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HEAT CAPACITY OF ALUMINUM FROM 80 TO 880 K *

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ABSTRACT

The heat capacity of 99.999% pure metallic aluminum has been measured by laser-flash calorimetry in the temperature range 80–880 K. The results are compared with available low- and high-temperature heat capacities, as well as with those of recent independent critical evaluations.

INTRODUCTION

Aluminum is one of the metals whose heat capacity has been extensively studied. In 1974, Brooks and Stansbury [1] summarized the available heat-capacity data on aluminum and pointed out that there was considerable disparity among the data above 300 K. Recently, Downie and Martin [2] made measurements on very pure aluminum from 6 to 300 K, while Ditmars et al. [3] reported the relative enthalpy of pure aluminum over the temperature range from 273 to 929 K. These measurements suggested somewhat lower heat capacities than those of the earlier studies at around 300 K. Recent independent critical evaluations of the heat capacity of aluminum by Chase et al. [4] and by Desai [5] have given substantial weight to these new data.

It should be noted that the results of our heat-capacity measurements by laser-flash calorimetry have been incorporated in these evaluations. Unfortunately we have published [6,7] only preliminary results, and thus our data have been cited incompletely or as a "private communication". We feel that it is necessary to publish our data in full, and here we report details of the experimental results of the heat-capacity measurements on 99.999% pure aluminum over the temperature range 80–880 K.

* Dedicated to Professor Edgar F. Westrum, Jr., in honor of his contribution to calorimetry and thermal analysis.

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EXPERIMENTAL

Measurements were made on 99.999% pure aluminum prepared at Sumitomo Chemical Co., Japan. The reported mass fractions $10^6 x_i$ of impurities in the sample were as follows: Mg, 2; Fe, Si, Cu, Na, 1. The experimental specimen was in the form of a disc about 10 mm in diameter and 2 mm thick, weighing 0.6081 g. Before use, the specimen was annealed at 880 K for 4 h in vacuo.

Details of heat-capacity measurements by laser-flash calorimetry were described in a previous paper [8]. Experimental results on an alumina reference sample showed [8] that the accuracy was to within $\pm 0.5\%$ over the temperature range 100–800 K, and to within $\pm 1\%$ from 800 to 1100 K. A brief outline of the present measurements is as follows. First, the heat capacity of the aluminum sample at room temperature was determined by comparison with an α-alumina reference sample. In these measurements the same absorbing disk made of glassy carbon (mass 0.0230 g) with a small mass (less than 0.002 g) of Apiezon-N grease as an adhesive were used. Correction was made for these materials using available data [9,10], and their total contributions to the gross heat capacity determined were less than 3%. The temperature dependence of the heat capacity was then determined on the same aluminum sample. The front surface of the sample was coated with a thin layer of Dry Graphite Film (Miracle Power Products Corp., Cleveland, OH) for these measurements.

RESULTS AND DISCUSSION

The experimental results are listed in Table 1 in chronological order and are shown in Fig. 1 as a function of temperature. A molar mass of 26.981539 g mol^{-1} was used for aluminum and no correction for impurities was made. The heat capacities were reproducible within $\pm 1.5\%$ on different series of experiments over the whole temperature range investigated.

Smoothed values of molar heat capacities from 80 to 880 K were obtained from the best-fit polynomials and graphically. The experimental values in the temperature range 80–350 K fitted the equation

$$C_p\ (\mathrm{J\ K^{-1}\ mol^{-1}}) = 21.18 + 24.45T/\mathrm{kK} - 30.17(T/\mathrm{kK})^2 - 0.1791(\mathrm{kK}/T)^2 + 0.007654(\mathrm{kK}/T)^3 \quad (1)$$

Above 350 K, the smoothed values were taken graphically. The resulting values at selected temperatures are given in Table 2.

A comparison of the present heat capacities with those from other investigations is shown in Fig. 1. At 298.15 K the present value for the heat capacity is 24.05 J K^{-1} mol^{-1}, which can be compared with the value of

TABLE 1

Experimental heat capacity of aluminum (M(Al) = 26.981539 g mol^{-1})

T (K)	C_p (J mol^{-1} K^{-1})	T (K)	C_p (J mol^{-1} K^{-1})	T (K)	C_p (J mol^{-1} K^{-1})
Series I		195.98	21.13	271.71	23.54
81.49	10.12	197.88	21.20	279.69	23.71
85.62	10.83	199.76	21.38	281.21	23.76
89.53	11.45	201.61	21.39	290.35	23.98
93.42	12.05	203.44	21.43	292.37	23.95
97.03	12.67	205.26	21.62	300.87	24.12
100.61	13.17	207.04	21.69	302.53	24.10
103.95	13.63	208.80	21.67	310.95	24.30
110.22	14.44	210.54	21.72	312.75	24.26
113.20	14.84	212.26	21.90	321.47	24.43
116.08	15.24	214.00	21.87	323.54	24.37
118.85	15.53	215.76	21.99	329.75	24.58
121.52	15.92	217.49	22.03	331.81	24.59
124.11	16.17	220.94	22.14	341.41	24.69
126.62	16.36	222.66	22.18	343.29	24.73
129.05	16.62	224.38	22.31		
131.41	16.93	226.09	22.44	Series III	
133.71	17.10	227.81	22.40	334.55	24.53
135.92	17.22	229.55	22.34	357.44	24.78
138.07	17.45	231.30	22.43	377.36	25.13
140.24	17.63	232.99	22.65	397.99	25.33
142.54	17.86	234.72	22.53	416.65	25.56
144.61	18.14	236.54	22.67	449.76	25.92
146.75	18.16	238.12	22.75	502.76	26.54
148.92	18.33	239.74	22.72	516.44	26.82
151.06	18.65	241.43	22.76	530.03	26.84
153.16	18.69	243.12	22.86	545.46	27.13
155.27	18.91	244.84	22.80	561.72	27.17
157.34	18.94	246.54	22.98	585.31	27.58
159.40	19.15	248.19	22.99	610.77	27.86
161.43	19.29	249.78	23.01	632.81	28.13
163.45	19.39	251.42	23.04	660.02	28.53
165.45	19.50	253.13	23.11		
167.42	19.75	254.81	23.14	Series IV	
169.38	19.85	256.45	23.10	310.99	24.23
171.32	19.90	258.05	23.19	311.84	24.24
175.13	20.20	259.69	23.24	329.77	24.45
177.08	20.19			330.69	24.51
179.04	20.37	Series II		331.99	24.47
180.99	20.34	220.83	22.19	350.43	24.65
182.91	20.57	223.23	22.33	351.72	24.80
184.83	20.62	231.18	22.60	352.95	24.71
186.71	20.75	233.31	22.69	377.09	25.19
188.59	20.76	241.70	22.90	378.37	25.15
190.06	20.94	259.64	23.25	379.68	25.38
192.30	21.01	265.95	23.34	402.73	25.39
194.15	21.00	270.19	23.51	404.00	25.49

TABLE 1 (continued)

T (K)	C_p (J mol^{-1} K^{-1})	T (K)	C_p (J mol^{-1} K^{-1})	T (K)	C_p (J mol^{-1} K^{-1})
405.27	25.49	600.51	27.65	711.55	28.88
433.51	25.97	601.35	27.80	712.73	28.94
434.78	25.89	602.13	27.53	741.11	29.41
436.04	25.88			743.12	29.30
463.48	26.16	Series V		743.99	29.39
464.73	26.24	504.61	26.45	771.38	29.71
465.98	26.25	505.68	26.49	772.27	29.67
494.43	26.34	506.77	26.71	773.12	29.74
495.80	26.52	551.10	27.03	801.45	30.12
497.02	26.41	552.07	27.22	801.67	30.04
523.48	26.66	624.38	28.07	802.43	30.30
524.67	26.90	625.39	28.06	825.18	30.64
525.84	26.85	653.11	28.22	826.09	30.73
543.02	26.98	654.12	28.30	826.76	30.58
544.26	27.05	655.09	28.34	850.29	31.04
545.59	27.12	680.95	28.54	850.57	31.22
575.02	27.51	681.78	28.55	851.43	31.19
576.15	27.40	682.69	28.61	873.13	31.79
577.26	27.56	710.90	28.89	874.04	32.09

Downie and Martin [2] of 24.21 J K^{-1} mol^{-1}. Chase et al. [4] recommended the value of 24.209 J K^{-1} mol^{-1} in their critical compilation of existing data, while Desai [5] adopted the value of 24.225 J K^{-1} mol^{-1}. The present value is about 0.7% lower than these reported values. It should be noted that, with the sample which had not been annealed, we observed heat capacity values a little higher than those reported here above 260 K, and at 300 K, the difference became about 1%.

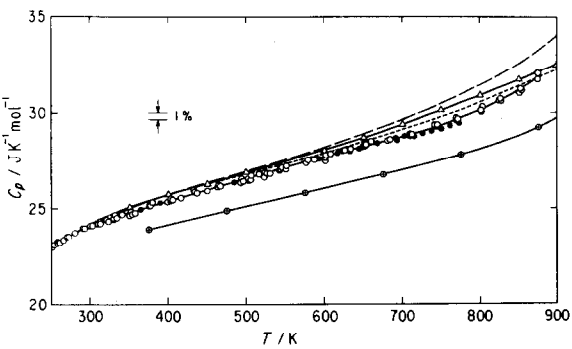

Fig. 1. Molar heat capacity of aluminum. (○) Present work; (●) Leadbetter [11]; (— — —) Brooks and Bingham [12]; (⊕) Schmidt et al. [13]; (- - - - -) Ditmars et al. [3] and Chase et al. [4]; (△) Desai [5].

TABLE 2

Molar heat capacity of aluminum (M(Al) = 26.981539 g mol^{-1})

T (K)	C_p (J mol^{-1} K^{-1})	T (K)	C_p (J mol^{-1} K^{-1})
80	9.91	500	26.53
100	13.11	550	27.12
150	18.47	600	27.71
200	21.35	650	28.27
298.15	24.05	700	28.81
300	24.08	750	29.39
350	24.77	800	30.13
400	25.44	850	31.20
450	25.98	880	32.00

In general, the present data show close agreement with those obtained by Ditmars et al. [3], using relative enthalpy measurements, and deviate by less than 1% from their curve above 250 K to 880 K. Thus, the heat-capacity data reported here generally substantiate the recent compilations of thermodynamic functions of aluminum [4,5].

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