

# Measured Enthalpy and Derived Thermodynamic Properties of Alpha Beryllium Nitride, $\text{Be}_3\text{N}_2$ , from 273 to 1200 K<sup>1</sup>

Thomas B. Douglas and William H. Payne<sup>2</sup>

Institute for Basic Standards, National Bureau of Standards, Washington, D.C. 20234

(June 9, 1969)

The relative enthalpy of a sample of alpha beryllium nitride,  $\text{Be}_3\text{N}_2$ , of 95 percent purity was precisely measured over the temperature range 273 to 1173 K using a drop calorimetric method. Corrections were applied for the impurities, and the resulting heat capacity-temperature function was required to join smoothly that from recent precise NBS adiabatic calorimetry which covered the range 20 to 315 K. The enthalpy, heat capacity, entropy, and Gibbs free-energy function were computed from empirical functions of temperature and tabulated from 273 to 1200 K.

Key words: Beryllium nitride; drop calorimetry; enthalpy data; light-element compounds; refractory crystals; thermodynamic properties.

## 1. Introduction

In a research program for the past several years at the National Bureau of Standards, the thermodynamic properties of numerous light-element compounds have been under investigation. One of the simplest of these compounds, beryllium nitride ( $\text{Be}_3\text{N}_2$ ), is the subject of the present paper. Several investigators [1, 2, 3]<sup>3</sup> have determined the structure of the crystalline form which is stable at relatively low temperatures ("alpha") (bcc lattice with a D5, or "anti- $\text{Mn}_2\text{O}_3$ ", structure). It has been reported to undergo a phase transition at 1400 °C to a hexagonal structure ("beta"), it being stated that its conversion to the alpha form has not been observed [3]. The melting point lies at or above 2000 °C, and even at somewhat lower temperatures it decomposes reversibly to an appreciable extent into its elements. Its decomposition equilibrium has recently been studied from 1450 to 1650 K by a torsion-effusion method [4], and the resulting value for its heat of formation is in very good agreement with two independent calorimetric determinations of the same property [5, 6].

The present paper reports enthalpy measurements on  $\alpha\text{-Be}_3\text{N}_2$  over the temperature range 273 to 1173 K. Recent precise heat-capacity measurements at the National Bureau of Standards from 20 to 315 K [7] define the heat capacity, as well as the enthalpy and

entropy relative to 0 K, in the overlap region near room temperature. Another series of low-temperature heat-capacity measurements (25 to 310 K), which are in good agreement, has been reported [8]. The only high-temperature enthalpy measurements that have been reported are three which covered the temperature range 273 to 773 K [9].

## 2. Sample

The sample of beryllium nitride was prepared specifically for the NBS calorimetric measurements by the Brush Beryllium Co., of Cleveland, Ohio, by reacting pure nitrogen and beryllium powder at elevated temperatures and crushing the product to particle sizes between 0.3 and 0.8 mm. The material received was thoroughly mixed and preserved in an atmosphere of dry argon. A specimen was subjected to x-ray examination at the Bureau, showing only the cubic (alpha) form within the detection limits of this method.

Another specimen (of about 3.7 g) was weighed into a sample container of 80 Ni-20 Cr for the enthalpy measurements, and was thereafter kept in a desiccator, or in an atmosphere of dry helium during the measurements. The sample container was deliberately closed not quite gas-tight, in order to allow any chemically bound hydrogen present to escape as water vapor or ammonia during heating. The sample mass did in fact fluctuate by several tenths of a percent during the initial 5 hrs of heating (at 400 to 600 °C), and the enthalpy measurements made then were discarded. Thereafter the mass of the sample remained constant

<sup>1</sup> Research sponsored by the Advanced Research Projects Agency, U.S. Department of Defense, under Order No. 20, and by the Air Force Office of Scientific Research, Office of Aerospace Research, U.S. Air Force, under AFOSR Contract No. ISSA 68-0004.

<sup>2</sup> Present address: Science Information Exchange, 1730 M St., N.W., Washington, D.C. 20036.

<sup>3</sup> Figures in brackets indicate the literature references at the end of this paper.

within a range of about 0.1 percent. Despite the efforts to exclude moisture and oxygen, undoubtedly appreciable hydrolysis and possibly also oxidation of the sample occurred during the initial changes in sample mass, and therefore the chemical composition on which the corrections for impurities were based was calculated solely from the analyses of the sample performed after the completion of the enthalpy measurements.

The results of the analyses of the sample, carried out in the Analytical Chemistry Division of the Bureau after the enthalpy measurements, are recorded in table 1. Each individual analysis for beryllium and nitrogen was made on an aliquot portion of the sample in solution in dilute hydrochloric acid, the beryllium being precipitated by ammonium hydroxide and weighed as BeO, and the nitrogen being determined by the Kjeldahl method with standardization against ammonium dihydrogen phosphate. Of the numerous elements searched for spectrochemically, only those detected are listed in the table.

TABLE 1. Chemical and spectrochemical analyses of the sample

Elements	Individual analyses	Mean
	<i>Weight %</i>	<i>Weight %</i>
	(a) By chemical analysis	
Be	<sup>a</sup> 48.63, <sup>a</sup> 48.67	<sup>b</sup> 48.57
N	48.07, 48.13, 48.23	48.14
	(b) By qualitative spectrochemical analysis	
Al	0.001—0.01	
Ca	< 0.001	
Cr	0.001—0.01	
Cu	< 0.001	
Fe	0.01—0.1	
Mg	0.001—0.01	
Mn	< 0.001	
Ni	0.001—0.01	
Si	0.01—0.1	
Ti	0.001—0.01	

<sup>a</sup> Uncorrected for the metallic elements listed below.

<sup>b</sup> This value includes a correction of -0.08 percent to account for the oxides of the 10 elements listed under (b) below which were assumed to have been weighed as BeO.

The heating of the sample to approximately constant weight is believed to have simplified the problem of interpreting its subsequent analysis by allowing the reasonable assumption that water and ammonia (even as hydrates or ammoniates) were absent. The small amounts of foreign metallic elements found were assumed to be present in half the respective maximum amounts indicated in table 1, and, when assumed furthermore to be present in the form of their most stable oxides, account for 0.22 weight percent of the sample. The remainder is assumed to have been composed entirely of Be<sub>3</sub>N<sub>2</sub>, BeO, and, because of the method of preparation of the sample, possibly some Be metal (or an amount of subnitride or suboxide that would evolve an equal amount of hydrogen when treated with dilute acid). Although the sample was not analyzed for oxygen, the average beryllium and nitrogen

analyses in table 1 correspond to definite percentages of Be<sub>3</sub>N<sub>2</sub> and BeO, plus several tenths of a percent of Be metal.

However, it seems more likely that much less (if any) Be metal was present. The original sample showed only 0.10 ± 0.01 percent, the sample on which the NBS low-temperature calorimetry had been conducted showed only 0.04 ± 0.00 percent, and the small amount of water and possibly oxygen that must have been initially in contact with the specimen used in the present calorimetry would be expected to have oxidized most of these small amounts of the free metal at the elevated temperatures. It was therefore assumed that the remaining 99.78 percent of the sample was composed wholly of Be<sub>3</sub>N<sub>2</sub> and BeO, and that either the beryllium or the nitrogen analysis (or both) was somewhat in error. This is equivalent to assuming that the true weight percentages of these two elements are related according to

$$\%N = 3.8904 \times \%Be - 139.87. \quad (1)$$

According to table 1 and the analysis of the original sample, the beryllium analysis was several times as precise as the nitrogen analysis (very possibly because of the much smaller amount of sample used in each Kjeldahl analysis and the greater chance for error from the distillation and titration of this method). One might therefore conclude that the beryllium analysis was more accurate; and, according to eq (1) it would need to be, in order to establish the percentage of Be<sub>3</sub>N<sub>2</sub> with a given accuracy. It may be added that the above-mentioned analyses of the original sample and the sample that had undergone low-temperature calorimetry showed similar discrepancies, and consequently afforded no clue to the ambiguity under discussion here.

It was decided to assume, somewhat arbitrarily, that the sample contained 48.39 percent Be and 48.40 percent N, which are respectively 0.18 percent below and 0.26 percent above the corresponding mean values in table 1. (If the mounts of foreign elements were nearer the maxima in the table, the Be discrepancy would be smaller.) This leads to the final assumed sample composition shown in table 2. The heat capacities of Be<sub>3</sub>N<sub>2</sub> and BeO *per unit mass* are sufficiently close to each other as to render the uncertainty in the finally corrected thermal values smaller from this arbitrariness of assumed composition than from other sources.

### 3. Enthalpy Measurements

The enthalpy measurements were made using the "drop" method, which, as used in this laboratory, is described in detail in a recent publication [10]. Briefly, the method is as follows. The sample in its container is suspended inside a vertical thick-wall silver pipe in a furnace until it has had time to reach the temperature of the silver. It is then dropped into a Bunsen ice calorimeter, which measures precisely the heat evolved by the sample and container in cooling

to 0 °C (273.15 K). In order to account for the enthalpy change of the container itself and the small amount of heat lost from its surface during the drop, a separate measurement is made on the empty container at the same furnace temperature.

TABLE 2. Assumed chemical composition of the sample

Substance	Weight percent	Substance	Weight percent
Be <sub>3</sub> N <sub>2</sub>	95.11	Fe <sub>2</sub> O <sub>3</sub>	0.07
BeO	4.67	MgO	.008
Be metal	0.00	NiO	.006
Al <sub>2</sub> O <sub>3</sub>	.009	SiO <sub>2</sub>	.11
Cr <sub>2</sub> O <sub>3</sub>	.007	TiO <sub>2</sub>	.008
Total: 100.00			

<sup>a</sup>Equivalent to 48.39 percent Be and 48.40 percent N.

In the case of beryllium nitride, the furnace (i.e., the silver-pipe) temperature was measured by two

Pt/Pt-10 percent Rh thermocouples. One of the thermocouples was calibrated before the enthalpy measurements by the NBS Pyrometry Laboratory, and after the enthalpy measurements by comparison in the furnace with another similarly calibrated thermocouple. The thermocouple calibration during the enthalpy measurements changed by less than 0.1 kelvin during the whole series of enthalpy measurements.

The heats observed in individual measurements are listed (in joules) in the second and third columns of table 3. These values are for the actual sample and container used, except that corrections have been applied for very small unavoidable departures from the "standard" masses of parts of the container, but not for impurities in the sample. For each furnace temperature the values are given in chronological order, although the different furnace temperatures were run in somewhat random order. As always with this method, the times in the furnace adequate for

TABLE 3. Relative enthalpy of beryllium nitride, Be<sub>3</sub>N<sub>2</sub>

Furnace temperature, <sup>a</sup> t	Individual enthalpy measurements		Net enthalpy of Be <sub>3</sub> N <sub>2</sub> <sup>d</sup>		Mean obs. - calculated	
	Container plus sample <sup>b,c</sup>	Empty container	Mean observed <sup>e</sup>	Calc. from equations		
°C	J	J	J mol <sup>-1</sup>	J mol <sup>-1</sup>	J mol <sup>-1</sup>	
99.75.....	{	671.45	{	6,979	6,980	-1
		1,140.69				
		1,142.95				
		1,143.11				
		673.50				
199.65.....	{	1,391.6	{	15,710	15,744	-34
		1,390.6				
299.80.....	{	2,132.0	{	25,821	25,786	+35
		2,131.8				
399.65.....	{	2,910.5	{	36,574	36,615	-41
		2,904.2				
		2,903.5				
499.40.....	{	3,691.2	{	47,983	47,988	-5
		3,693.5				
		3,697.8				
		3,698.5				
599.50.....	{	4,518.2	{	59,781	59,812	-31
		4,515.2				
		5,387.1				
		5,389.8				
700.00.....	{	6,301.4	{	84,430	84,480	-50
		6,298.2				
		7,222.0				
800.40.....	{	7,225.2	{	97,194	97,193	+1
		7,225.1				
		13,780.8				
		13,787.5				
900.75.....	{	13,793.0	{	97,194	97,193	+1
		13,795.1				
		13,790.1				

<sup>a</sup> International Practical Temperature Scale of 1968 [13].

<sup>b</sup> Sample mass = 3.7440 g.

<sup>c</sup> Uncorrected for sample impurity.

<sup>d</sup> Molecular weight = 55.050. Enthalpy relative to that at 0 °C.

<sup>e</sup> Corrected for sample impurity.

reaching thermal equilibrium were predetermined from preliminary measurements at one temperature with deliberately inadequate times, and checked by choosing substantially different times for each set of duplicate measurements (without detecting any trend of the results with time).

The net mean observed enthalpy of the sample at each furnace temperature (relative to that at 0 °C) is given in the fourth column of table 3, and was obtained by converting the difference of the means of the second and third columns to a molar basis. These net molar enthalpies have been corrected for the sample impurities (assuming additivity) as given in table 2, the total correction amounting to very nearly +0.7 percent at each furnace temperature, on the basis of replacing the impurities by the same mass of beryllium nitride. (The corrections for BeO are based on accurate measurements on this substance in this laboratory [11]; the very small corrections for the remaining impurities were made using the adequate assumption that their enthalpy changes over a given temperature interval are the same as for the same number of gram-atoms of Be<sub>3</sub>N<sub>2</sub>.)

The "calculated" values of enthalpy referred to in the last two columns of table 3 are the smoothed, finally adopted values arrived at as described in section 4.

#### 4. Derivation of Thermodynamic Functions

The mean "observed" values of the enthalpy of beryllium nitride (table 3, column 4) were smoothed by using them to determine (by the method of least squares, using equal weighting) the linear coefficients of several alternative empirical functions of temperature. The equation adopted is identical with eq (5) below (except with the constant term adjusted to make the function vanish at 273.15 K).

Such a formulation is adequate to represent such monotonic enthalpy values within their uncertainties. But when the relative enthalpy has been measured over temperature intervals no smaller than 100 kelvins, as here, it cannot be relied on to provide accurate interpolation (such as for heat capacity) near the ends of the temperature range covered, owing to the empirical nature of the equation—particularly at the low-temperature end, where the heat capacity-temperature curve of a typical solid shows the greatest curvature. Nevertheless, experience in this laboratory has shown that for transition-free solids whose enthalpy has been measured relative to 273.15 K, this "end-effect" uncertainty in the heat capacity is usually minor at and above 298 K.

Fortunately, Furukawa and Reilly [7] have recently measured the heat capacity of beryllium nitride from 20 to 315 K, with a precision of ±0.01 percent between 50 and 300 K. It was decided to adopt in this paper their values for its heat capacity, enthalpy, and entropy from 273.15 to 298.15 K, to adopt the above-mentioned enthalpy equation only above 400 K, and to derive a new equation for the interval 298.15 to 400 K. The new enthalpy equation was taken simply

as a quartic polynomial in  $(T-400)$ , with its five constants required to provide continuity in the enthalpy (relative to 0 K) at 298.15 K, and in the heat capacity and its temperature derivative at 298.15 and 400 K. The constant term of the enthalpy equation for use above 400 K was then adjusted so as to provide continuity in the enthalpy at this temperature. It will be noted that the above procedure was not explicitly required to represent the observed enthalpies, but it does so within their precision, as is shown by the last column of table 3. The nature of the fit, for the three regions of temperature covered by the present investigation, is shown in figure 1 as percentage deviations from the adopted heat capacities. Furukawa and Reilly's maximum deviation (at 315 K) is +0.15 percent, which constitutes an injustice to their precision, but not to their absolute accuracy, which is limited by some ambiguity in the composition of their sample.

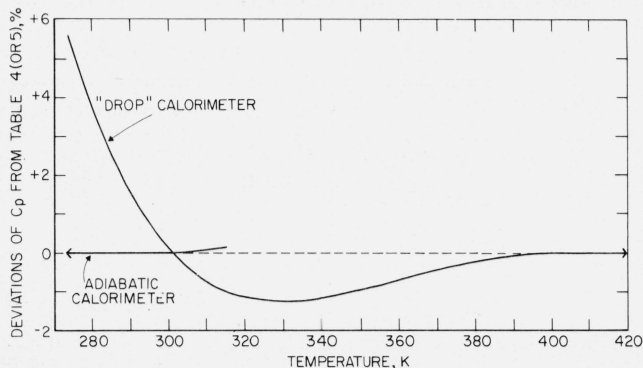


FIGURE 1. Deviations of heat capacity, derived separately from the adiabatic calorimetry of Furukawa and Reilly [7] and from the "drop" calorimetry of the present work, from the final values of table 4 (or 5).

The dotted portion of the base line (298.15 to 400 K) corresponds to equation (3).

The following numerical equations, which resulted from the above procedure, give the final values of the enthalpy ( $H$ ), heat capacity ( $C_p$ ), and entropy ( $S$ ) of alpha beryllium nitride adopted in this paper for the temperature interval 298.15 to 1200 K. The enthalpy is relative to that at 0 K, and the entropy is absolute if the value at 0 K is zero (presumably so in the case of beryllium nitride). The units are joules per mole for energy (with 1 mol = 55.050 g), and kelvins (International Practical Temperature Scale of 1968 [13]) for the absolute temperature  $T$ .

##### 298.15-400 K:

$$H^\circ - H_0^\circ = 15690.33 - 204.00263T + 0.9489086 T^2 - 1.5025526 (10^{-3})T^3 + 9.779786 (10^{-7})T^4 \quad (2)$$

$$C_p^\circ = -204.0026 + 1.8978172T - 4.5076578 (10^{-3})T^2 + 3.911914 (10^{-6})T^3 \quad (3)$$

$$S^\circ = 796.6989 - 204.00263 \ln T + 1.8978172T - 2.253829 (10^{-3})T^2 + 1.303971 (10^{-6})T^3 \quad (4)$$

<sup>4</sup>"ln" indicates the natural logarithm (base e).

$$H^\circ - H_0^\circ = -352093.01 + 73.83810T \\ + 1.3979455 (10^{-2})T^2 + 4.6161343 (10^4) \ln T \\ + 2.8241611 (10^7)T^{-1} - 1.931104 (10^9)T^{-2} \quad (5)$$

$$C_p^\circ = 73.8381 + 2.79589 (10^{-2})T + 4.616134 (10^4)T^{-1} \\ - 2.824161 (10^7)T^{-2} + 3.862208 (10^9)T^{-3} \quad (6)$$

$$S^\circ = -349.9251 + 73.83810 \ln T + 2.79589 (10^{-2})T \\ - 4.616134 (10^4)T^{-1} + 1.412081 (10^7)T^{-2} \\ - 1.287403 (10^9)T^{-3} \quad (7)$$

\* "ln" indicates the natural logarithm (base e).

Values from Furukawa and Reilly [7] below 298.15 K and from eqs (2)–(7) above 298.15 K are listed in table 4, the Gibbs free-energy function  $-(G^\circ - H_0^\circ)/T$  being computed from the thermodynamic relation

$$-(G^\circ - H_0^\circ)/T = S^\circ - (H^\circ - H_0^\circ)/T. \quad (8)$$

For convenience, table 4 is repeated as table 5 except in terms of the defined calorie ( $\equiv 4.1840$  joules) instead of the joule, since the defined calorie is commonly used in the calculations of chemical thermodynamics.

## 5. Comparison With Other Work; Estimates of Accuracy

The heat capacity of beryllium nitride is shown as a function of temperature in figure 2, where the solid curve represents the values of table 4, and the open circles represent the unsmoothed drop-calorimetry values  $\Delta H/\Delta t$  for the nine successive intervals of temperature (from table 3, columns 1 and 4). Each unsmoothed value has been corrected for curvature by subtracting  $(d^2C_p/dt^2)(\Delta t)^2/24$  [calculated from eq (3) or (6)] and assigned to the mean temperature of its interval. The mean deviation of the points from the curve is 0.45 percent. However, the enthalpy, not heat capacity, was determined experimentally, and "observed" heat capacity calculated in this way is dependent on the size of the temperature interval of enthalpy measurement, and hence is only roughly indicative of the experimental imprecision.

Satoh [9] used an ice calorimeter, and reported three measurements of the enthalpy of beryllium nitride, relative to 0 °C, at 99.5, 303.3, and 500.3 °C. His values, which he corrected for the 1.87 percent of impurity, are respectively 2.1, 0.5, and 2.2 percent higher than the corresponding values from table 4 or 5. The "observed" heat capacities similarly calculated from his enthalpies are shown as filled circles in figure 2, and the dotted line represents the linear equation derived by Kelley [12] to represent these results.

Obviously Satoh's heat capacities are in good agreement with the present work up to above 300 °C, but the extrapolation of the straight line to considerably higher temperatures would, of course, lead to large errors.

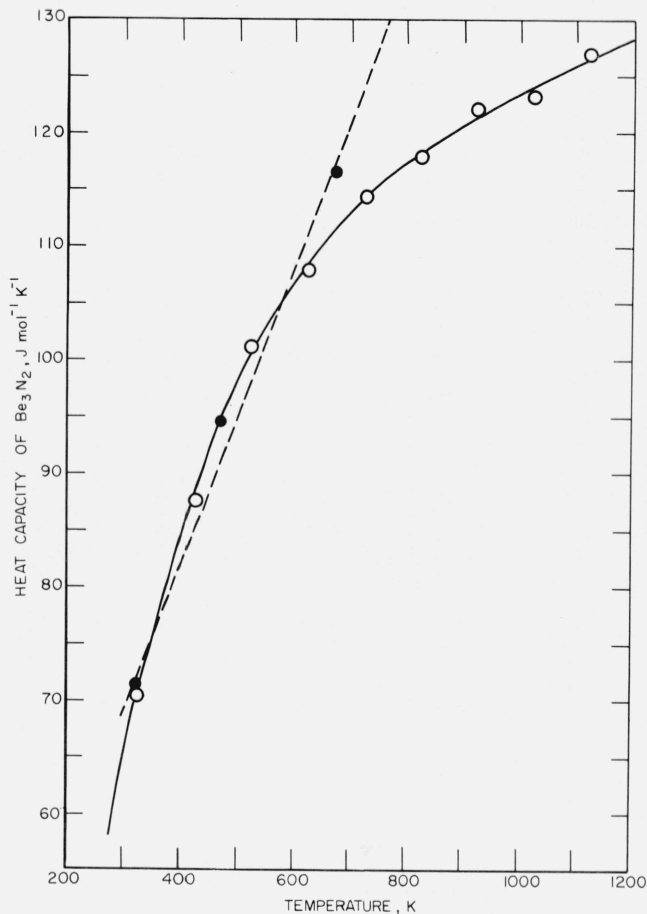


FIGURE 2. Heat capacity of  $\text{Be}_3\text{N}_2(c)$ .  
This work: —, smoothed; ○, unsmoothed.  
Satoh [9]: ···, smoothed by Kelley [12]; ●, unsmoothed.

The principal sources of systematic error in the present work are the uncertainties in the sample composition and in the furnace temperatures. The uncertainty in the heat capacities derived from the drop calorimetry arising from the corrections for sample impurities is estimated as 0.2 percent—equivalent to assuming that the beryllium analysis in table 1 might be correct. The uncertainty in the thermocouple calibration was stated to be no greater than 0.5 kelvin, and it is believed that the uncertainty in measuring furnace temperature introduced a systematic error of less than 0.1 percent into the heat capacities. The general overall uncertainty in the heat-capacity values of tables 4 and 5 above 298.15 K is estimated as 0.7 percent.

The values of  $S_{298.15}^\circ$  and  $(H_{298.15}^\circ - H_0^\circ)$  given by Furukawa and Reilly [7] are  $34.42 \pm 0.3 \text{ J mol}^{-1} \text{ K}^{-1}$  and  $7123.7 \text{ J mol}^{-1}$ , respectively, and the other values of entropy and enthalpy in tables 4 and 5 are based

TABLE 4. *Thermodynamic functions for beryllium nitride (Be<sub>3</sub>N<sub>2</sub>) solid phase (in terms of JOULES per mole)*

(1 mole = 55.050 g; International Practical Temperature Scale of 1968)

<i>T</i>	$H^\circ - H_0^\circ$	$C_p^\circ$	$S^\circ$	$-(G^\circ - H_0^\circ)/T$
<i>K</i>	<i>J mol<sup>-1</sup></i>	<i>J mol<sup>-1</sup> K<sup>-1</sup></i>	<i>J mol<sup>-1</sup> K<sup>-1</sup></i>	<i>J mol<sup>-1</sup> K<sup>-1</sup></i>
273.15	5585.2	58.195	29.033	8.590
275	5693.2	58.706	29.430	8.728
280	5989.8	60.066	30.497	9.104
285	6294.0	61.400	31.572	9.489
290	6604.0	62.718	32.652	9.883
295	6920.8	64.007	33.736	10.276
298.15	7123.7	64.810	34.418	10.527
300	7244.0	65.275	34.820	10.673
305	7573.5	66.498	35.909	11.078
310	7908.9	67.675	37.000	11.487
315	8250.2	68.808	38.092	11.901
320	8596.9	69.900	39.184	12.319
330	9306.4	71.976	41.367	13.166
340	10036.0	73.924	43.545	14.027
350	10784.6	75.769	45.715	14.902
360	11551.1	77.533	47.874	15.788
370	12335.0	79.242	50.022	16.684
380	13135.9	80.917	52.158	17.590
390	13953.3	82.582	54.281	18.503
400	14787.5	84.262	56.393	19.424
410	15638.6	85.923	58.494	20.351
420	16505.9	87.519	60.584	21.284
430	17388.8	89.049	62.661	22.222
440	18286.6	90.516	64.725	23.165
460	20124.8	93.262	68.810	25.061
480	22015.6	95.774	72.834	26.968
500	23954.4	98.072	76.791	28.882
520	25937.1	100.173	80.678	30.799
540	27960.1	102.097	84.496	32.718
560	30019.9	103.862	88.241	34.634
580	32113.6	105.485	91.914	36.546
600	34238.5	106.981	95.516	38.452
620	36392.1	108.363	99.047	40.350
640	38572.3	109.643	102.508	42.238
660	40777.2	110.833	105.900	44.116
680	43005.1	111.941	109.225	45.983
700	45254.4	112.978	112.485	47.836
720	47523.8	113.951	115.682	49.677
740	49812.0	114.866	118.817	51.503
760	52118.1	115.729	121.891	53.315
780	54440.9	116.546	124.908	55.112
800	56779.6	117.323	127.869	56.894
820	59133.5	118.062	130.775	58.661
840	61501.9	118.769	133.628	60.412
860	63884.1	119.446	136.431	62.147
880	66279.6	120.096	139.185	63.867
900	68687.8	120.723	141.891	65.571
950	74761.4	122.202	148.458	69.762
1000	80906.3	123.579	154.761	73.855
1050	87118.0	124.879	160.823	77.853
1100	93393.2	126.119	166.661	81.758
1150	99729.2	127.316	172.294	85.572
1200	106124.2	128.479	177.737	89.300

$H_0^\circ$  and  $S_0^\circ$  are, respectively, the enthalpy and entropy at 0 K and 1 atm pressure. Values below 300 K are taken from G. T. Furukawa and M. L. Reilly [7].

TABLE 5. *Thermodynamic functions for beryllium nitride (Be<sub>3</sub>N<sub>2</sub>) solid phase (in terms of CALORIES per mole)*

(1 cal = 4.1840 J; 1 mole = 55.050 g; International Practical Temperature Scale of 1968)

<i>T</i>	$H^\circ - H_0^\circ$	$C_p^\circ$	$S^\circ$	$-(G^\circ - H_0^\circ)/T$
<i>K</i>	<i>cal mol<sup>-1</sup></i>	<i>cal mol<sup>-1</sup> K<sup>-1</sup></i>	<i>cal mol<sup>-1</sup> K<sup>-1</sup></i>	<i>cal mol<sup>-1</sup> K<sup>-1</sup></i>
273.15	1334.9	13.909	6.939	2.053
275	1360.7	14.031	7.034	2.086
280	1431.6	14.356	7.289	2.176
285	1504.3	14.675	7.546	2.268
290	1578.4	14.990	7.804	2.362
295	1654.1	15.298	8.063	2.456
298.15	1702.6	15.490	8.226	2.516
300	1731.4	15.601	8.322	2.551
305	1810.1	15.893	8.582	2.648
310	1890.3	16.175	8.843	2.746
315	1971.8	16.445	9.104	2.844
320	2054.7	16.707	9.365	2.944
330	2224.3	17.203	9.887	3.147
340	2398.7	17.668	10.408	3.353
350	2577.6	18.109	10.926	3.562
360	2760.8	18.531	11.442	3.773
370	2948.1	18.939	11.956	3.988
380	3139.5	19.340	12.466	4.204
390	3334.9	19.738	12.973	4.422
400	3534.3	20.139	13.478	4.642
410	3737.7	20.536	13.980	4.864
420	3945.0	20.918	14.480	5.087
430	4156.0	21.283	14.976	5.311
440	4370.6	21.634	15.470	5.537
460	4809.9	22.290	16.446	5.990
480	5261.8	22.891	17.408	6.445
500	5725.2	23.440	18.353	6.903
520	6199.1	23.942	19.283	7.361
540	6682.6	24.402	20.195	7.820
560	7174.9	24.824	21.090	8.278
580	7675.3	25.212	21.968	8.735
600	8183.2	25.569	22.829	9.190
620	8697.9	25.899	23.673	9.644
640	9219.0	26.205	24.500	10.095
660	9746.0	26.490	25.311	10.544
680	10278.5	26.755	26.105	10.990
700	10816.1	27.002	26.885	11.433
720	11358.5	27.235	27.649	11.873
740	11905.4	27.454	28.398	12.310
760	12456.5	27.660	29.133	12.743
780	13011.7	27.855	29.854	13.172
800	13570.7	28.041	30.561	13.598
820	14133.3	28.218	31.256	14.020
840	14699.3	28.386	31.938	14.439
860	15268.7	28.548	32.608	14.854
880	15841.2	28.704	33.266	15.265
900	16416.8	28.854	33.913	15.672
950	17868.4	29.207	35.482	16.673
1000	19337.1	29.536	36.989	17.652
1050	20821.7	29.847	38.438	18.607
1100	22321.5	30.143	39.833	19.541
1150	23835.9	30.429	41.179	20.452
1200	25364.3	30.707	42.480	21.343

$H_0^\circ$  and  $S_0^\circ$  are, respectively, the enthalpy and entropy at 0 K and 1 atm pressure. Values below 300 K are taken from G. T. Furukawa and M. L. Reilly [7].

on these values. For the same quantities the JANAF table [6] gives  $34.13 \text{ J mol}^{-1} \text{ K}^{-1}$  (0.8 percent lower) and  $7075 \text{ J mol}^{-1}$  (0.7 percent lower), which are based on the measurements of Justice [8].

The sample of beryllium nitride was analyzed chemically by Rolf A. Paulson and spectrochemically by Elizabeth K. Hubbard, both of the Analytical Chemistry Division of the Bureau.

## 6. References

- [1] Stackelberg, M., and Paulus, R., *Z. physik. Chem.* **B22**, 305 (1933).
- [2] Chiotti, P., *J. Am. Ceram. Soc.* **35**, 123 (1952).
- [3] Eckerlin, P., and Rabenau, A., *Z. anorg. allgem. Chem.* **304**, 218 (1960).
- [4] Yates, R. E., Greenbaum, M. A., and Farber, M., *J. Phys. Chem.* **68**, 2682 (1964).
- [5] Gross, P., Hayman, C., Greene, P. D., and Bingham, J. T., *Trans. Faraday Soc.* **62**, 2719 (1966).
- [6] JANAF Thermochemical Tables, Second Addendum (PB 168 370-2), Clearinghouse, U.S. Department of Commerce, Springfield, Va., Aug. 1967 (table for  $\alpha\text{-Be}_3\text{N}_2$ , dated Mar. 31, 1967).
- [7] Furukawa, G. T., and Reilly, M. L., unpublished data.
- [8] Justice, B. H., (see ref. [6]).
- [9] Satoh, S., *Sci. Papers Inst. Phys. and Chem. Research (Tokyo)* **34**, 888 (1938).
- [10] *Experimental Thermodynamics*, Vol. I, McCullough, J. P., and Scott, D. W., Ed. (Butterworths, London, 1968) (Ch. 8, High-temperature Drop Calorimetry, Douglas, T. B., and King, E. G., p. 293).
- [11] Victor, A. C., and Douglas, T. B., *J. Res. NBS* **67A** (Phys. and Chem.) No. 4, 325 (1963).
- [12] Kelley, K. K., *Bur. Mines Bulletin 584*, Contributions to the Data on Theoretical Metallurgy. XIII. High-Temperature Heat-Content, Heat-Capacity, and Entropy Data for the Elements and Inorganic Compounds, U.S. Government Printing Office, Washington, D.C., 1960, p. 25.
- [13] International Practical Temperature Scale of 1968, *Metrologia* **5**, 35 (1969).

(Paper 73A5-564)