

National Bureau of Standards

Certificate

Standard Reference Material 720

Synthetic Sapphire (α -Al₂O₃)

This Standard Reference Material (SRM) is intended for use in calibrating or checking calorimeters used to measure either enthalpy or heat capacity within the range of 10 to 2250 K.

The material furnished is synthetic sapphire cylinders, cut from centerless-ground rods grown by the Vernieul process and obtained from the Union Carbide Corporation.

The enthalpy and heat-capacity data have been derived from high-temperature enthalpy and low-temperature heat-capacity measurements. These data are presented in both tabular and equation format.

The enthalpy values are accurate to ± 0.1 percent from 70 to 1173 K and the heat-capacity values have an accuracy ranging from ± 0.1 percent at 70 K to ± 0.3 percent at 1200 K. Below 70 K, the inaccuracy in heat-capacity and enthalpy values increase gradually to ± 10 percent at 10 K, because, with decreasing temperature, the heat capacity of sapphire diminishes at a much faster rate than does that of the sample container (mainly copper). The precision of the heat-capacity measurement between 100 and 380 K is estimated to be ± 0.02 percent. The precision of the enthalpy measurement from 273.15 to 1173 K is estimated to be 0.02 percent. For the temperature range 1173 to 2250 K, the precision of the enthalpy measurement is estimated to be ± 0.03 percent, and the accuracy of the measured enthalpy is estimated to be ± 0.2 percent, to a large extent reflecting the uncertainty in temperature measurements at these high temperatures. Above 1700 K, a detectable weight loss was observed in an open container due to evaporation of material.

Relative Enthalpy and Heat Capacity ^b

Temp ^a	H _T -H ₀ K	C _p	Temp	H _T -H ₀ K	C _p
K	J·mol ⁻¹	J·mol ⁻¹ ·K ⁻¹	K	J·mol ⁻¹	J·mol ⁻¹ ·K ⁻¹
10	0.02 ₃	0.009 ₁	70	74.6 ₈	4.59 ₂
15	0.11 ₅	0.030 ₇	80	131.7	6.90 ₁
20	0.36 ₄	0.073 ₂	90	214.2	9.67 ₉
25	0.89 ₈	0.14 ₆	100	326.6	12.85 ₅
30	1.90 ₅	0.26 ₅	110	472.4	16.34 ₇
35	3.64 ₆	0.44 ₃	120	654.3	20.0 ₇
40	6.46 ₀	0.69 ₇	130	874.3	23.9 ₅
45	10.7 ₇	1.04 ₆	140	1133.7	27.9 ₃
50	17.1 ₁	1.50 ₇	150	1433.1	31.9 ₅
60	38.1 ₈	2.79 ₃	160	1772.7	35.9 ₅

^aTemperatures expressed on IPTS-68 scale

^bMolecular Weight = 101.9613

(Table continued on page 2)

Heat-capacity measurements from 10 to 380 K were made by S.S. Chang in the Polymers Division of the Center for Materials Science. Enthalpy measurements from 273.15 to 1173.15 K were made by D.A. Ditmars and T.B. Douglas; those from 1173.15 K to 2250 K were made by S. Ishihara and E.D. West. The enthalpy measurements were made with facilities located in the Chemical Thermodynamics Division of the Center for Chemical Physics.

The technical and support aspects in the preparation, certification, and issuance of this Standard Reference Material were coordinated through the Office of Standard Reference Materials by J.L. Hague and R.K. Kirby.

Washington, D.C. 20234
 April 13, 1982
 (Revision of Certificate
 dated 8-26-70)

George A. Uriano, Chief
 Office of Standard Reference Materials

(over)

Relative Enthalpy and Heat Capacity

Temp	$H_T - H_0$ K	C_p	Temp	$H_T - H_0$ K	C_p
K	$J \cdot mol^{-1}$	$J \cdot mol^{-1} \cdot K^{-1}$	K	$J \cdot mol^{-1}$	$J \cdot mol^{-1} \cdot K^{-1}$
170	2152.0	39.9 ₀	600	4012 ₁	112.5 ₅
180	2570.3	43.7 ₅	610	4124 ₉	113.0 ₆
190	3026.7	47.5 ₀	620	4238 ₂	113.5 ₅
200	3519.9	51.1 ₂	630	4352.0	114.0 ₂
210	4048.7	54.6 ₁	640	4466 ₃	114.4 ₈
220	4611.6	57.9 ₅	650	4581 ₀	114.9 ₂
230	5207.1	61.1 ₄	660	4696 ₁	115.3 ₅
240	5833.9	64.1 ₈	670	4811 ₇	115.7 ₆
250	6490.3	67.0 ₈	680	4927 ₆	116.1 ₆
260	7175.0	69.8 ₂	690	5044 ₀	116.5 ₅
270	7886.3	72.1 ₂	700	5160 ₇	116.9 ₂
273.15	8115.6	73.2 ₁	720	5395 ₃	117.6 ₄
280	8622.8	74.8 ₇	740	5631 ₃	118.3 ₂
290	9383.2	77.2 ₀	760	5868 ₅	118.9 ₆
298.15	1002 ₀	79.0 ₁	780	6107 ₁	119.5 ₆
300	1016 ₆	79.4 ₁	800	6346 ₈	120.1 ₄
310	1097 ₁	81.5 ₁	820	6587 ₆	120.6 ₉
320	1179 ₆	83.4 ₉	840	6829 ₅	121.2 ₁
330	1264 ₁	85.3 ₇	860	7072 ₄	121.7 ₁
340	1350 ₃	87.1 ₆	880	7316 ₃	122.2 ₀
350	1438 ₃	88.8 ₄	900	7561 ₂	122.6 ₆
360	1528 ₀	90.4 ₅	920	7807 ₀	123.1 ₁
370	1619 ₂	91.9 ₇	940	8053 ₆	123.5 ₅
380	1711 ₉	93.4 ₁	960	8301 ₁	123.9 ₇
390	1806 ₀	94.7 ₈	980	8549 ₅	124.3 ₇
400	1901 ₄	96.0 ₈	1000	8798 ₆	124.7 ₇
410	1998 ₂	97.3 ₂	1020	9048 ₆	125.1 ₆
420	2096 ₁	98.5 ₀	1040	9299 ₂	125.5 ₃
430	2195 ₁	99.6 ₂	1060	9550 ₇	125.9 ₀
440	2295 ₃	100.6 ₉	1080	9802 ₈	126.2 ₆
450	2396 ₅	101.7 ₁	1100	1005 ₆₀	126.6 ₁
460	2498 ₇	102.6 ₈	1120	1030 ₉₀	126.9 ₅
470	2601 ₈	103.6 ₀	1140	1056 ₄₀	127.2 ₉
480	2705 ₉	104.4 ₈	1160	1081 ₈₀	127.6 ₁
490	2810 ₈	105.3 ₃	1180	1107 ₄₀	127.9 ₄
500	2916 ₅	106.1 ₃	1200	1133 ₀₀	128.2 ₅
510	3023 ₀	106.9 ₀	1250	1197 ₃₀	129.0 ₁
520	3130 ₃	107.6 ₄	1300	1262 ₀₀	129.7 ₄
530	3238 ₃	108.3 ₅	1350	1327 ₁₀	130.4 ₃
540	3347 ₀	109.0 ₂	1400	1392 ₄₀	131.0 ₈
550	3456 ₃	109.6 ₇	1450	1458 ₁₀	131.7 ₀
560	3566 ₃	110.2 ₉	1500	1524 ₁₀	132.2 ₉
570	3676 ₉	110.8 ₉	1550	1590 ₄₀	132.8 ₄
580	3788 ₁	111.4 ₆	1600	1657 ₀₀	133.3 ₆
590	3899 ₈	112.0 ₂	1650	1723 ₈₀	133.8 ₅

Relative Enthalpy and Heat Capacity

Temp	H ₁ -H ₀ K	C _p	Temp	H ₁ -H ₀ K	C _p
K	J·mol ⁻¹	J·mol ⁻¹ ·K ⁻¹	K	J·mol ⁻¹	J·mol ⁻¹ ·K ⁻¹
1700	1790 ₈₀	134.31	2000	2197 ₂₀	136.50
1750	1858 ₁₀	134.73	2050	2265 ₅₀	136.80
1800	1925 ₅₀	135.13	2100	2334 ₀₀	137.10
1850	1993 ₂₀	135.50	2150	2402 ₆₀	137.41
1900	2061 ₀₀	135.85	2200	2471 ₄₀	137.73
1950	2129 ₀₀	136.18	2250	2540 ₃₀	138.06

Below 273.15 K, the heat-capacity values were calculated from a spline function fitted to the heat-capacity data over three temperature intervals and employing polynomials, P_n (n = 1,2,3) of the form,

$$P_n = \sum_{i=0}^6 \frac{A_i}{i!} (T - T_0)^i$$

45.0 K > T ≥ 8.61 K:

$$C_p = \exp(P1) \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$$

$$\begin{aligned} T_0 &= 8.61 \text{ K} & A_3 &= +0.450764\text{E}-02 \\ A_0 &= -0.5147\text{E}+01 & A_4 &= -0.51464\text{E}-03 \\ A_1 &= +0.34127\text{E}+00 & A_5 &= +0.397864\text{E}-04 \\ A_2 &= -0.333446\text{E}-01 & A_6 &= -0.152136\text{E}-05 \end{aligned}$$

125.0 K > T ≥ 45.0 K:

$$C_p = P2 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$$

$$\begin{aligned} T_0 &= 40.0 \text{ K} & A_3 &= +0.95173\text{E}-04 \\ A_0 &= +0.6966\text{E}+00 & A_4 &= -0.35910\text{E}-05 \\ A_1 &= +0.59387\text{E}-01 & A_5 &= -0.6498\text{E}-07 \\ A_2 &= +0.40357\text{E}-02 & A_6 &= +0.4089\text{E}-08 \end{aligned}$$

273.15 K > T ≥ 125.0 K:

$$C_p = P3 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$$

$$\begin{aligned} T_0 &= 125.0 \text{ K} & A_3 &= -0.83967\text{E}-04 \\ A_0 &= +0.21993\text{E}+02 & A_4 &= +0.19133\text{E}-05 \\ A_1 &= +0.38853\text{E}+00 & A_5 &= -0.31778\text{E}-07 \\ A_2 &= +0.13955\text{E}-02 & A_6 &= +0.29562\text{E}-09 \end{aligned}$$

Above 273.15 K, enthalpy and heat-capacity values were derived from the following equation

$$H_1 - H_{273.15} = AT^{-2} + BT^{-1} + C \ln T + K + DT + ET^2 + FT^3 + GT^4 + HT^5 \text{ J}\cdot\text{mol}^{-1}$$

$$\begin{aligned} A &= +6.6253\text{E}+07 & E &= -8.57516\text{E}-02 \\ B &= -4.54238\text{E}+06 & F &= +4.299063\text{E}-05 \\ C &= -5.475599\text{E}+04 & G &= -1.15192\text{E}-08 \\ K &= +2.5819702\text{E}+05 & H &= +1.26351\text{E}-12 \\ D &= +2.574076\text{E}+02 & & \end{aligned}$$

Low-temperature measurements from 10 to 380 K were made with a vacuum adiabatic calorimeter [1,2] operated automatically under the control of a minicomputer. Enthalpy measurements at eighteen temperatures from 273 to 1173 K were made by the drop method using a Bunsen ice calorimeter [3,4]. From 1173 to 2250 K, enthalpy measurements were made with an adiabatic receiving calorimeter [5,6]. All temperatures are expressed on the IPTS-68 scale. In the correction of specimen mass data for atmospheric buoyancy, a density of 3.97 g·cm⁻³ for α-Al₂O₃ was assumed. The functions presented were fitted by the method of least squares to these data. The tabulated values were calculated using these functions.

An occasional particle may contain an end smear due to the method employed in cutting the material. These smears do not contribute significantly to the enthalpy values given in this certificate. However, it is recommended that the material be heated to 1000 °C in air prior to heat-capacity measurements below 350 K. Microprobe analyses indicate small quantities of chloride, titanium, calcium, silicon, iron, copper, and zinc on the surfaces. Spectrographic examination indicates the purity of the bulk material to be at least 99.95 + percent, with the major impurities being magnesium, calcium, chromium, iron, silicon, and titanium. Examination by atomic absorption spectrometry for magnesium, indicated as the major impurity by the above tests, shows that the surface contamination by this element amounts to 1 ppm, or less, and that the bulk material contains 10 ppm, or less, of magnesium. In addition, the material absorbs a small amount (30 ppm or less, presumably moisture) of weight on the ground surfaces on exposure to room air, and may require heating in an inert atmosphere, if this amount of moisture is of concern. Combustion analysis in oxygen indicates the material contains on the order of 10 ppm or less of carbonaceous material calculated as carbon.