I. THERMOCHEMICAL PROPERTIES

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INTRODUCTION

In the present review, thermodynamic data for beryllium, its compounds and alloys, are presented both in individual discussions of experimental measurements on specific substances and in critically compiled tables of selected thermodynamic properties. In preparing these data, reference has been made to various publications containing assessed thermodynamic values, in particular the JANAF Thermochemical Tables [1], Report No.10004 [2] and Technical Note TN 270-6 [3] from the National Bureau of Standards, and Selected Values of Thermodynamic Properties of Metals and Alloys by Hultgren et al. [4]. Since the above-mentioned assessments are generally comprehensive and include some experimental values published as recently as 1971, it has in many cases been possible to accept the tabulated data without change. Indeed, for the sake of consistency, it has frequently been considered undesirable to change values within the error limits quoted in the assessments, and the present effort has therefore largely been concentrated on substances for which new information is available.

Data for beryllium and its inorganic compounds are presented in Sections 1 to 9 and Tables I to VI, and the thermodynamic properties of beryllium alloys are discussed in individual assessments in Section 10.

The more frequently used symbols are listed below.

NOTATION

Symbol	Meaning	Common units
C_p	molar heat capacity	cal/$°K \cdot$mol
ΔG	free energy of reaction	cal, kcal
$\Delta \bar{G}_i$	partial molar free energy of solution of component i	cal/mol, kcal/mol
$\Delta \bar{G}_i^E$	partial molar excess free energy of solution of component i	cal/mol, kcal/mol
ΔH_{298}	heat of formation at 298°K	cal/mol, kcal/mol
ΔH	heat of reaction	cal, kcal

$\Delta \bar{H}_i$	partial molar heat of solution of component i	cal/mol, kcal/mol
$L_{t, f, s, e}$	molar heats of transformation, fusion, sublimation and evaporation	cal/mol, kcal/mol
S^0_{298}	standard entropy at 298°K	cal/°K · mol
ΔS	entropy of reaction	cal/°K · mol
$\Delta \bar{S}_i$	partial molar entropy of solution of component i	cal/°K · mol
$\Delta \bar{S}^E_i$	partial molar excess entropy of solution of component i	cal/°K · mol
ln	$\log_e$	
log	$\log_{10}$	
N_A	mole fraction of A	
p	pressure	atm, mmHg (=torr)
T	absolute temperature	°K
⟨ ⟩	solid state	
{ }	liquid state	
( )	gaseous state	
[ ]	dissolved state (subscript denoting solvent)	

1.   BERYLLIUM

1.1. Heat capacity

Published experimental data for the heat capacity of beryllium have been assessed by Hultgren et al. [4].

A number of low-temperature measurements of C_p have been made [5-10] and these have led to a selected value of $S^0_{298} = 2.27 \pm 0.02$ cal/°K · mol.

High-temperature C_p values are based largely on the measurements by Ginnings, Douglas and Ball [11] (367 - 1169°K) and by Kantor, Krasovitskaya and Kisel [12] (600 - 2200°K), but the data obtained by Kanazawa and Packer [13] (298 - 1368°K), by Walker, Ewing and Miller [14] (303 - 1073°K), by Mit'kina [15] (298 - 748°K) and by Lewis [9] (97 - 463°K) have also been included in the assessment. More recent C_p measurements have been made by Tye and Brazel [16] using adiabatic and drop calorimetry. In the

temperature range 300 - 1100°K their results are a maximum of 2% higher than those of Ginnings et al. [11].

Selected C_p values for α-Be have been fitted by the equation

$$C_p = 5.068 + 1.361 \times 10^{-3} T + 0.23 \times 10^{-6} T^2 - 1.404 \times 10^5 T^{-2} \quad (298-1527°K)$$

The results of Kantor et al. [12] do not include values in the restricted temperature range of stability of β-Be. The heat capacity of β-Be between 1527°K and the melting point of 1560°K has therefore been estimated by Hultgren as 7.7 cal/°K·mol.

The selected C_p value for liquid beryllium is 7.04 cal/°K·mol and this is assumed to remain constant above 2200°K, the maximum temperature of experimental measurements.

Data for gaseous beryllium have been taken by Hultgren et al. from Hilsenrath, Messina and Evans [17]. The standard entropy at 298°K is given as 32.54 cal/°K·mol, and in the temperature range 298 - 1900°K, C_p(Be) has a constant value of 4.968. At temperatures between 1900°K and 3000°K the C_p of the gas has been fitted by the equation:

$$C_p = 4.53 + 0.14 \times 10^{-3} T + 6.51 \times 10^5 T^{-2}$$

1.2. Solid transformation and melting characteristics

The temperature of the $\alpha \rightarrow \beta$ transformation has been determined by Amonenko et al. [18] as 1527 ± 5°K. Since the heat content studies of Kantor et al. [12] did not include results in the β-range, a heat of transformation ($\alpha \rightarrow \beta$) was estimated by Hultgren using the suggestion of Dennison, Gschneidner and Daane [19] that $\Delta S_{\alpha \rightarrow \beta} = 0.2 \times$ valence, i.e. $\Delta S_{\alpha \rightarrow \beta} = (0.4)$. Hence L_t ($\alpha \rightarrow \beta$) = 1527 × (0.4) = 611 cal/mol.

The melting point has been reported by Kantor et al. [12] to be 1560 ± 5°K. This temperature is in excellent agreement with that given by Martin and Moore [20].

The heat content results of Kantor et al. only allow a combined value of L_t ($\alpha \rightarrow \beta$) + L_f to be obtained. This sum is approximately 3500 cal/mol, so that the heat of fusion is obtained by subtraction of the heat of the $\alpha \rightarrow \beta$ transformation. Hultgren has selected a value of L_f of 2920 cal/mol.

1.3. Vapour pressure

The vapour pressure of beryllium has been determined by Baur and Brunner [21] (1850 - 2331°K, boiling point method), Schuman and Garrett [22] (1174 - 1336°K, Langmuir method), Holden, Speiser and Johnston [23] (1172 - 1552°K, Knudsen and Langmuir methods), Gulbransen and Andrew [24] (1103 - 1229°K, Langmuir method), Kovtun, Kruglykh and Pavlov [25] (1178 - 1373°K, Knudsen and Langmuir methods) and Ansara and Bonnier [26] (1578 - 1665°K, Knudsen method). By applying a Third-Law test to the experimental measurements, Hultgren et al. [4] have obtained standard heats of vaporization at 298°K ranging from 76 210 to 80 620 cal/mol. Their selected value of L_e (298°K) is 77 500 ± 1500 cal/mol.

The selected thermodynamic properties of condensed and gaseous beryllium have been used to calculate the following vapour pressure equations for the solid and liquid metal. The additional check that the vapour

pressure is equal to 1 atm at the normal boiling point of 2745°K has also been used.

$\langle Be \rangle$ log p (mmHg) = 11.279 - 0.56 log T - 17058 T^{-1} (298 - 1560°K)

$\{Be\}$ log p (mmHg) = 12.483 - 1.04 log T - 16518 T^{-1} (1560 - 2745°K)

2.   HALIDES

2.1. Fluorides

2.1.1. Beryllium monofluoride

In a report presenting a comprehensive assessment of the thermo-dynamic properties of condensed and gaseous beryllium difluoride, Parker [2] has re-evaluated the data for BeF gas (i.e. (BeF)). The value he selects for ΔH_{298} is -41.8 kcal/mol and the standard entropy is given as S^0_{298} = 49.15 cal/°K·mol.

The heat capacity of the gas, obtained using molecular constants taken from Herzberg [27], is tabulated in the JANAF Thermochemical Tables [1]. The data may be represented by the equation:

C_p = 7.69 + 1.10 × 10^{-3} T - 0.21 × $10^{-6} T^2$ - 0.85 × 10^5 T^{-2} (298 - 3000°K)

2.1.2. Beryllium difluoride

Experimental results for the heat of formation of $\langle BeF_2 \rangle$ (α-quartz) have been considered in detail by Parker [2]. The methods of investigation used for determining ΔH_{298} fall into three main categories:

(a)   Measurement of the heat of solution of both the α-quartz and glassy forms of BeF_2 in acetic acid-sodium acetate solutions. This has been done by Taylor and Gardner [28] who thereby obtained a value for the heat of transformation quartz → glass of 1.12 kcal/mol. This value may be used in conjunction with measured heats of formation of amorphous BeF_2, obtained by the combustion of $\langle Be \rangle$ in (F_2), to calculate ΔH_{298} $\langle BeF_2 \rangle$ (α-quartz), assuming the amorphous and glassy states to be equivalent.

(b)   Reaction of $\langle Be \rangle$ with (F_2). Measurements have been made by Churney and Armstrong [29] (who also quote in Ref.[30] unpublished work of Simmons), and by Good [31].

(c)   Reaction of $\langle Be \rangle$ with $\langle PbF_2 \rangle$. Gross [32] has measured the heat of the reaction:

$$\langle Be \rangle + \langle PbF_2 \rangle \rightarrow \{BeF_2\} \text{ glass} + \langle Pb \rangle$$
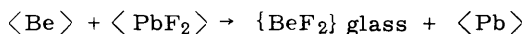
so that from a knowledge of the heat of formation of $\langle PbF_2 \rangle$, ΔH_{298} $\{BeF_2\}$ glass can be obtained.

The above investigations provide values of ΔH_{298} $\langle BeF_2 \rangle$ (α-quartz) that vary from -244 kcal/mol to -245.7 kcal/mol. Parker has selected a 'best' value for $\Delta H_{298} \langle BeF_2 \rangle$ of -245.4 ± 1.0 kcal/mol. The corresponding value for ΔH_{298} $\{BeF_2\}$ glass is -244.3 ± 1.0 kcal/mol.

The heat capacity of $\langle BeF_2 \rangle$ has been measured by Taylor and
Gardner [28] using low-temperature adiabatic calorimetry (8 - 300°K) and
ice calorimetry (354 - 776°K). Their specimen was composed almost
completely of quartz-type crystals and contained about 0.3% oxygen as
the major impurity. The value of S^0_{298} derived from the smoothed C_p
values is 12.75 ± 0.05 cal/°K·mol. From their enthalpy measurements,
Taylor and Gardner have selected a transformation temperature for
$\langle BeF_2 \rangle$ (low quartz → high quartz) of 500°K. This transition has also
been studied by Levina [33] by observing the C_p peak near the transition
temperature. The peak was found to begin near 438°K, was complete near
503°K and gave a value of 0.17 kcal/mole for the heat of transition. A
value of L_t of 0.053 kcal/mol obtained in Ref.[1] from a fit of the experi-
mental enthalpy data for the two crystalline forms is preferred. The
heat capacity data for $\langle BeF_2 \rangle$ have been fitted by the following equations:

$$C_p = 15.56 + 5.15 \times 10^{-3}\, T - 4.20 \times 10^5\, T^{-2} \ (298 - 500°K)$$

$$C_p = 1.24 + 18.59 \times 10^{-3}\, T + 13.14 \times 10^5\, T^{-2} \ (500 - 825°K)$$

The melting temperature of 825°K selected by Taylor and Gardner [28]
from their calorimetric studies has been accepted, although T_f has been
variously reported as 815°K [34], 821°K [35], 818°K [36] and 816 ± 5°K [37].
A value of 1.135 kcal/mol for the heat of fusion is consistent with the
calorimetric data of Taylor and Gardner [28], Melnichak [38] and Gross [39].
The heat capacity of liquid BeF_2 between 828°K and 1183°K has been
determined by Taylor and Gardner [28] from heat content studies. The
following equation may be used to represent the heat capacity of $\{BeF_2\}$
from the melting temperature to the boiling point of 1448°K and above:

$$C_p = 13.81 + 7.105 \times 10^{-3}\, T - 4.51 \times 10^5\, T^{-2} \ (825 - 1448°K)$$

The heat of sublimation of BeF_2 has been determined by a large number
of investigators using a variety of vapour pressure methods. In a recent
Third-Law analysis of the experimental data [1], a value of
-55.15 ± 0.1 kcal/mol for L_s (298°K) has been selected. This gives a
heat of formation of BeF_2 gas at 298°K of -190.25 ± 1.0 kcal/mol. The
entropy and heat capacity of (BeF_2) given here are also those quoted in
Ref.[1]. S^0_{298} has a value of 54.36 ± 0.3 cal/°K·mol and the heat capacity
may be represented by the equations:

$$C_p = 12.23 + 2.02 \times 10^{-3}\, T - 1.59 \times 10^5\, T^{-2} \ (298 - 1000°K)$$

$$C_p = 14.78 + 0.04 \times 10^{-3}\, T - 7.83 \times 10^5\, T^{-2} \ (1000 - 3000°K)$$
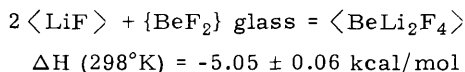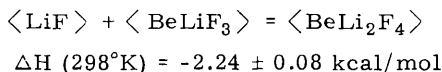
The selected thermodynamic properties of condensed and gaseous
BeF_2 have been used to calculate the following vapour pressure equations:

$$\langle BeF_2 \rangle \ \log p \ (mmHg) = 16.950 - 1.69 \log T - 12\,290\, T^{-1} \ (298 - 825°K)$$

$$\{BeF_2\} \ \log p \ (mmHg) = 23.599 - 3.75 \log T - 12\,823\, T^{-1} (825 - 1448°K)$$

2.1.3. Beryllium-lithium fluorides

Heats of formation of $\langle BeLiF_3 \rangle$ and $\langle BeLi_2F_4 \rangle$ have been deter-
mined from calorimetric measurements made by Gross [40, 41] of the
heats of the following two reactions:

$$\langle LiF \rangle + \langle BeLiF_3 \rangle = \langle BeLi_2F_4 \rangle$$

$$\Delta H \,(298°K) = -2.24 \pm 0.08 \text{ kcal/mol}$$

$$2\langle LiF \rangle + \{BeF_2\} \text{ glass} = \langle BeLi_2F_4 \rangle$$

$$\Delta H \,(298°K) = -5.05 \pm 0.06 \text{ kcal/mol}$$

Using assessed values for the heats of formation of $\langle LiF \rangle$ and
$\{BeF_2\}$ glass (-147.45 kcal/mol [1] and -244.3 kcal/mol, respectively),
values of $\Delta H_{298} \langle BeLiF_3 \rangle$ = -394.5 $\pm$ 2.5 kcal/mol and $\Delta H_{298} \langle BeLi_2F_4 \rangle$
= -544.2 $\pm$ 2.0 kcal/mol have been obtained.
    Enthalpy data for $\langle BeLi_2F_4 \rangle$ in the temperature range 323 - 723°K
have been obtained by Douglas and Payne [42]. The following heat capacity
equation for the solid, up to the melting point of 745°K, is based on their
experimental data:

$$C_p = 21.99 + 35.36 \times 10^{-3} \, T - 0.24 \times 10^5 \, T^{-2} \,(298 - 745°K)$$

The heat capacity of the liquid between 745°K and 2000°K is assumed
to be constant at 55.5 cal/°K·mol, as indicated by Douglas and Payne, and
the above results provide a value of 10.61 kcal/mol for the heat of fusion
of $BeLi_2F_4$.
    The heat capacity of $\langle BeLiF_3 \rangle$ has been estimated [1] from the
difference of the C_p values for $\langle BeLi_2F_4 \rangle$ and $\langle LiF \rangle$. The following
equation may be used to represent the data:

$$C_p = 18.43 + 20.29 \times 10^{-3} \, T - 2.09 \times 10^5 \, T^{-2} \,(298 - 633°K)$$

Standard entropy values for $\langle BeLiF_3 \rangle$ and $\langle BeLi_2F_4 \rangle$ have been
estimated by addition of the S^0_{298} values for the component fluorides.
The values obtained are 21.3 $\pm$ 2 cal/°K·mol and 29.8 $\pm$ 2 cal/°K·mol,
respectively.
    Berkowitz and Chupka [43] have determined a value for the heat of
reaction at 900°K of

$$(LiF) + (BeF_2) = (LiBeF_3)$$
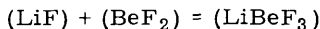
The value of ΔH_{298} (LiBeF$_3$) obtained from their reported heat of
reaction (53 kcal/mol) using estimated heat capacity data [1] is
-212 kcal/mol. The estimated value of S^0_{298} for LiBeF$_3$ gas is 64 cal/°K·mol
and the estimated heat capacity between 298°K and 3000°K may be repre-
sented by the equations:

$$C_p = 12.86 + 21.07 \times 10^{-3} \, T - 9.79 \times 10^{-6} \, T^2 - 3.26 \times 10^5 \, T^{-2} \,(298 - 1000°K)$$

$$C_p = 25.65 + 0.05 \times 10^{-3} \, T - 18.80 \times 10^5 \, T^{-2} \,(1000 - 3000°K)$$

2.2. Chlorides

2.2.1. Beryllium monochloride

The heat of formation of BeCl gas has been obtained by Greenbaum et al. [44] from molecular flow effusion studies and by Novikov and Tunitskii [45] and Hildenbrand et al. [46] from spectroscopic studies. Second- and Third-Law analyses of the results give values of ΔH_{298} varying from about 1 kcal/mol to 15 kcal/mol. A more recent determination of ΔH_{298} (BeCl) by Gross and Lewin [47], using the transportation method applied to the reaction:

$$\langle Be \rangle + (BeCl_2) = 2(BeCl)$$
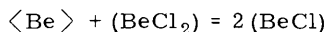
yields a value of 2.0 ± 1.0 kcal/mol. This figure is in good agreement with the value obtained by Greenbaum et al. [44] and is accepted.

The standard entropy, $S_{298}^0 = 53.0 \pm 2.5$ cal/°K·mol, is based on the work of Greenbaum et al. [44], and estimated heat capacity data [1] are represented by the equation:

$$C_p = 8.46 + 0.49 \times 10^{-3} \, T - 0.09 \times 10^{-6} \, T^2 - 0.97 \times 10^5 \, T^{-2} \quad (298\text{-}3000°K)$$

2.2.2. Beryllium dichloride

Beryllium dichloride exists in two crystal forms, denoted α and β. The heat of formation has been determined by Johnson and Gilliland [48] by direct reaction of beryllium and chlorine. The value they have obtained for ΔH_{298} was -118.03 ± 0.56 kcal/mol, but the crystal form of the product has not been specified. Gross et al. [49] have also obtained the heat of formation by direct combustion of the elements, their value of -117.1 ± 0.4 kcal/mol relating to the α-form of $\langle BeCl_2 \rangle$. Thompson et al. [50] have obtained a value of $\Delta H_{298} \langle BeCl_2 \rangle = -118.25 \pm 0.5$ kcal/mol from solution calorimetry. In a private communication to JANAF, these authors have quoted their sample as consisting of approximately 50% α-form and 50% β-form of $\langle BeCl_2 \rangle$. From the above results, values of $\Delta H_{298} \, \alpha\text{-}\langle BeCl_2 \rangle = -117.3 \pm 0.8$ kcal/mol and $\Delta H_{298} \beta\text{-}\langle BeCl_2 \rangle = -118.6 \pm 0.8$ kcal/mol have been selected by JANAF.

McDonald and Oetting [51] have measured the heat capacity between 13°K and 304°K and the enthalpy from 676°K to 688°K of $\alpha\text{-}\langle BeCl_2 \rangle$. These authors have also obtained heat capacities between 13°K and 304°K and enthalpies from 298°K to 676°K for $\beta\text{-}\langle BeCl_2 \rangle$. The crystal form of their specimens was confirmed both before and after the experiments. The heat capacity data obtained from their results may be represented by the following equations:

$$\alpha\text{-}\langle BeCl_2 \rangle: \quad C_p = 18.31 + 2.95 \times 10^{-3} \, T - 3.29 \times 10^5 \, T^{-2} \quad (298\text{-}688°K)$$

$$\beta\text{-}\langle BeCl_2 \rangle: \quad C_p = 15.69 + 4.99 \times 10^{-3} \, T - 2.01 \times 10^5 \, T^{-2} \quad (298\text{-}676°K)$$

Integration of the heat capacity curves provides S_{298}^0 values for $\alpha\text{-}\langle BeCl_2 \rangle$ and $\beta\text{-}\langle BeCl_2 \rangle$ of 19.76 ± 0.06 cal/°K·mol and 18.12 ± 0.05 cal/°K·mol, respectively.

The temperature of the $\beta \rightarrow \alpha$ transition obtained from the results of McDonald and Oetting [51] is 676°K, and the corresponding heat of transition, which depends on the form of the C_p-curve chosen for α-$\langle BeCl_2\rangle$ between 304°K and 676°K, is 1.63 ± 0.15 kcal/mol.

The heat capacity of liquid $BeCl_2$ has again been determined by McDonald and Oetting [51] from enthalpy measurements made in the temperature range 688 - 713°K. Their results indicate that C_p has a constant value of 29.02 cal/°K·mol and this value is used, up to the normal boiling point of 805°K. The melting point of 688°K and the heat of fusion, 2.07 ± 0.06 kcal/mol, are both based on the results obtained by McDonald and Oetting.

The vapour pressure over β-$\langle BeCl_2\rangle$ has been determined by Rahlfs and Fischer [52], Fischer et al. [53], Hildenbrand et al. [54] and Ko et al. [55]. Second- and Third-Law analyses of the results give values for the heat of sublimation at 298°K which vary between 30.9 kcal/mol and 35.6 kcal/mol. The data of Hildenbrand et al. show greatest consistency between Second- and Third-Law values and give a value for the heat of sublimation of $BeCl_2$ at 298°K of 32.5 ± 1 kcal/mol. This corresponds to a heat of formation of $BeCl_2$ gas at 298°K of -86.1 ± 2.5 kcal/mol. The heat capacity and standard entropy data for ($BeCl_2$) are those listed by JANAF. S_{298}^0 has a value of 60 ± 1 cal/°K·mol and the heat capacity values have been fitted by the equation:

$$C_p = 13.89 + 0.83 \times 10^{-3}\, T - 0.18 \times 10^{-6}\, T^2 - 1.67 \times 10^5\, T^{-2} \quad (298 - 3000°K)$$

The selected thermodynamic properties of condensed and gaseous $BeCl_2$ have been used to calculate the following vapour pressure equations:

$$\langle BeCl_2\rangle : \log p \text{ (mmHg)} = 17.584 - 1.89 \log T - 7365\, T^{-1} \quad (298 - 688°K)$$

$$\{BeCl_2\} : \log p \text{ (mmHg)} = 36.605 - 8.07 \log T - 8394\, T^{-1} \quad (688 - 805°K)$$

2.2.3. Beryllium dichloride (dimeric)

Ko et al. [55] have used the transpiration method to determine the thermodynamic properties and composition of the vapour over $\langle BeCl_2\rangle$ in the temperature range 623 - 683°K. The authors have used an iterative procedure to combine their results with previous torsion-effusion and gravimetric effusion data in the temperature range 440 - 600°K, and thereby obtained a value for the heat of formation of Be_2Cl_4 gas at 298°K of -196.3 kcal/mol. In the absence of other experimental information this value is accepted, although the error limit is likely to be large. The value of S_{298}^0 = 92.5 ± 2 cal/°K·mol [55] is also accepted and is in reasonable agreement with the value of 91.15 cal/°K·mol estimated by JANAF. The estimated heat capacity data [1] for (Be_2Cl_4) have been fitted by the equation:

$$C_p = 31.40 + 0.15 \times 10^{-3}\, T - 3.58 \times 10^5\, T^{-2} \quad (298 - 3000°K)$$

2.3. Bromides and iodides

2.3.1. Beryllium monobromide and monoiodide

Heats of formation, standard entropies and heat capacity data for BeBr and BeI gases have all been estimated by JANAF from the experimental data for (BeF), (BeCl) and the gaseous lithium halides. The values listed by JANAF are as follows:

(BeBr): $\Delta H_{298} = 8.8 \pm 5.0$ kcal/mol $S^0_{298} = (54.84)$ cal/$^\circ$K·mol

C_p (fitted) $= 8.80 + 0.14 \times 10^{-3}$ T $- 1.06 \times 10^5$ T^{-2} (298 - 3000°K)

(BeI): $\Delta H_{298} = 24.7 \pm 5.0$ kcal/mol $S^0_{298} = (56.7)$ cal/$^\circ$K·mol

C_p (fitted) $= 8.84 + 0.13 \times 10^{-3}$ T $- 0.93 \times 10^5$ T^{-2} (298 - 3000°K)

2.3.2. Beryllium dibromide and diiodide

The heats of formation of $\langle BeBr_2 \rangle$ and $\langle BeI_2 \rangle$ have been estimated by the National Bureau of Standards [56] from results reported by Biltz and Messerknecht [57] and Biltz, Klatte and Rahlfs [58], who have measured the heat of solution of $BeBr_2$ and BeI_2 in [HCl]$_{aq.}$ to an unknown concentration. Adjusted experimental values were used with data for Be^{++} (estimated) and 2Br$^-$ or 2I$^-$ to obtain the heats of formation of the crystals. A recent report from NBS by Parker [2] gives recalculated values of ΔH_{298} for $\langle BeBr_2 \rangle$ and $\langle BeI_2 \rangle$. These are -84.5 kcal/mol and -46.0 kcal/mol, respectively. No error limits are reported. The heat capacity of both dihalides has been estimated graphically by JANAF by comparison with $\langle BeCl_2 \rangle$ and $\langle BeF_2 \rangle$, while standard entropy values were obtained using additive entropy values for the halide ions. The selected values are given below:

$$\langle BeBr_2 \rangle: \quad S^0_{298} = 25.4 \pm 2.0 \text{ cal/}^\circ\text{K·mol}$$

$$C_p \text{ (fitted)} = 19.52 + 1.07 \times 10^{-3} \text{ T} - 2.96 \times 10^5 \text{ T}^{-2} \text{ (298 - 761}^\circ\text{K)}$$

$$\langle BeI_2 \rangle \quad : \quad S^0_{298} = 28.8 \pm 2.0 \text{ cal/}^\circ\text{K·mol}$$

$$C_p \text{ (fitted)} = 19.91 + 0.86 \times 10^{-3} \text{ T} - 2.81 \times 10^5 \text{ T}^{-2} \text{ (298 - 753}^\circ\text{K)}$$

The melting points of $BeBr_2$ and BeI_2 have been reported by Rahlfs and Fischer [59]. Heats of fusion of 4.5 kcal/mol and 5 kcal/mol, respectively, were estimated by JANAF from the sums of the heats of transition and fusion for BeF_2 and $BeCl_2$. Liquid heat capacities were estimated as described for the crystals.

$$\{BeBr_2\}: \quad C_p = 27.0 \text{ (761 - 794}^\circ\text{K)}$$

$$\{BeI_2\}: \quad C_p = 27.0 \text{ (753 - 900}^\circ\text{K)}$$

Rahlfs and Fischer [59] have measured the vapour pressure of $BeBr_2$ in the temperature range 624 - 695°K and of BeI_2 in the temperature range

578 - 703°K. Values for the heats of sublimation at 298°K obtained from their results are 31.1 kcal/mol and 30.3 kcal/mol, respectively. These lead to values of ΔH_{298} (BeBr$_2$) = -53.4 kcal/mol and ΔH_{298} (BeI$_2$) = -15.7 kcal/mol. Heat capacities and standard entropies for the two gases have been estimated by JANAF from data for the gaseous beryllium dihalide series. The values obtained are:

$$(BeBr_2): \ S_{298}^{0} = 66.4 \pm 2 \ cal/°K \cdot mol$$

$$C_p \ (fitted) = 14.89 - 2.66 \times 10^{5} \ T^{-2} \ (298 - 3000°K)$$

$$(BeI_2): \ S_{298}^{0} = 70.4 \pm 2 \ cal/°K \cdot mol$$

$$C_p \ (fitted) = 14.89 - 2.03 \times 10^{5} \ T^{-2} \ (800 - 3000°K)$$

The selected data for condensed and gaseous BeBr$_2$ and BeI$_2$ have been used to calculate vapour pressure equations:

$$\langle BeBr_2 \rangle: \ \log p \ (mmHg) = 19.343 - 2.57 \log T - 7139 \ T^{-1} \ (298 - 761°K)$$

$$\{BeBr_2\}: \ \log p \ (mmHg) = 9.457 - 5250 \ T^{-1} \qquad (761 - 794°K)$$

$$\langle BeI_2 \rangle: \ \log p \ (mmHg) = 19.443 - 2.56 \log T - 6961 \ T^{-1} \ (298 - 753°K)$$

$$\{BeI_2\}: \ \log p \ (mmHg) = 32.307 - 6.88 \log T - 7290 \ T^{-1} \ (753 - 900°K)$$

3.   OXIDES

3.1. Beryllium oxide

Parker, in a fairly recent NBS report [2], has assessed all the experimental values obtained for the heat of formation of $\langle BeO \rangle$. The methods used to obtain ΔH_{298} fall into two categories, namely, bomb combustion as performed by Mielenz and von Wartenberg [60], Moose and Parr [61], Neumann, Kröger and Kunz [62], Roth, Börger and Siemonsen [63] and Cosgrove and Snyder [64], and solution of $\langle Be \rangle$ or $\langle BeO \rangle$ in aqueous HF solution, as carried out by Copaux and Philips [65], Matignon and Marchal [66], Fricke and Wullhorst [67], Neumann, Kröger and Haebler [68], Smirnov and Chukreev [69], Kolesov, Popov and Skuratov [70], Thompson, Sinke and Stull [50], Bear and Turnbull [71], Armstrong and Coyle [72] and Kilday, Prosen and Wagman [73]. The direct, combustion experiments give values of ΔH_{298} $\langle BeO \rangle$ varying between -134.4 kcal/mol and -147.3 kcal/mol, while results from the indirect, solution experiments vary between -141.1 kcal/mol and -146.0 kcal/mol. Parker selects a 'best' value for ΔH_{298} $\langle BeO \rangle$ of -145.4 ± 0.8 kcal/mol.

The low-temperature heat capacity of $\langle BeO \rangle$ between 55.5°K and 292.4°K has been determined by Kelley [74]. On the assumption that C_p follows the T^3 law below 55.5°K, the value of $S_{55.5}$ has been estimated to be 0.045 cal/°K·mol, and S_{298}^{0} has been obtained as 3.38 ± 0.05 cal/°K·mol. High-temperature enthalpy data for $\langle BeO \rangle$ have been determined by

Magnus and Danz [75], Kandyba et al. [76], Rodigina and Gomel'skij [77], Walker et al. [78], Victor and Douglas [79] and Greenbaum et al. [80]. The experimental studies cover the temperature range up to 2840°K. Although a high-temperature phase change has been reported at temperatures around 2300°K [81, 82], neither the measurements of Kandyba et al. nor those of Greenbaum et al. were sufficiently accurate to determine a heat of transformation. Heat capacity values obtained from the experimental studies have therefore been fitted by a single equation up to the melting temperature of 2853 ± 10°K reported by Greenbaum et al. [80]:

$$C_p = 9.94 + 2.44 \times 10^{-3} \ T - 0.32 \times 10^{-6} \ T^2 - 4.15 \times 10^5 \ T^{-2} \quad (298 - 2853°K)$$

The heat of fusion measurements made by Greenbaum et al. as an integral part of their study provide a value of $L_f = 19.3 \pm 0.8$ kcal/mol for BeO at 2853°K. The liquid heat capacity, assumed constant up to 4000°K, is estimated to be 15.5 cal/°K · mol.

In the recent Technical Note 270-6 [3], NBS records a value of ΔH_{298} BeO gas of 28 kcal/mol. No references are given relating to this value, which is presumably largely based on the work of Chupka et al. [83]. This heat of formation corresponds to a value of 173.4 kcal/mol for L_s (298°K).

JANAF have used the spectroscopic constants listed by Herzberg [27] to obtain standard entropy and heat capacity data for gaseous beryllium oxide. These are as follows:

$$S_{298}^0 = 47.2 \text{ cal/°K} \cdot \text{mol}$$

$$C_p \text{(fitted)} = 7.27 + 1.39 \times 10^{-3} \ T - 0.27 \times 10^{-6} \ T^2 - 0.64 \times 10^5 \ T^{-2} \quad (298 - 3000°K)$$

The selected thermodynamic values for condensed and gaseous BeO have been used to derive the following vapour pressure equation:

$$\langle BeO \rangle : \ \log p \ (\text{mmHg}) = 18.015 - 1.77 \ \log T - 38 \ 247 \ T^{-1} \quad (298 - 2500°K)$$

It should be noted that at 2300°K the vapour above BeO consists of Be, O, BeO, $(BeO)_2$, $(BeO)_3$, $(BeO)_4$, $(BeO)_5$, $(BeO)_6$, Be_2O and other species. Values for the heats of formation of the dimeric, trimeric, tetrameric, pentameric and hexameric forms of gaseous BeO have been tabulated by NBS [3]. The values are presumably again obtained from the work of Chupka et al. [83]. JANAF have estimated corresponding standard entropy and heat capacity data. The results are summarized below:

$(BeO)_2$: $\Delta H_{298} = -103$ kcal/mol $S_{298}^0 = 59.2$ cal/°K · mol

$$C_p = 15.89 + 3.26 \times 10^{-3} \ T - 0.69 \times 10^{-6} \ T^2 - 4.26 \times 10^5 \ T^{-2} \quad (298 - 3000°K)$$

$(BeO)_3$: $\Delta H_{298} = -260$ kcal/mol $S_{298}^0 = 65.3$ cal/°K · mol

$$C_p = 20.77 + 9.04 \times 10^{-3} \ T - 1.90 \times 10^{-6} \ T^2 - 7.58 \times 10^5 \ T^{-2} \quad (298 - 3000°K)$$

$(BeO)_4$: $\Delta H_{298} = -391$ kcal/mol $S_{298}^0 = 72.3$ cal/°K · mol

$$C_p = 32.84 + 9.15 \times 10^{-3} \ T - 1.95 \times 10^{-6} \ T^2 - 12.90 \times 10^5 \ T^{-2} \quad (298 - 3000°K)$$

(BeO)$_5$: ΔH_{298} = -518 kcal/mol S^0_{298} = 77.2 cal/°K · mol

C_p = 47.73 + 3.64 × 10^{-3} T - 0.24 × 10^{-6} T^2 - 20.57 × 10^5 T^{-2} (298 - 3000°K)

(BeO)$_6$: ΔH_{298} = -651 kcal/mol S^0_{298} = 82 cal/°K · mol

C_p = 50.94 + 14.02 × 10^{-3} T - 3.00 × 10^{-6} T^2 - 21.47 × 10^5 T^{-2} (298 - 3000°K)

The error limits on the above values are very large, e.g. of the order of
± 25 kcal/mol on ΔH_{298} (BeO)$_6$.

3.2. Diberyllium oxide

Hildenbrand, Theard and Ju [84], using a mass spectrometer, have
determined equilibrium constants for the reactions:

$$2 \langle BeO \rangle \rightarrow (Be_2O) + (O)$$

$$2 (BeO) \rightarrow (Be_2O) + (O)$$

$$(BeO)_2 \rightarrow (Be_2O) + (O)$$
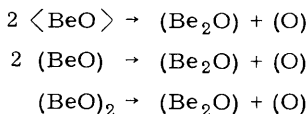
NBS has presumably used the results of these investigations and its own
revised data for BeO [2] to obtain a heat of formation of Be$_2$O gas of
ΔH_{298} = -20 kcal/mol [3]. The error limit on this value is probably of
the order of ± 10 kcal/mol. The heat capacity and standard entropy have
been estimated by JANAF:

$$S^0_{298} = 52.7 \text{ cal/°K} \cdot \text{mol}$$

C_p (fitted) = 7.74 + 10.61 × 10^{-3} T - 4.61 × 10^{-6} T^2 - 0.63 × 10^5 T^{-2} (298 - 1000°K)

        = 14.73 + 0.05 × 10^{-3} T - 11.03 × 10^5 T^{-2} (1000 - 3000°K)

3.2.1. Diberyllium dilithium oxide

Hayman [85] has reported the value of $\Delta H_{298} \langle Be_2Li_2O_3 \rangle$ to be
-437.8 ± 2.0 kcal/mol, based on calorimetric measurements made at
the Fulmer Research Institute.

3.3. Oxyhalides

3.3.1. Beryllium oxyfluoride

Efimenko [86] has made a mass-spectrometric investigation of the
reaction $\langle BeO \rangle$ + (BeF$_2$) → (Be$_2$OF$_2$) in the temperature range
1570 - 2195°K and has reported two sets of equilibrium constants.
Parker [2] has presumably used these values and his own assessed data
for BeO and BeF$_2$ to calculate a value of ΔH_{298} (Be$_2$OF$_2$) = -292 kcal/mol.
Estimated heat capacity and standard entropy data are from JANAF

$$S^0_{298} = 71.4 \text{ cal/°K} \cdot \text{mol}$$

C_p (fitted) = 22.16 + 2.98 × 10^{-3} T - 0.62 × 10^{-6} T^2 - 4.52 × 10^5 T^{-2} (298 - 3000°K)

4. NITRIDES

4.1. Beryllium nitride

Gross et al. [87] have determined the heat of formation of α-$\langle Be_3N_2 \rangle$ (cubic form) from measurements of the heats of the following two reactions:

$$\alpha\text{-}\langle Be_3N_2 \rangle + 3(Cl_2) \rightarrow 3\,\alpha\text{-}\langle BeCl_2 \rangle + (N_2)$$

$$3\,\langle Be \rangle + 2(NH_3) \rightarrow \alpha\text{-}\langle Be_3N_2 \rangle + 3(H_2)$$
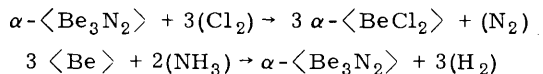
The observed heat for the chlorination reaction is -210.3 ± 1.1 kcal/mol. When combined with the selected heat of formation of α-$\langle BeCl_2 \rangle$ (-117.3 kcal/mol), a value of $\Delta H_{298}\ \alpha$-$\langle Be_3N_2 \rangle = -141.6 \pm 1.5$ kcal/mol is obtained. The heat of reaction of beryllium with ammonia has been observed to be -214.6 ± 0.3 kcal/mol at 298°K, resulting in a value of $\Delta H_{298}\ \alpha$-$\langle Be_3N_2 \rangle = -140.3 \pm 0.4$ kcal/mol.

Using the torsion-effusion vapour-pressure method, Yates, Greenbaum and Farber [88] have studied the decomposition of $\langle Be_3N_2 \rangle$ to (Be) and (N_2) in the temperature range 1438 - 1661°K and obtained a Third-Law value of $\Delta H_{298}\ \langle Be_3N_2 \rangle = -140.3 \pm 1.5$ kcal/mol. The same decomposition has been investigated by Hoenig [89] using the Knudsen method in the temperature range 1648 - 1946°K. The values of $\Delta H_{298}\ \langle Be_3N_2 \rangle$ derived from his results are on average about 5 kcal/mol more exothermic than those of Yates et al. [88].

A value of $\Delta H_{298}\ \alpha$-$\langle Be_3N_2 \rangle = -140.9 \pm 0.6$ kcal/mol has been selected from the calorimetric results.

In Ref. [3] a value of -136.5 kcal/mol for the heat of formation of hexagonal $\langle Be_3N_2 \rangle$ is quoted, but no references are given for this value.

The low-temperature heat capacity of α-$\langle Be_3N_2 \rangle$ between 25°K and 310°K has been measured by Justice [90]. Integration of these data provides a value of S_{298}^{0} of 8.16 cal/°K·mol. Furukawa and Reilly [91] also have more recently made low-temperature heat capacity measurements at temperatures between 20°K and 315°K and obtained a value of 8.23 ± 0.08 cal/°K·mol for the standard entropy. A value of $S_{298}^{0}\ \alpha$-$\langle Be_3N_2 \rangle = 8.20 \pm 0.05$ cal/°K·mol is selected.

The relative enthalpy of α-$\langle Be_3N_2 \rangle$ at temperatures between 273°K and 1173°K has been determined by Douglas and Payne [92] using drop calorimetry. Corrections were applied for impurities. Their data have been used to obtain the following heat capacity equations:

$$C_p = 12.89 + 24.75 \times 10^{-3}\,T - 4.22 \times 10^5\,T^{-2} \quad (298 - 430°K)$$

$$C_p = 27.37 + 3.60 \times 10^{-3}\,T - 14.23 \times 10^5\,T^{-2} \quad (430 - 1200°K)$$

5. CARBIDES

5.1. Diberyllium monocarbide

The heat of formation of $\langle Be_2C \rangle$ has been determined by Blachnik, Gross and Hayman [93] from acid solution calorimetry measurements at 110°C. Their experimental value of $\Delta H_{298}\ \langle Be_2C \rangle$ is -27.96 ± 0.21 kcal/mol.

The value of S^0_{298} has been estimated by Krikorian [94] to be
3.9 ± 1.0 cal/°K·mol.

Neely, Teeter and Trice [95] have determined mean heat capacity
values in the temperature range 298 - 1200°K. They have quoted the
analysis of their powder specimen to be 74 - 80% Be_2C with beryllium
oxide and nitride as the main impurities. No corrections have been made
for these impurities and the authors have estimated their measured data
to be accurate to 15% only. JANAF have extrapolated these heat capacity
data from 1200°K to 2400°K so as to approach the value of 22 cal/°K·mol
calculated by Krikorian [94]. The results have been fitted by the following
equation:

$$C_p = 9.17 + 10.76 \times 10^{-3} \, T - 2.29 \times 10^{-6} \, T^2 - 2.01 \times 10^5 \, T^{-2} \, (298 - 2400°K)$$

6.   BORATES, ALUMINATES AND SILICATES

6.1. Triberyllium diborate

Gross [96] has carried out calorimetric measurements of the heat of
the reaction:

$$3 \langle BeO \rangle + \{ B_2O_3 \} \text{ glass} = \langle Be_3B_2O_6 \rangle$$
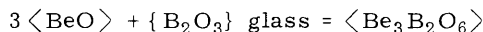
His value of -13.38 ± 0.5 kcal/mol has been combined with $\Delta H_{298} \langle BeO \rangle$
$= -145.4 \pm 0.8$ kcal/mol and $\Delta H_{298} \{ B_2O_3 \}$ glass $= -299.3 \pm 0.5$ kcal/mol to
obtain a heat of formation for $\langle Be_3B_2O_6 \rangle$ of -748.9 ± 3.5 kcal/mol.

Blackburn and Buchler [97] have made vacuum balance and ion
intensity investigations of the reactions:

$$\{ B_2O_3 \} \rightarrow (B_2O_3)$$
$$\langle Be_3B_2O_6 \rangle \rightarrow 3 \langle BeO \rangle + (B_2O_3)$$
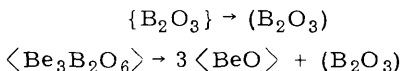
They have reported values of K_p of 2.7×10^{-5} atm and 9.3×10^{-6} atm
for the two reactions respectively at 1500°K. These values provide Gibbs
energies for the two reactions which, when combined, give -3.17 kcal/mol
for the reaction

$$3 \langle BeO \rangle + \{ B_2O_3 \} = \langle Be_3B_2O_6 \rangle$$
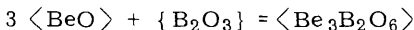
The value obtained by Gross [96] for the heat of this reaction may
now be combined with the Gibbs energy value at 1500°K to give an entropy
of reaction of -6.81 cal/°K·mol. From this latter value and the standard
entropies of $\{ B_2O_3 \}$ and $\langle BeO \rangle$ a value of $S^0_{298} \langle Be_3B_2O_6 \rangle = 22.1 \pm 3$ cal/°K·mol
is obtained.

The heat capacity of $\langle Be_3B_2O_6 \rangle$ has been estimated by JANAF from
the heat capacities of the component oxides:

$$C_p \text{ (fitted)} = 26.90 + 62.92 \times 10^{-3} \, T - 21.08 \times 10^{-6} \, T^2 - 9.51 \times 10^5 \, T^{-2} \, (298 - 1768°K)$$

The melting point of 1768 ± 5°K is that reported by Blackburn and Buchler [97].

6.2. Beryllium aluminates

6.2.1. Beryllium monoaluminate

The heat of formation of $\langle BeAl_2O_4 \rangle$, at about 1000°K, has been determined by Holm and Kleppa [98] using molten oxide solution calorimetry. Their value of -4.0 kcal/mol for formation from the component oxides provides a value of $\Delta H_{298} \langle BeAl_2O_4 \rangle$ = -549.4 kcal/mol from the elements. This value is in good agreement with the figure obtained by Young [99] from equilibrium studies.

The low-temperature heat capacity of the compound has been measured by Furukawa et al. [100]. The results give a value of S_{298}^0 = 15.84 cal/°K·mol. High-temperature enthalpy measurements have also been reported by these authors and by Ditmars and Douglas [101], enabling heat capacity data to be obtained at temperatures up to the melting point of 2143°K.

$$C_p = 29.26 + 22.62 \times 10^{-3} \, T - 9.36 \times 10^{-6} \, T^2 - 8.93 \times 10^5 \, T^{-2} \; (298 - 1200°K)$$

$$= 37.58 + 4.10 \times 10^{-3} \, T \; (1200 - 2143°K)$$

6.2.2. Beryllium trialuminate

The molten oxide solution calorimetry measurements of Holm and Kleppa [98] provide a value of $\Delta H_{298} \langle BeAl_6O_{10} \rangle$ = -1342.6 kcal/mol for formation from the elements. The value of S_{298}^0 = 42.0 cal/°K · mol is reported by NBS [3]. The heat capacity of the compound has been determined by Ditmars and Douglas [102] for temperatures up to 2150°K.

$$C_p = 88.45 + 18.57 \times 10^{-3} \, T - 2.77 \times 10^{-6} \, T^2 - 27.75 \times 10^5 \, T^{-2} \; (298 - 2150°K)$$

6.3. Beryllium silicate

The heat of formation of $\langle Be_2SiO_4 \rangle$ has been determined by Holm and Kleppa [98] using molten oxide solution calorimetry. Their measured value of -4.7 kcal/mol for formation from the oxides at 968°K has been used in conjunction with a room temperature C_p-value obtained by Kelley [74] from low-temperature heat capacity measurements, and high-temperature heat capacity data based on the C_p-values for the component oxides, to obtain $\Delta H_{298} \langle Be_2SiO_4 \rangle$ = -512.8 ± 2.5 kcal/mol from the elements. The value of S_{298}^0 = 15.37 ± 0.1 cal/°K · mol is the figure given by Kelley's data.

At 1833°K, $\langle Be_2SiO_4 \rangle$ dissociates into its component oxides [103] and the resulting requirement that ΔG_{1833} = 0 for the reaction

$$\langle Be_2SiO_4 \rangle = 2 \langle BeO \rangle + \langle SiO_2 \rangle$$
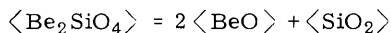
was used to refine the estimated heat capacity equation for the compound.

$$C_p = 29.65 + 18.77 \times 10^{-3} \, T - 8.0 \times 10^{-6} \, T^2 - 10.84 \times 10^5 \, T^{-2} \; (298 - 1833°K)$$

7. HYDRIDES AND HYDROXIDES

7.1. Beryllium monohydride

The heat of formation of BeH gas has been selected by JANAF from the tabulations of Gaydon [104]. The value is 77 ± 7 kcal/mol. The heat capacity and entropy have also been calculated by JANAF from the molecular constants listed by Herzberg [27]: $S^0_{298} = 42.24$ cal/$^\circ$K·mol.

$$C_p = 6.44 + 1.98 \times 10^{-3} T - 0.36 \times 10^{-6} T^2 - 0.08 \times 10^5 T^{-2} \quad (298 - 3000^\circ K)$$

7.2. Beryllium dihydride

The heat of formation of $\langle BeH_2 \rangle$ has been determined by Akhachinskij et al. [105] and by Ivanov and Karpova [106] using bomb calorimetry. Their results are in good agreement and provide a value of $\Delta H_{298} = -4.55 \pm 0.5$ kcal/mol.

Data for gaseous (BeH_2) are the estimated values listed by JANAF.

$$\Delta H_{298} = 30 \text{ kcal/mol} \qquad S^0_{298} = 41.4 \text{ cal/}^\circ K \cdot mol$$

$$C_p = 7.50 + 5.66 \times 10^{-3} T - 1.14 \times 10^{-6} T^2 - 1.95 \times 10^5 T^{-2} \quad (298 - 3000^\circ K)$$

7.3. Beryllium monohydroxide

The heat of formation of BeOH gas has been obtained by Hildenbrand et al. [84] from mass-spectrometric studies of the reaction:

$$(Be_2O) + (H_2O) \rightarrow 2 (BeOH)$$
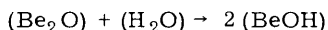
and by Ko et al. [107] from molecular flow effusion studies of the reaction:

$$\langle BeO \rangle + \tfrac{1}{2} (H_2) \rightarrow (BeOH)$$
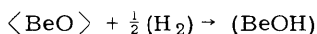
The two values of ΔH_{298} (BeOH) are not in good agreement, being -24.8 ± 10 kcal/mol and -47.5 ± 7 kcal/mol (average of Second- and Third-Law values) respectively. The latter figure is more consistent with values for gaseous (CaOH) and (MgOH) however and has therefore been selected.

The standard entropy and heat capacity are those estimated by JANAF.

$$S^0_{298} = 53.28 \text{ cal/}^\circ K \cdot mol$$

$$C_p = 8.13 + 3.73 \times 10^{-3} T - 0.68 \times 10^{-6} T^2 - 0.98 \times 10^5 T^{-2} \quad (298 - 3000^\circ K)$$

7.4. Beryllium dihydroxide

The heat of formation of α-$\langle Be(OH)_2 \rangle$ (tetragonal) has been determined by Bear and Turnbull [71] from calorimetric studies of the heats of solution of pure beryllium metal and of α-$\langle Be(OH)_2 \rangle$ in aqueous HF. Values have thereby been obtained for the heat of the reaction:

$$\langle Be \rangle + 2 \{ H_2O \} = \alpha\text{-}\langle Be(OH)_2 \rangle + (H_2)$$
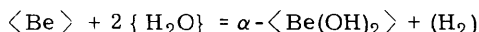
and the value calculated for ΔH_{298} α-$\langle Be(OH)_2 \rangle$ = -215.7 ± 0.5 kcal/mol.

The heat of formation of β-$\langle Be(OH)_2 \rangle$ (orthorhombic) has been determined by Bear and Turnbull [71] in the same manner, while studies made by Fricke and Severin [108] and Baur and Lecocq [109] of the decomposition pressure of water vapour over β-$\langle Be(OH)_2 \rangle$ give Third-Law values of ΔH_{298} β-$\langle Be(OH)_2 \rangle$ in very good agreement with the calorimetrically determined value. The selected heat of formation is -216.5 ± 0.5 kcal/mol. JANAF have estimated a value of S_{298}^0 for β-$\langle Be(OH)_2 \rangle$ = 11.0 ± 2 cal/°K·mol, which finds independent confirmation from the data of Baur and Lecocq. The value of S_{298}^0 α-$\langle Be(OH)_2 \rangle$ = 11.8 ± 2 cal/°K·mol has been obtained via the difference in Gibbs energies [110] and heats of formation at 298°K of α- and β-$\langle Be(OH)_2 \rangle$. Beryllium dihydroxide has been calculated to decompose into $\langle BeO \rangle$ and (H_2O) at 407°K in the case of the α-form and at 417°K in the case of the β-form. The heat capacity for both α and β has been estimated by JANAF and is assumed to be the same for the two crystal structures, namely,

$$C_p = 4.56 + 36.75 \times 10^{-3} \, T + 0.10 \times 10^5 \, T^{-2} \quad (298 - 400°K)$$

A number of investigators [99, 111-115] have studied the equilibrium reaction:

$$\langle BeO \rangle + (H_2O) \rightarrow (Be(OH)_2)$$

Their results have been subjected to Second- and Third-Law analyses by JANAF, who have used their own functions to obtain a best value of ΔH_{298} $(Be(OH)_2)$ = -156.4 ± 5 kcal/mol.

To obtain standard entropy and heat capacity data for $(Be(OH)_2)$, the structure assumed by Altman [116] has been adopted by JANAF. Further estimates have been made to obtain S_{298}^0 = (59.2) cal/°K·mol and
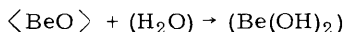
$$C_p = 15.47 + 6.86 \times 10^{-3} \, T - 1.27 \times 10^{-6} \, T^2 - 3.83 \times 10^5 \, T^{-2} \quad (298 - 3000°K)$$

8. SULPHIDE, SULPHATE, SELENATE

8.1. Beryllium sulphide

In a recent survey of the thermodynamic properties of sulphides, selenides and tellurides, Mills [117] has selected a value of $\Delta H_{298} \langle BeS \rangle$ = -55.8 ± 1.0 kcal/mol. His estimated value for S_{298}^0 is 8.0 ± 1.5 cal/°K·mol and we have estimated the following heat capacity equation:

$$C_p = 9.97 + 1.94 \times 10^{-3} \, T - 2.30 \times 10^5 \, T^{-2} \quad (298 - 1800°K)$$

8.2. Beryllium sulphate

The heat of formation of α-$\langle BeSO_4 \rangle$ has been determined by Bear and Turnbull [118] from measurements of the heat of solution of $\langle Be \rangle$ and α-$\langle BeSO_4 \rangle$ in concentrated $[HF]_{aq.}$ and the heat of reaction of

H_2SO_4 with $BeSO_4$ in HF solution. The resulting value is: $\Delta H_{298} \, \alpha - \langle BeSO_4 \rangle$ = -286.65 ± 0.5 kcal/mol. Taylor et al. [119] have measured the heats of solution of $\langle Be \rangle$ and $\alpha - \langle BeSO_4 \rangle$ in H_2SO_4 and obtained a value of -287.55 ± 0.13 kcal/mol for the heat of formation of $\alpha - \langle BeSO_4 \rangle$. JANAF have selected the average value of these two results to give $\Delta H_{298} \, \alpha - \langle BeSO_4 \rangle$ = -287.0 ± 0.8 kcal/mol.

The standard entropy of $\alpha - \langle BeSO_4 \rangle$ has been obtained from the low-temperature heat capacity measurements of Taylor et al. [120], giving S^0_{298} = 18.64 cal/°K·mol. The same authors have measured the enthalpy of $\langle BeSO_4 \rangle$ in the temperature range 366 to 864°K, while the transformation temperatures of 863°K ($\alpha \rightarrow \beta - \langle BeSO_4 \rangle$) and 908°K ($\beta \rightarrow \gamma - \langle BeSO_4 \rangle$) observed by Bosik et al. [121] have been used by JANAF, together with the single enthalpy value obtained by Taylor et al. at 863.9°K, to give a heat of transformation ($\alpha \rightarrow \beta$) of 0.266 kcal/mol at 863°K. A value for the heat of the $\beta \rightarrow \gamma$ transformation has been chosen by JANAF so as to give good agreement with the equilibrium vapour pressure data obtained by Marchal [122] in the temperature range 863 - 1103°K. Their selected value for $L_t \, \beta \rightarrow \gamma - \langle BeSO_4 \rangle$ is 4.673 kcal/mol at 908°K. The following equations represent the heat capacity of α-, β- and $\gamma - \langle BeSO_4 \rangle$ respectively:

$$C_p = 26.96 - 2.21 \times 10^{-3} \, T + 18.17 \times 10^{-6} \, T^2 - 6.62 \times 10^5 \, T^{-2} \quad (298 - 863°K)$$

$$= 38.73 \quad (863 - 908°K)$$

$$= 69.32 - 12.56 \times 10^{-3} \, T + 2.03 \times 10^{-6} \, T^2 - 171.51 \times 10^5 \, T^{-2} \quad (908 - 1500°K)$$

8.3. Beryllium selenate

The heat of formation of $\langle BeSeO_4 \rangle$ has been reported by Selivanova and Shneider [123] to be -213.2 kcal/mol.

9.   MISCELLANEOUS

Thermodynamic data for a number of substances not discussed previously in this article have been tabulated by the National Bureau of Standards in their recent publication TN 270-6 [3]. No references or error limits have been given with their selected values, which are reproduced in Table I. The references in Table I are obtained from NBS Circular 500 [124] which records the earlier work on most of the substances listed in this table.

10. THERMODYNAMIC PROPERTIES OF BERYLLIUM ALLOYS

In this section, published data for beryllium alloys, including inter-metallic compounds, are presented in an assessed form. The tabulations of Hultgren et al. [4] have been frequently used as a reference source and the selected values they quote are sometimes repeated in the following discussions of individual alloy systems. In certain cases, however, values have been adjusted to give better accord with the published phase diagram or with more recent experimental data.

10.1. Beryllium-aluminium

Serebryakov et al. [132] have carried out e.m.f. measurements on liquid alloys dilute in beryllium. Their investigations were made in the temperature range 953 - 1073°K for compositions of N_{Be} = between 0.00224 and 0.0130. At the experimental temperatures the liquid solutions were found to obey Henry's Law over the entire concentration range investigated. The expression derived by the authors for the temperature variation of the solubility of beryllium in aluminium does not reproduce the liquidus of the phase diagram very closely, and enthalpy and entropy values obtained from the temperature coefficients of the measurements are not considered to be reliable.

Schaub, Potard and Desré [133] have measured the vapour pressure of beryllium and aluminium over liquid alloys of compositions of N_{Be} = between 0.389 and 0.956 in the temperature range 1642 - 1760°K. The temperature coefficients of their measurements provide $\Delta \bar{H}_{Be}$ and $\Delta \bar{S}_{Be}$ values which lead to reasonable agreement between the calculated and experimental liquidus of the phase diagram. The partial enthalpies and entropies of beryllium are therefore considered to be fairly reliable, but some adjustment of the values has been made to give greater consistency with the liquidus.

Bienvenu et al. [134] have determined a value for the activity coefficient of aluminium in liquid beryllium at a temperature of 1600°K from studies of the distribution of aluminium between liquid beryllium and liquid tin.

Data for liquid alloys at 1600°K
(liquid beryllium and liquid aluminium standard states)

N_{Be}	$\Delta \bar{G}_{Be}$ (cal/g-atom)	$\Delta \bar{G}_{Al}$ (cal/g-atom)	$\Delta \bar{H}_{Be}$ (cal/g-atom)	$\Delta \bar{S}_{Be}$ (cal/g-atom·°K)	ΔG (cal/g-atom)
0.001 [a]	-8095				
0.005 [a]	-4900				
0.01 [a]	-3520				
0.4	-1610	-1685	6470	5.05	-1655
0.5	-1143 ± 100	-2152 ± 100	5112 ± 200	3.91 ± 0.3	-1647 ± 100
0.6	-804	-2585	3756	2.85	-1516
0.7	-543	-2977	2450	1.87	-1273
0.8	-322	-3401	1278	1.00	-938
0.9	-164	-4288	380	0.34	-576

[a] The reference temperature for these data is 1000°K (liquid beryllium standard state).

10.2. Beryllium-cerium

The vapour pressure of beryllium over the nearly-pure metal (N_{Ce} = 0.0003) and over an alloy of composition $Be_{13}Ce$ (N_{Ce} = 0.0714) has been measured in the temperature range 1193 - 1523°K by Amonenko et al. [135]. Their data are represented by the equations

$\log p$ (mmHg) = 9.35 - 17 000/T and $\log p$ (mmHg) = 10.473 - 18 990/T for the two cases respectively. These expressions enable a value of $\Delta \bar{G}_{Be}$ of -1935 cal/g- atom to be calculated for the $Be_{13}Ce$ phase at a temperature of 1400°K.

Data for solid alloys at 1400°K
(solid α-Be standard state)

N_{Be}	Phase	$\Delta \bar{G}_{Be}$ (cal/g-atom)
0.0714	$Be_{13}Ce$	-1935

10.3. Beryllium-copper

Partial Gibbs energies of beryllium for solid alloys have been obtained from the e.m.f. studies of Anfinogenov et al. [136]. Their measurements were made in the temperature range 983 - 1108°K for alloys of compositions of N_{Cu} = between 0.004 and 0.98. The results are scattered and have been corrected by Hultgren et al. to agree with the solid-phase boundaries given by Jacobson and Hammond [137]. Partial Gibbs energies of copper have been obtained by Gibbs-Duhem integration.

Bienvenu et al. [134] have obtained a value for the activity coefficient of copper (γ_{Cu}) at infinite dilution in beryllium from measurements of the distribution coefficient of copper between liquid beryllium and liquid lead. However, the value of $\Delta \bar{G}_{Cu}^E$ given below is based on the assessment of Hultgren et al. for γ_{Cu} at N_{Pb} = 1.0 in the Cu-Pb system rather than on the value used by the authors.

Values selected by Hultgren et al. for solid and liquid alloys are given below.

Data for solid alloys at 1073°K
(solid α- Be and solid copper standard states)

N_{Cu}	Phase	$\Delta \bar{G}_{Cu}$ (cal/g-atom)	$\Delta \bar{G}_{Be}$ (cal/g-atom)	ΔG (cal/g-atom)
0.00	(α-Be)	$-\infty$	0	0
0.057[a]	(α-Be)	-17 670	-300	-1290
0.191[a]	δ	-17 670	-300	-3615
0.25		-3630	-3850	-3795
0.324[a]	δ	-3230	-4000	-3750
0.509[a]	β'	-3230	-4000	-3610
0.519[a]	β'	-2665 ± 800	-4600 ± 800	-3595 ± 800
0.616[a]	β	-2665	-4600	-3405
0.65		-2545	-4810	-3335
0.736[a]	β	-1100	-8400	-3030
0.851[a]	(Cu)	-1100	-8400	-2190
0.90		-820	-10 500	-1790
1.00	(Cu)	0	$-\infty$	0

[a] Phase boundary.

Data for liquid alloys at 1623°K
(liquid copper standard state)

N_{Cu}	$\Delta\bar{G}_{Cu}^E$ (cal/g-atom)
0.0	434 ± 600

10.4. Beryllium-iron

Liquid alloys in the concentration range N_{Fe} = 0.0114 - 0.0529 have
been investigated by Daguet et al. [138], who determined the distribution
coefficient of iron between liquid tin and liquid beryllium at a temperature
of 1645°K. The miscibility gap in the Fe-Sn system was used to calculate
the activity coefficient of iron at N_{Sn} = 1.0. This value was assumed to
be constant over the entire composition range covered, to N_{Sn} = 0.9975.
Gibbs energy values calculated from the data by Hultgren et al. are given
below.

Data for liquid alloys at 1645°K
(liquid beryllium and liquid iron standard states)

N_{Fe}	$\Delta\bar{G}_{Fe}$ (cal/g-atom)	$\Delta\bar{G}_{Be}$ (cal/g-atom)	ΔG (cal/g-atom)
0.01	-24 140	-35	-276
0.02	-21 410	-75	-502
0.03	-19 545	-123	-706
0.04	-17 785	-186	-890
0.05	-15 210	-310	-1055

10.5. Beryllium-gadolinium

Kruglykh et al. [139] have measured the vapour pressure of beryllium
over $Be_{13}Gd$ (N_{Gd} = 0.071) in the temperature range 1328 - 1513°K. From
their results they obtained the equation log p (mmHg) = 10.0 - 19 180/T.
The data have been used to calculate $\Delta\bar{G}_{Be}$ for the $Be_{13}Gd$ phase at 1400°K.

Data for solid alloys at 1400°K
(solid α-Be standard state)

N_{Gd}	Phase	$\Delta\bar{G}_{Be}$ (cal/g-atom)
0.071	$Be_{13}Gd$	-6850

10.6. Beryllium-lanthanum

Amonenko et al. [140] have measured the vapour pressure of beryllium over $Be_{13}La$ (N_{La} = 0.071) in the temperature range 1355 - 1540°K. Their results are represented by the equation log p (mmHg) = 8.73 - 16 600/T. From the measurements, $\Delta \overline{G}_{Be}$ for the $Be_{13}La$ phase has been calculated at 1400°K.

Data for solid alloys at 1400°K
(solid α - Be standard state)

N_{Be}	Phase	$\Delta \overline{G}_{Be}$ (cal/g-atom)
0.071	$Be_{13}La$	-3200

10.7. Beryllium-molybdenum

The heat content of a solid alloy of composition $Be_{12}Mo$ (N_{Mo} = 0.0769) has been measured in the temperature range 303 - 1073°K by Walker, Ewing and Miller [14]. Their data have been used to derive the following C_p equation:

$$C_p = 57.72 + 28.59 \times 10^{-3}\,T - 12.05 \times 10^5\,T^{-2} \text{ cal/°K} \cdot \text{mol}$$

10. 8. Beryllium-niobium

Walker, Ewing and Miller [14] have measured the heat content of $Be_{12}Nb$ (Nb = 0. 0769) in the temperature range 303 - 1073°K. Their results have been used to obtain the following equation for the heat capacity of $Be_{12}Nb$:

$$C_p = 63.\,70 + 18.\,81 \times 10^{-3}\,T - 15.\,15 \times 10^5\,T^{-2} \text{ cal/°K} \cdot \text{mol}$$

The National Bureau of Standards, in Technical Note TN 270-6 [3], quotes the heats of formation at 298°K of $NbBe_2$, $NbBe_8$ and $NbBe_{12}$ as -4. 87, -2. 22 and -1. 55 kcal/g-atom, respectively.

10.9. Beryllium-nickel

Kornilov et al. [141] and Ilyushchenko et al. [142] have obtained Gibbs energy values for solid alloys using an e.m.f. method. They have investigated alloys of compositions of N_{Ni} = between 0. 03 and 0. 96 in the temperature range 963 - 1113°K. No attempt has been made to calculate partial enthalpy or entropy values because the temperature coefficients of the data scatter too widely. Values selected by Hultgren et al. are given below.

Data for solid alloys at 1100°K
(solid α-Be and solid nickel standard states)

N_{Ni}	Phase	$\Delta\bar{G}_{Be}$ (cal/g-atom)	$\Delta\bar{G}_{Ni}$ (cal/g-atom)	ΔG (cal/g-atom)
0.00	(α-Be)	0	$-\infty$	0
0.04[a]	(α-Be)	-251	-36 110	-1685
0.16[a]	γ	-251	-36 110	-5990
0.20		-4560	-16 715	-6990
0.205[a]	γ	-4610	-16 520	-7050
0.46[a]	δ	-4610	-16 520	-10 090
0.50		-17 240 ± 4000	-2403 ± 500	-9820 ± 2500
0.51[a]	δ	-18 160	-1503	-9665
0.92[a]	(Ni)	-18 160	-1503	-2836
0.95		-32 148	-488	-2071
1.00	(Ni)	$-\infty$	0	0

[a] Phase boundary.

10.10. Beryllium-plutonium

Akhachinskij and Kopytin [143] have determined the heat of formation of $Be_{13}Pu$ using acid solution calorimetry.

Data for solid alloys at 298°K
(α-Be and α-Pu standard states)

N_{Pu}	Phase	ΔH (cal/g-atom)
0.0714	$Be_{13}Pu$	-2550 ± 250

10.11. Beryllium-tantalum

Walker, Ewing and Miller [14] have measured the heat content of $Be_{12}Ta$ in the temperature range 303 - 1073°K. Their results can be represented by the heat capacity equation:

$$C_p = 58.63 + 25.61 \times 10^{-3}\, T - 11.83 \times 10^5\, T^{-2} \text{ cal/°K·mol}$$

Booker, Paine and Stonehouse [144] have measured the vapour pressure of beryllium in equilibrium with the phases $Be_{12}Ta$ and $Be_{17}Ta_2$ in the temperature range 1533 - 1728°K. Their results are represented by the

equations $\log p_{Be} = 3.277 - 12\,540/T$ and $\log p_{Be} = 2.938 - 12\,340/T$, respectively. From these results $\Delta \bar{G}_{Be}$ has been calculated, but integral ΔG values cannot be obtained.

Data for solid alloys at 1600°K
(solid β-Be standard state)

N_{Ta}	Phase	$\Delta \bar{G}_{Be}$ (cal/g-atom)
0.0769	$Be_{12}Ta$ (Ta-rich)	-3726
0.1053	$Be_{17}Ta_2$ (Be-rich)	-3726
0.1053	$Be_{17}Ta_2$ (Ta-rich)	-5293

10.12. Beryllium-titanium

Walker, Ewing and Miller [14] have measured the heat content of $Be_{12}Ti$ in the temperature range 303 - 1073°K. Their results can be represented by the equation:

$$C_p = 60.15 + 25.73 \times 10^{-3}\, T - 13.39 \times 10^5\, T^{-2} \text{ cal/°K} \cdot \text{mol}$$

10.13. Beryllium-uranium

Using acid solution calorimetry, Ivanov and Tumbakov [145] have measured the heat of formation of $Be_{13}U$ at 298°K. Pyatkov et al. [146] have determined values of $\Delta \bar{G}_U$ for solid alloys using an e.m.f. method. They have investigated three alloys of compositions $N_U = 0.0038$, 0.0094 and 0.0145 in the temperature range 973 - 1123°K. From their results a value for the Gibbs energy of formation at 1050°K of $Be_{13}U$ of -390 cal/g-atom is obtained (γ-U and α-Be standard states). By converting the ΔH value of Ivanov and Tumbakov to a standard state of γ-U, and assuming $\Delta C_p = 0$ between 298°K and 1050°K, a value for the entropy of formation of $Be_{13}U$ can be calculated from the measured ΔH and ΔG values.

Data for solid alloys at 298°K
(α-Be and α-U standard states)

N_U	Phase	ΔH (cal/g-atom)	ΔS (cal/g-atom · °K)
0.0714	$Be_{13}U$	$-2800 \pm (300)$	-2.29 ± 1.0

10.14. Beryllium-yttrium

Amonenko et al. [140] have measured the equilibrium vapour pressure
of beryllium over $Be_{13}Y$ in the temperature range 1313 - 1563°K. Although
the authors state that the phase decomposed into its components at the
temperatures of investigation, the phase diagram indicates that this can
only be true at temperatures below the eutectic temperature (1343°K).
Therefore, the Gibbs energy of formation at 1330°K has been calculated
from values obtained below the eutectic temperature.

Data for solid alloys at 1330°K
(solid α-Be and solid yttrium standard states)

N_Y	Phase	ΔG (cal/g-atom)
0.071	$Be_{13}Y$	-3875 ± 500

10.15. Beryllium-zirconium

McMullen [147] has measured the equilibrium vapour pressure of
beryllium over two-phase alloys of compositions of N_{Zr} = between 0.07
and 0.33 in the temperature range 1223 - 1616°K. His results are preferred
to the considerably different values obtained by Booker, Paine and
Stonehouse [144] (N_{Zr} = 0.07, 0.105; 1533 - 1728°K) who obtained vapour
pressure values for pure beryllium which differ widely from the selected
data. Values of ΔG at 1300°K calculated by Hultgren et al. are given below.

Data for solid alloys at 1300°K
(solid α-Be and solid zirconium standard states)

N_{Zr}	Phase	ΔG (cal/g-atom)
0.071	γ	-4030 ± 100
0.105	δ	-4320
0.167	ϵ	-4700
0.333	ζ	-4210

The heat content data of Walker, Ewing and Miller [14] for $Be_{13}Zr$
(γ) in the temperature range 303 - 1073°K have been used to obtain the
following C_p equation:

$$C_p = 60.48 + 32.80 \times 10^{-3} \, T - 11.98 \times 10^5 \, T^{-2} \text{ cal/°K} \cdot \text{mol}$$

11. TABULATION

In this section, thermochemical data for beryllium and its inorganic compounds are presented in the form of tabulations of heats of formation and standard entropies (Table II), heats and temperatures of transformation, fusion and vaporization (Table III), heat capacities (Table IV), vapour pressures (Table V), and Gibbs energies of formation (Table VI). The latter table presents values calculated at selected temperatures, thereby avoiding the inaccuracies, although small, which would be caused by representing the data by simple two- or three-term equations. Such εquations do not directly reflect the transformations which may occur in the reactants or products. For any temperature, the standard states are the appropriate forms of the pure reactants at that temperature. Uncertain values are enclosed in round brackets.

TABLE I.   HEATS OF FORMATION AND STANDARD ENTROPIES
TABULATED BY NBS [3, 124]

Substance	ΔH_{298} (kcal/mol)	Reference	S^0_{298} (cal/°K·mol)
$\langle BeBr_2 . 2H_2S \rangle$	-112.1	[125]	
$\langle BeBr_2 . 4NH_3 \rangle$	-235.1	[57,58]	
$\langle BeBr_2 . 6NH_3 \rangle$	-274.4	[57,58]	
$\langle BeBr_2 . 10NH_3 \rangle$	-349.2	[57,58]	
$\langle BeCO_3 \rangle$	-245		
$\langle BeCl_2 . 4H_2O \rangle$	-432.2	[57]	
$\langle BeCl_2 . 2NH_3 \rangle$	-201.7	[57,58]	
$\langle BeCl_2 . 4NH_3 \rangle$	-260.4	[57,58]	
$\langle BeCl_2 . 6NH_3 \rangle$	-298.2	[57,58]	
$\langle BeCl_2 . 12NH_3 \rangle$	-409.9	[57,58]	
$\langle BeI_2 . 2H_2S \rangle$	-69.8	[125]	
$\langle BeI_2 . 4NH_3 \rangle$	-207.6	[57,58]	
$\langle BeI_2 . 6NH_3 \rangle$	-247.2	[57,58]	
$\langle BeI_2 . 13NH_3 \rangle$	-378.4	[57,58]	
$\langle BeMoO_4 \rangle$	-328	[126]	
(BeOAl)	-5		
$\langle BeSO_4 . H_2O \rangle$	-364.2	[127-131]	
$\langle BeSO_4 . 2H_2O \rangle$	-435.7	[127-131]	39.01
$\langle BeSO_4 . 4H_2O \rangle$	-579.3	[127-131]	55.68
$\langle BeSeO_4 . 2H_2O \rangle$	-360.3		
$\langle BeSeO_4 . 4H_2O \rangle$	-505.0		

TABLE II. HEATS OF FORMATION AND STANDARD ENTROPIES

Substance	ΔH_{298} (kcal/mol)	S^0_{298} (cal/°K · mol)
$\langle Be \rangle$	0	2.27 ± 0.02
(Be)	77.5 ± 1.5	32.54
$\langle BeAl_2O_4 \rangle$	-549.4 ± 3	15.84
$\langle BeAl_6O_{10} \rangle$	-1342.6 ± 5	42.0
$\langle Be_3B_2O_6 \rangle$	-748.9 ± 3.5	22.1 ± 3
(BeBr)	8.8 ± 5.0	(54.84)
$\langle BeBr_2 \rangle$	-84.5	25.4 ± 2
(BeBr₂)	-53.4	66.4 ± 2
$\langle Be_2C \rangle$	-27.96 ± 0.5	3.9 ± 1.0
(BeCl)	2.0 ± 1.0	53.0 ± 2.5
α-$\langle BeCl_2 \rangle$	-117.3 ± 0.8	19.76 ± 0.06
β-$\langle BeCl_2 \rangle$	-118.6 ± 0.8	18.12 ± 0.05
(BeCl₂)	-86.1 ± 2.5	60 ± 1
(Be₂Cl₄)	(-196.3)	92.5 ± 2
(BeF)	-41.8 ± 2.5	49.15
$\langle BeF_2 \rangle$ quartz	-245.4 ± 1.0	12.75 ± 0.05
{BeF₂} glass	-244.3 ± 1.0	
(BeF₂)	-190.25 ± 1.0	54.36 ± 0.3
(BeH)	77 ± 7	42.24
$\langle BeH_2 \rangle$	-4.55 ± 0.5	
(BeH₂)	(30)	41.4
(BeI)	24.7 ± 5.0	(56.7)
$\langle BeI_2 \rangle$	-46.0	28.8 ± 2
(BeI₂)	-15.7	70.4 ± 2
$\langle BeLiF_3 \rangle$	-394.5 ± 2.5	21.3 ± 2
(BeLiF₃)	-212	64
$\langle BeLi_2F_4 \rangle$	-544.2 ± 2.0	29.8 ± 2
$\langle Be_2Li_2O_3 \rangle$	-437.8 ± 2.0	
$\langle Be_3N_2 \rangle$ cubic	-140.9 ± 0.6	8.20 ± 0.05
$\langle Be_3N_2 \rangle$ hexag.	-136.5	
$\langle BeO \rangle$	-145.4 ± 0.8	3.38 ± 0.05
(BeO)	28	47.2
(BeO)₂	-103	59.2

TABLE II.   (cont.)

Substance	ΔH_{298} (kcal/mol)	S^0_{298} (cal/°K · mol)
$(BeO)_3$	-260	65. 3
$(BeO)_4$	-391	72. 3
$(BeO)_5$	-518	77. 2
$(BeO)_6$	-651	82
(Be_2O)	-20 ± 10	52. 7
(Be_2OF_2)	-292	71. 4
(BeOH)	-47. 5 ± 7	(53. 28)
α - $\langle Be(OH)_2 \rangle$	-215. 7 ± 0. 5	11. 8 ± 2
β - $\langle Be(OH)_2 \rangle$	-216. 5 ± 0. 5	11. 0 ± 2
$(Be(OH)_2)$	-156. 4 ± 5	(59. 2)
$\langle BeS \rangle$	-55. 8 ± 1. 0	8. 0 ± 1. 5
α - $\langle BeSO_4 \rangle$	-287. 0 ± 0. 8	18. 64
$\langle BeSeO_4 \rangle$	-213. 2	
$\langle Be_2SiO_4 \rangle$	-512. 8 ± 2. 5	15. 37 ± 0. 1

TABLE III.   HEATS AND TEMPERATURES OF TRANSFORMATION, FUSION AND VAPORIZATION

Substance	T_t (°K)	L_t (cal/mol)	T_f (°K)	L_f (cal/mol)	$T_{b.p.}$ (°K)	L_e at b.p. (cal/mol)	L_s at 298°K (cal/mol)
Be	1527 ± 5	(611)	1560 ± 5	(2919)	2745	69 885	77 500 ± 1500
BeBr₂			761	(4500)	(794)	23 900	31 100 ± 1500
BeCl₂	676	1630 ± 150	688	2070 ± 60	805	25 000 ± 2000	32 500 ± 1500
BeF₂	500	53	825	1135	1448	47 650	55 150
BeI₂			753	(5000)	(755)	(23 000)	30 300 ± 2000
BeLi₂F₄			745	10 610			
BeO			2853	19 300 ± 1000			173 400 ± 3000
BeSO₄	863; 908	266; 4673					

TABLE IV. HEAT CAPACITIES

$$C_p = a + bT + cT^2 + dT^{-2} \text{ cal/}^\circ K \cdot mol$$

Substance	C_p (cal/$^\circ$K $\cdot$ mol)				Temperature range ($^\circ$K)
	a	b × 10³	c × 10⁶	d × 10⁻⁵	
α-⟨Be⟩	5.068	1.361	0.23	-1.404	298-1527
β-⟨Be⟩	7.70				1527-1560
{Be}	7.04				1560-2800
(Be)	4.968				298-1900
	4.53	0.14		6.51	1900-3000
⟨BeAl₂O₄⟩	29.26	22.62	-9.36	-8.93	298-1200
	37.58	4.10			1200-2143
⟨BeAl₆O₁₀⟩	88.45	18.57	-2.77	-27.75	298-2150
⟨Be₃B₂O₆⟩	26.90	62.92	-21.08	-9.51	298-1768
(BeBr)	8.80	0.14		-1.06	298-3000
⟨BeBr₂⟩	19.52	1.07		-2.96	298-761
{BeBr₂}	27.0				761-794
(BeBr₂)	14.88	0.01		-2.66	298-3000
⟨Be₂C⟩	9.17	10.76	-2.29	-2.01	298-2400
(BeCl)	8.46	0.49	-0.09	-0.97	298-3000
α-⟨BeCl₂⟩	18.31	2.95		-3.29	298-688
β-⟨BeCl₂⟩	15.69	4.99		-2.01	298-676
{BeCl₂}	29.02				688-805
(BeCl₂)	13.89	0.83	-0.18	-1.67	298-3000
(Be₂Cl₄)	31.40	0.15		-3.58	298-3000
(BeF)	7.69	1.10	-0.21	-0.85	298-3000
⟨BeF₂⟩ quartz	15.56	5.15		-4.20	298-500
	1.24	18.59		13.14	500-825
{BeF₂}	13.81	7.105		-4.51	825-1448
(BeF₂)	12.23	2.02		-1.59	298-1000
	14.78	0.04		-7.83	1000-3000
(BeH)	6.44	1.98	-0.36	-0.08	298-3000
(BeH₂)	7.50	5.66	-1.14	-1.95	298-3000
(BeI)	8.84	0.13		-0.93	298-3000
⟨BeI₂⟩	19.91	0.86		-2.81	298-753
{BeI₂}	27.0				753-900

TABLE IV. (cont.)

Substance	C_p (cal/°K · mol)				Temperature range (°K)
	a	$b \times 10^3$	$c \times 10^6$	$d \times 10^{-5}$	
(BeI_2)	14.89			-2.03	800-3000
$\langle BeLiF_3 \rangle$	18.43	20.29		-2.09	298-633
$(BeLiF_3)$	12.86	21.07	-9.79	-3.26	298-1000
	25.65	0.05		-18.80	1000-3000
$\langle BeLi_2F_4 \rangle$	21.99	35.36		-0.24	298-745
$\{BeLi_2F_4\}$	55.50				745-2000
$\alpha - \langle Be_3N_2 \rangle$	12.89	24.75		-4.22	298-430
	27.37	3.60		-14.23	430-1200
$\langle BeO \rangle$	9.94	2.44	-0.32	-4.15	298-2853
$\{BeO\}$	15.5				2853-4000
(BeO)	7.27	1.39	-0.27	-0.64	298-3000
$(BeO)_2$	15.89	3.26	-0.69	-4.62	298-3000
$(BeO)_3$	20.77	9.04	-1.90	-7.58	298-3000
$(BeO)_4$	32.84	9.15	-1.95	-12.90	298-3000
$(BeO)_5$	47.73	3.64	-0.24	-20.57	298-3000
$(BeO)_6$	50.94	14.02	-3.00	-21.47	298-3000
(Be_2O)	7.74	10.61	-4.61	-0.63	298-1000
	14.73	0.05		-11.03	1000-3000
(Be_2OF_2)	22.16	2.98	-0.62	-4.52	298-3000
$(BeOH)$	8.13	3.73	-0.68	-0.98	298-3000
$\langle Be(OH)_2 \rangle$	4.56	36.75		0.10	298-400
$(Be(OH)_2)$	15.47	6.86	-1.27	-3.83	298-3000
$\langle BeS \rangle$	9.97	1.94		-2.30	298-1800
$\alpha - \langle BeSO_4 \rangle$	26.96	-2.21	18.17	-6.62	298-863
$\beta - \langle BeSO_4 \rangle$	38.73				863-908
$\gamma - \langle BeSO_4 \rangle$	69.32	-12.56	2.03	-171.51	908-1500
$\langle Be_2SiO_4 \rangle$	29.65	18.77	-8.0	-10.84	298-1833

TABLE V. VAPOUR PRESSURES

$\log p$ (mmHg) = $A + B \log T + CT^{-1}$

Substance	log p (mmHg)			Temperature range (°K)
	A	B	C	
$\langle Be \rangle$	11.279	-0.56	-17 058	298-1560
$\{Be\}$	12.483	-1.04	-16 518	1560-2745
$\langle BeBr_2 \rangle$	19.343	-2.57	-7 139	298-761
$\{BeBr_2\}$	9.457		-5 250	761-794
$\langle BeCl_2 \rangle$	17.584	-1.89	-7 365	298-688
$\{BeCl_2\}$	36.605	-8.07	-8 394	688-805
$\langle BeF_2 \rangle$	16.950	-1.69	-12 290	298-825
$\{BeF_2\}$	23.599	-3.75	-12 823	825-1448
$\langle BeI_2 \rangle$	19.443	-2.56	-6 961	298-753
$\{BeI_2\}$	32.307	-6.88	-7 290	753-900
$\langle BeO \rangle$	18.015	-1.77	-38 247	298-2500

TABLE VI. STANDARD GIBBS ENERGIES OF FORMATION FROM THE COMPONENT ELEMENTS

Standard states: α-Be (298-1527°K); β-Be (1527-1560°K); liquid Be (1560-2500°K)

Substance	ΔH_{298} (kcal/mol)	ΔS_{298} (cal/°K·mol)	ΔG^0 (kcal/mol)							
			298°K	500°K	750°K	1000°K	1250°K	1500°K	2000°K	2500°K
$\langle BeAl_2O_4 \rangle$	-549.4	-97.98	-520.2	-500.3	-475.8	-451.3	-425.8	-400.6	-349.6	
$\langle BeAl_6O_{10} \rangle$	-1342.6	-245.9	-1269.3	-1219.4	-1158.1	-1096.3	-1031.9	-968.0	-840.7	
$\langle Be_3B_2O_6 \rangle$	-748.9	-134.5	-708.8	-681.5	-648.0	-615.0	-582.8	-551.2		
$(BeBr)$	8.8	34.4	-1.45	-6.47	-12.09	-17.57	-22.90	-28.10	-37.16	-45.77
$\langle BeBr_2 \rangle$	-84.5	-13.27	-80.6	-74.4	-66.3					
$(BeBr_2)$	-53.4	27.74	-61.7	-63.5	-64.8	-66.1	-67.3	-68.4	-69.5	-70.3
$\langle Be_2C \rangle$	-27.96	-2.01	-27.36	-26.93	-26.28	-25.55	-24.78	-23.98	-20.38	
$(BeCl)$	2.0	24.09	-5.18	-10.00	-15.83	-21.50	-27.04	-32.44	-41.90	-50.90
$\{\langle BeCl_2 \rangle\}$	-118.6	-37.44	-107.4	-100.1	-91.7					
$(BeCl_2)$	-86.1	4.44	-87.4	-88.3	-89.4	-90.4	-91.4	-92.3	-92.8	-93.0
(Be_2Cl_4)	-196.3	-18.62	-190.8	-187.2	-183.0	-178.9	-174.8	-170.7	-160.4	-149.7
(BeF)	-41.8	22.66	-48.6	-53.1	-58.5	-63.8	-68.9	-73.8	-82.4	-90.5
$\{\langle BeF_2 \rangle\}$	-245.4	-37.97	-234.1	-226.5	-217.4	-208.9	-200.7			
(BeF_2)	-190.25	3.64	-191.3	-192.0	-192.8	-193.5	-194.1	-194.6	-194.4	-193.8
(BeH)	77	24.37	69.7	64.9	59.0	53.3	47.7	42.2	32.6	23.3
(BeH_2)	30	7.92	27.6	26.2	24.9	23.7	22.6	21.6	20.9	20.4
(BeI)	24.7	40.48	12.6	5.6	0	-5.5	-10.9	-16.1	-25.2	-33.8
$\langle BeI_2 \rangle$	-46.0	-1.23	-45.6	-43.3	-35.3					
(BeI_2)	-15.7	40.41	-27.7	-33.5	-35.0	-36.4	-37.7	-39.0	-40.4	-41.4

TABLE VI. (cont.)

Substance	ΔH_{298} (kcal/mol)	ΔS_{298} (cal/°K·mol)	ΔG^0 (kcal/mol)							
			298°K	500°K	750°K	1000°K	1250°K	1500°K	2000°K	2500°K
$\langle BeLiF_3 \rangle$	-394.5	-60.59	-376.4	-364.2				-177.9	-163.6	
$(BeLiF_3)$	-212	-17.9	-206.7	-202.6	-196.8	-190.7	-184.3	-435.6	-407.7	
$\{\langle BeLi_2F_4 \rangle\}$	-544.2	-83.27	-519.4	-502.5	-481.6	-465.3	-450.0	-435.6	-407.7	
$\langle Be_3N_2 \rangle$	-140.9	-44.38	-127.7	-118.6	-107.4	-96.4				
$\langle BeO \rangle$	-145.4	-23.39	-138.4	-133.7	-127.8	-122.0	-116.3	-110.6	-98.4	-86.3
(BeO)	28	20.43	21.9	17.8	12.9	8.2	3.6	-0.9	-8.4	-15.5
$(BeO)_2$	-103	5.66	-104.7	-105.7	-106.6	-107.3	-107.8	-108.1	-106.1	-103.4
$(BeO)_3$	-260.0	-15.01	-255.5	-252.1	-247.3	-242.1	-236.6	-230.8	-215.6	-199.5
$(BeO)_4$	-391.0	-34.78	-380.6	-373.2	-363.6	-353.6	-343.4	-332.9	-307.3	-280.9
$(BeO)_5$	-518.0	-56.65	-501.1	-489.2	-474.1	-458.6	-442.9	-426.9	-389.0	-350.0
$(BeO)_6$	-651.0	-78.63	-627.6	-611.1	-590.1	-568.8	-547.2	-525.3	-474.8	-423.1
(Be_2O)	-20	23.66	-27.1	-31.7	-37.2	-42.4	-47.5	-52.3	-59.3	-65.6
(Be_2OF_2)	-292	-6.09	-290.2	-288.9	-287.3	-285.5	-283.6	-281.5	-275.1	-268.1
$(BeOH)$	-47.5	10.91	-50.8	-52.8	-55.0	-56.9	-58.6	-60.1	-61.8	-63.0
$\langle Be(OH)_2 \rangle$	-215.7	-70.68	-194.6							
$(Be(OH)_2)$	-156.4	-23.28	-149.5	-144.5	-138.1	-131.6	-124.9	-118.2	-103.7	-89.0
$\langle BeS \rangle$	-55.8	-1.89	-55.2	-54.6	-55.3	-50.1	-44.9	-39.8		
$\langle BeSO_4 \rangle$	-287.0	-89.30	-260.4	-242.1	-220.6	-195.5	-171.6	-148.5		
$\langle Be_2SiO_4 \rangle$	-512.8	-91.68	-485.5	-466.9	-444.0	-421.4	-398.9	-376.6		

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