	310.7	318.2	328.9	336.5	342.2
400	164.9	220.6	266.5	297.5	319.4	336.0	349.3	359.0	372.8	382.7	390.0
450	169.5	228.7	283.5	321.9	349.3	370.0	386.5	398.8	416.1	428.4	437.7
500	174.1	236.3	298.3	344.2	377.2	402.4	422.6	437.6	458.8	473.8	485.1
550	178.7	243.6	311.4	364.6	403.6	433.5	457.5	475.5	500.9	518.9	532.5
600	183.3	250.8	323.4	383.4	428.4	463.2	491.4	512.6	542.5	563.6	579.6
650	188.0	258.0	334.7	400.9	451.8	491.8	524.3	548.8	583.6	608.1	626.7
700	192.8	265.1	345.7	417.5	474.2	519.4	556.2	584.4	624.2	652.4	673.7
750	197.5	272.2	356.5	433.4	495.6	546.0	587.4	619.2	664.3	696.4	720.7
800	202.4	279.4	367.1	448.9	516.2	571.8	617.7	653.3	704.1	740.2	767.5
850	207.3	286.6	377.7	463.7	536.2	596.9	647.5	686.9	743.5	783.8	814.4
900	212.3	293.8	388.1	478.3	555.7	621.4	676.6	720.0	782.6	827.3	861.3
950	217.3	301.1	398.6	493.0	574.8	645.4	705.1	752.5	821.3	870.7	908.1
1000	222.5	308.5	409.0	507.3	593.6	669.0	733.3	784.7	859.8	913.9	955.0
1100	233.0	323.4	430.0	535.8	630.6	715.3	788.5	847.9	936.1	1000	1049
1200	243.8	338.8	451.3	564.3	667.2	760.7	842.7	910.2	1012	1086	1143
1300	254.9	354.5	473.0	592.9	703.7	805.8	896.3	971.6	1087	1172	1237
1400	266.4	370.7	495.2	622.1	740.3	850.6	949.5	1033	1162	1259	1332

Calculated from specific volume for H_2O of;

a. Holser, W. T. and Kennedy, G. C., Am. Jour. Sci. 256, 744, (1958).
b. Holser, W. T., and Kennedy, G. C., Am. Jour. Sci. 257, 71, (1959).

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H_2O

STEAM

CHANGE IN FREE ENERGY WITH PRESSURE, $F_{P,T} - F^{\circ}_{T}$, calories

PRESSURE ATM.	TEMPERATURE °K												
			650	700	750	800	850	900	950	1000	1100	1200	1300
50			4946	5355	5760	6163	6562	6958	7353	7746	8531	9315	10097
100			5734	6231	6723	7209	7686	8158	8629	9096	10026	10954	11879
150			6135	6703	7256	7796	8324	8844	9362	9874	10892	11907	12918
200			6365	7007	7611	8195	8763	9320	9873	10419	11502	12580	13653
250			6479	7214	7867	8490	9092	9680	10262	10836	11970	13099	14221
300			6521	7353	8060	8720	9351	9967	10575	11172	12350	13521	14684
350			6558	7446	8209	8904	9564	10204	10834	11452	12669	13876	15075
400			6594	7507	8325	9054	9741	10404	11055	11692	12943	14182	15413
450			6630	7557	8417	9180	9891	10576	11247	11901	13183	14452	15711
500			6664	7602	8493	9286	10022	10727	11415	12085	13397	14692	15977
550			6698	7645	8557	9378	10136	10860	11565	12250	13589	14908	16217
600			6732	7685	8613	9458	10236	10978	11700	12400	13763	15106	16437
650			6764	7724	8664	9529	10326	11085	11822	12535	13923	15287	16638
700			6796	7762	8713	9593	10408	11183	11934	12659	14070	15454	16825
750			6828	7799	8758	9653	10482	11272	12037	12775	14206	15610	16999
800			6859	7835	8802	9708	10551	11355	12132	12882	14333	15756	17162
850			6890	7871	8844	9760	10615	11432	12220	12981	14452	15892	17315
900			6921	7905	8885	9809	10676	11504	12303	13075	14564	16021	17460
950			6951	7939	8925	9857	10733	11571	12382	13162	14670	16143	17597
1000			6982	7973	8963	9903	10787	11636	12455	13246	14770	16258	17727
1100			7041	8039	9038	9990	10890	11755	12593	13400	14956	16473	17969
1200			7100	8104	9110	10072	10985	11866	12718	13540	15126	16670	18191
1300			7157	8167	9180	10151	11075	11968	12834	13670	15282	16852	18396
1400			7214	8229	9248	10227	11160	12065	12943	13792	15428	17021	18587

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H_2O

STEAM

CHANGE IN FREE ENERGY WITH PRESSURE, $F_{P,T} - F^{\circ}_{T}$, calories

PRESSURE BARS.	TEMPERATURE °K										
	650	700	750	800	850	900	950	1000	1100	1200	1300
50	4930	5338	5744	6152	6553	6943	7328	7718	8508	9295	10048
100	5719	6217	6698	7184	7658	8130	8596	9065	9990	10923	11851
150	6121	6690	7238	7775	8305	8820	9340	9850	10865	11879	12882
200	6354	6994	7593	8177	8745	9295	9848	10395	11473	12556	13623
250	6474	7202	7851	8472	9074	9655	10238	10816	11942	13070	14182
300	6522	7344	8046	8701	9335	9943	10553	11150	12320	13492	14647
350	6554	7438	8195	8888	9547	10183	10815	11432	12641	13849	15042
400	6590	7502	8312	9039	9724	10387	11033	11668	12916	14153	15380
450	6627	7552	8406	9167	9873	10559	11227	11877	13155	14427	15680
500	6661	7596	8482	9272	10002	10707	11395	12058	13369	14665	15945
550	6693	7638	8545	9365	10118	10841	11543	12226	13565	14880	16185
600	6727	7680	8604	9444	10221	10960	11678	12378	13738	15074	16404
650	6759	7718	8654	9516	10310	11069	11803	12515	13898	15255	16603
700	6792	7755	8700	9580	10394	11166	11915	12637	14043	15425	16790
750	6822	7791	8748	9641	10468	11255	12015	12753	14179	15580	16967
800	6853	7828	8793	9695	10538	11340	12108	12860	14305	15725	17129
850	6885	7863	8834	9747	10603	11417	12200	12959	14428	15864	17283
900	6914	7898	8875	9796	10665	11491	12285	13056	14539	15994	17428
950	6945	7930	8916	9844	10721	11557	12363	13144	14644	16115	17565
1000	6973	7963	8953	9890	10762	11619	12434	13226	14744	16230	17696
1100	7033	8030	9015	9978	10877	11740	12572	13380	14932	16443	17936
1200	7090	8095	9098	10060	10975	11852	12699	13520	15101	16642	18159
1300	7145	8154	9169	10139	11062	11953	12814	13647	15255	16823	18362
1400	7203	8215	9234	10217	11143	12048	12924	13771	15400	16990	18548

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REFERENCES

Cohen, E. R., Crowe, K. M., and Dumond, J. W. M., 1957, Fundamental constants of physics: New York, Interscience Publishers, 287 p.

Darken, L. S. and Gurry, R. W., 1946, The system iron-oxygen, II: Am. Chem. Soc. Jour., v. 68, p. 798-812.

Hilsenrath, Joel and others, 1955, Tables of thermal properties of gases; [U. S.] Natl. Bur. Standards Circ. 564, 488 p.

Holser, W. T. and Kennedy, G. C., 1958, Properties of water, IV. Pressure-volume-temperature relations of water in the range 100° -400°C and 100 to 1400 Bars: Am. Jour. Sci., v. 256, p. 744-754.

_____ 1959, Properties of water, V. Pressure-volume-temperature relations of water in the range 400° -1000° and 100-1400 bars: Am. Jour. Sci., v. 257, p. 71-77.

Humphrey, G. L., King, E. G., and Kelley, K. K., 1952, Some thermodynamic values for ferrous oxide: U. S. Bur. Mines Rept. Inv. 4870, 16 p.

Kelley, K. K., 1949, Contributions to the data on theoretical metallurgy X, high temperature heat content, heat capacity and entropy data for inorganic compounds: U. S. Bur. Mines Bull. 476, 241 p.

Kennedy, G. C., 1954, Pressure-volume-temperature relations in CO_2 at elevated pressures and temperatures: Am. Jour. Sci., v. 252, p. 225-241.

Price, Donna, 1955, Thermodynamic functions of carbon dioxide: Indus. and Eng. Chem., v. 47, p. 1649-1652.

Sosman, R. B., 1952, Temperature Scales and silicate research: Am. Jour. Sci., Bowen Volume, p. 517-528.

Stull, D. R., and Sinke, G. C., 1956, Thermodynamic properties of the elements: Am. Chem. Soc. Adv. in Chem., Series 18, 234 p.

Swanson, H. E., and others, 1959, Standard X-ray diffraction powder patterns; [U. S.] Natl. Bur. Standards Circ. 539, v. 8, 95 p.

Wickers, Edward, 1956, Report of the committee on atomic weights for 1955: Am. Chem. Soc. Jour., v. 78, p. 3235-3240.

Woolley, H. E., 1954, Thermodynamic functions for carbon dioxide in the ideal gas state: [U. S.] Natl. Bur. Standards Jour. Research, v. 52, p. 289-298.