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LOW-TEMPERATURE HEAT CAPACITIES AND STANDARD MOLAR ENTHALPY OF FORMATION OF ASPIRIN

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Abstract

Molar heat capacities ($C_{\mathrm{p,m}}$) of aspirin were precisely measured with a small sample precision automated adiabatic calorimeter over the temperature range from 78 to 383 K. No phase transition was observed in this temperature region. The polynomial function of $C_{\mathrm{p,m}}$ *vs.* T was established in the light of the low-temperature heat capacity measurements and least square fitting method. The corresponding function is as follows: for 78 K$\leq T \leq$383 K, $C_{\mathrm{p,m}}/\mathrm{J\ mol^{-1}\ K^{-1}}=19.086X^4+15.951X^3-5.2548X^2+90.192X+176.65$, $[X=(\mathrm{T}-230.50/152.5)]$. The thermodynamic functions on the base of the reference temperature of 298.15 K, $\{\Delta H_{\mathrm{T}}-\Delta H_{298.15}\}$ and $\{S_{\mathrm{T}}-S_{298.15}\}$, were derived.

Combustion energy of aspirin ($\Delta_{\mathrm{c}}U_{\mathrm{m}}$) was determined by static bomb combustion calorimeter. Enthalpy of combustion ($\Delta_{\mathrm{c}}H^0_{\mathrm{m}}$) and enthalpy of formation ($\Delta_{\mathrm{f}}H^0_{\mathrm{m}}$) were derived through $\Delta_{\mathrm{c}}U_{\mathrm{m}}$ as – (3945.26±2.63) kJ mol^{-1} and – (736.41±1.30) kJ mol^{-1}, respectively.

Keywords: adiabatic calorimetry, aspirin, combustion calorimetry, enthalpy of formation, heat capacity

Introduction

Aspirin is a kind of antiphlogistic drug which could relieve pain and cure asthma and heart disease [1] and has been paid much attention because of its remarkable curative effect. Most publications on aspirin and its derivatives are concerned with their dissolution kinetics, release mechanism, absorbing processes, incompatibility of drug-excipient and its pharmacology in the body [2–6]. Zhang [7] reported on thermal stability and thermal kinetics of aspirin. Habib [8] presented results of kinetics of hydrolysis and stabilization of aspirin in liposome formulation.

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Heat capacity measurements of materials have attracted many researchers' attentions [9, 10]. Thermal properties of aspirin, for example, molar heat capacity and enthalpy of formation, are significant to understand thermal stability of aspirin and prepare new drug from it, respectively. We have studied the thermodynamic properties of berberine sulphate by using thermal analysis and adiabatic calorimetry [11]. Up to now, only melting point of aspirin has been reported as 410±10 K by NIST. However, the molar heat capacities and enthalpy of formation for this substance have not been reported. In this paper, the low-temperature heat capacities and energy of combustion of aspirin were determined using a small sample precision automated adiabatic calorimeter and a static bomb combustion calorimeter. The enthalpy of formation was derived through energy of combustion for aspirin.

Experimental

Material

Aspirin (CAS 50-78-2) was supplied by Hunan Institute of Drug Detection, P. R. China. Quantitative analysis was performed using titration [12]. The purity of aspirin to be measured is 99.5%.

Adiabatic calorimetry

Heat capacity measurement of aspirin was carried out by a high-precision automatic adiabatic calorimeter over the temperature range from 78 to 400 K. The construction and principle of the calorimeter have been described previously in detail [13–18]. Briefly, the calorimeter mainly comprises a sample cell, a platinum resistance thermometer, an electric heater, two adiabatic shields, two sets of differential thermocouples and a high vacuum system. The samples were cooled by liquid nitrogen. The sample cell was made of gold-plated copper and had an internal volume of about 6 cm^3. Four gold-plated copper vanes of 0.2 mm thickness were put into the cell to promote heat distribution between the sample and the cell. The platinum resistance thermometer was inserted into the copper sheath, which was soldered at the bottom of the sample cell. The heater wire was wound on the side surface of the cell. The lid of the cell with a copper capillary was sealed to the sample cell with adhesive after the sample was loaded in it. The air on the cell was evacuated and a small amount of helium gas (0.1 MPa) was introduced into it to enhance the heat transfer within the cell. The temperature differences between the sample cell and the inner shield, and between the inner and outer shields were monitored by two sets of six-junction chromel–copper (Ni 55%, Cu 45%) thermocouples, and controlled by two sets of DWT-702 precision temperature controller (manufactured by Shanghai No.6 Automated Instrumentation Workshop). The electrical energy introduced into the sample cell and the equilibrium temperature of the cell after the energy input were automatically picked up by use of the Data Acquisition/Switch Unit (Model 34970A, Agilent, USA), and processed on line by a computer. To verify the reliability of the calorimeter, the molar heat capacity of the reference standard material (α-Al_2O_3) was measured over the same temperature range. The deviation of our experimental results from the recommended values [19] of the former National Bureau of Standards lies within ±0.2% over the investigated temperature range.

Static bomb combustion calorimeter

For the measurements of the enthalpy of combustion of aspirin, an isoperibol macro-calorimeter with a static bomb and a stirred water bath was used. The construction and principle of the static bomb combustion calorimeter have been described in [20, 21]. The aspirin sample to be measured was pressed into pellets of mass about 1 g and was burned in oxygen (99.99%) at p=3.0 MPa pressure. To ensure equilibrium in the final state, 1 mL of distilled water was added to the bomb. The energy equivalent (ε) of the bomb combustion calorimeter was determined from the combustion of benzoic acid (SRM 39I, NIST) which has a massic energy of combustion, of –(26434±3) J g^{-1}, under standard bomb conditions. The calibration results were corrected to give the energy equivalent (ε) corresponding to the average mass of water added to the calorimeter: 3850 g. From ten calibration experiments, ε=(13572.22±0.98) J K^{-1}, where the uncertainty quoted is the standard deviation of the mean. The amount of nitric acid formed during the reaction was determined by titration with standardized NaOH (*aq*). The energy of combustion was automatically picked up by the Data Acquisition/Switch Unit (Model 34970A, Agilent, USA), and processed on line with a computer.

Results and discussion

Before low-temperature heat capacity was measured, TG and DSC measurements were performed for aspirin. The results indicated no mass loss was observed before 420 K and melting temperature was 409.2±0.2 K for this substance.

Low-temperature heat capacities of aspirin were measured by the adiabatic calorimeter over the temperature range from 78 to 383 K (Fig. 1 and Table 1). The temperature increment for each experimental point was about 3 K in the whole temperature range. No phase transition was observed in this temperature region. The smooth value of molar heat capacities and other thermodynamic properties of aspirin (relative to 298.15 K) are listed in Table 2, where

$$H_T - H_{298.15} = \int_{298.15}^{T} C_{p,m}\,dT$$

$$S_T - S_{298.15} = \int_{298.15}^{T} \frac{C_{p,m}}{T}\,dT$$

The molar heat capacities of the aspirin in solid state were fitted to the following polynomial of heat capacities *vs*. reduced temperature (X) by means of the least square fitting method,

$$C_{p,m}/\mathrm{J\ mol^{-1}\ K^{-1}} = 19.086X^4 + 15.951X^3 - 5.2548X^2 + 90.192X + 176.65$$

Table 1 The experimental molar heat capacities ($C_{\mathrm{p,m}}$ in J mol^{-1} K^{-1}) of aspirin in the temperature range of 78–383 K (molar mass M=180.16)

T/K	$C_{\mathrm{p,m}}$	T/K	$C_{\mathrm{p,m}}$	T/K	$C_{\mathrm{p,m}}$	T/K	$C_{\mathrm{p,m}}$
78.436	83.903	144.770	123.94	215.299	166.84	296.667	216.97
80.321	84.713	147.320	125.38	217.349	167.98	299.863	218.73
82.124	85.921	149.842	127.01	219.381	169.61	309.288	224.81
83.956	86.384	152.343	128.56	221.416	171.05	301.093	221.11
85.716	87.464	154.821	129.90	223.420	172.17	304.289	221.01
87.448	89.016	157.282	131.30	225.429	173.77	307.485	223.11
89.153	89.303	159.713	132.80	227.420	175.28	310.599	225.47
90.832	90.338	162.134	134.59	229.387	177.27	313.795	227.12
92.485	91.502	164.529	135.95	231.272	178.72	316.909	229.30
94.114	92.946	166.911	137.43	233.239	179.35	320.023	231.89
95.724	93.937	169.271	138.61	235.205	180.59	323.137	234.21
97.310	94.716	171.608	139.69	237.172	181.42	326.251	237.86
98.876	95.889	173.933	140.91	239.057	183.28	329.283	239.33
100.424	96.180	176.232	143.12	240.942	184.01	332.397	242.63
101.955	97.045	178.497	144.93	242.827	184.84	335.429	244.33
103.467	97.936	180.783	145.69	244.712	186.08	338.543	246.80
104.964	98.959	183.046	146.72	246.596	187.64	341.576	249.75
106.445	99.891	185.284	148.04	249.301	188.61	344.584	252.77
107.911	100.71	187.519	149.43	252.906	190.20	347.640	256.66
109.363	101.69	189.731	151.50	256.430	192.58	350.590	259.63
111.590	102.61	191.934	152.10	259.954	195.41	353.622	262.51
114.587	104.93	194.121	153.24	263.396	197.28	356.572	266.38
117.530	106.76	196.294	154.86	266.920	199.66	359.604	270.73
120.425	108.61	198.455	156.45	270.280	200.46	362.555	273.66
123.277	110.39	200.608	157.65	273.722	202.32	365.505	276.46
126.087	112.08	202.745	158.71	277.082	205.75	368.373	279.36
128.858	113.70	204.867	160.14	280.359	206.64	371.241	282.68
131.593	115.42	206.979	161.33	283.719	209.30	374.109	286.20
134.294	117.82	209.077	162.32	286.997	212.30	376.814	288.69
136.961	119.34	211.159	163.49	290.275	213.24	379.518	291.18
139.592	121.00	213.232	165.51	293.471	214.38	382.059	293.97
142.196	122.44						

Table 2 Thermodynamic properties of aspirin

T/K	$C_{p,m}$/J mol^{-1} K^{-1}	H_T–$H_{298.15}$/J mol^{-1}	S_T–$S_{298.15}$/J mol^{-1} K^{-1}	T/K	$C_{p,m}$/J mol^{-1} K^{-1}	H_T–$H_{298.15}$/J mol^{-1}	S_T–$S_{298.15}$/J mol^{-1} K^{-1}
78	84.338	–32933	–181.11	235	179.31	–12457	–46.942
80	85.296	–32764	–179.02	240	182.25	–11557	–43.144
85	87.776	–32334	–173.86	245	185.19	–10642	–39.362
90	90.372	–31891	–168.81	250	188.14	–9713.1	–35.594
95	93.070	–31434	–163.86	255	191.08	–8769.4	–31.841
100	95.860	–30964	–159.02	260	194.04	–7810.9	–28.103
105	98.732	–30480	–154.26	265	197.02	–6837.7	–24.378
110	101.67	–29981	–149.58	270	200.02	–5849.6	–20.667
115	104.68	–29467	–144.98	275	203.06	–4846.4	–16.969
120	107.73	–28939	–140.45	280	206.13	–3828.1	–13.284
125	110.83	–28395	–135.98	285	209.25	–2794.4	–9.6107
130	113.96	–27835	–131.57	290	212.43	–1745.0	–5.9484
135	117.13	–27260	–127.22	295	215.67	–679.58	–2.2962
140	120.31	–26669	–122.91	298.15	217.76	0	0
145	123.51	–26063	–118.66	300	219.00	402.16	1.3469
150	126.71	–25440	–114.44	305	222.40	1500.6	4.9822

Table 2 Continued

T/K	$C_{p,m}$/J mol^{-1} K^{-1}	H_T–$H_{298.15}$/J mol^{-1}	S_T–$S_{298.15}$/J mol^{-1} K^{-1}	T/K	$C_{p,m}$/J mol^{-1} K^{-1}	H_T–$H_{298.15}$/J mol^{-1}	S_T–$S_{298.15}$/J mol^{-1} K^{-1}
155	129.92	–24801	–110.26	310	225.91	2616.3	8.6112
160	133.13	–24147	–106.12	315	229.52	3749.7	12.235
165	136.33	–23476	–102.01	320	233.26	4901.4	15.857
170	139.52	–22789	–97.930	325	237.13	6072.0	19.477
175	142.70	–22087	–93.879	330	241.15	7262.2	23.099
180	145.86	–21369	–89.854	335	245.33	8472.9	26.726
185	149.00	–20635	–85.854	340	249.68	9704.7	30.359
190	152.12	–19886	–81.877	345	254.22	10959	34.003
195	155.22	–19121	–77.921	350	258.97	12236	37.660
200	158.30	–18341	–73.985	355	263.94	13537	41.335
205	161.36	–17545	–70.069	360	269.14	14864	45.033
210	164.40	–16734	–66.172	365	274.60	16217	48.756
215	167.41	–15908	–62.293	370	280.33	17598	52.511
220	170.41	–15068	–58.430	375	286.35	19008	56.303
225	173.39	–14212	–54.585	380	292.67	20449	60.138
230	176.35	–13342	–50.755	382	295.29	21034	61.685

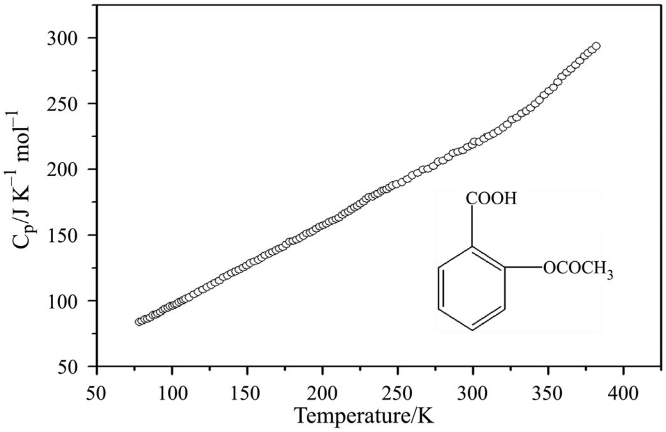

Fig. 1 Experimental molar heat capacities of aspirin as a function of temperature

where $X=\{T-[(T_{max}+T_{min})/2]/[(T_{max}-T_{min})/2]\}$, when T_{max}=383 K and T_{min}=78 K, $X=(T-230.5)/152.5$; the correlation coefficient of the fitting, R^2=0.9998. This equation is valid in the temperature range from 78 to 383 K. The standard deviation of the experimental points from the smoothed values in this temperature region is within ±0.5%.

The energy of combustion of aspirin was measured by means of a static bomb combustion calorimeter and calculated from following equation:

$$\Delta_c U_m/\text{J mol}^{-1} = (\varepsilon\Delta T - aG - 59.7\nu c)M/W$$

where ε /J K^{-1}, is the energy equivalent of the static bomb calorimeter; ΔT/K, the temperature increment of the calorimeter corrected; a/cm, length of Ni wire consumed; G/J cm^{-1}, enthalpy of combustion of Ni wire as 2.929 J cm^{-1}; –59.7/kJ mol^{-1}, molar enthalpy of formation of HNO_3 (*aq*) from (1/2)N_2(*g*), (5/4).O_2(*g*), and (1/2)H_2O(*l*) [22]; ν/mL, volume of NaOH consumed for titration of formation of HNO_3; c/mol L^{-1}, concentration of NaOH; M/g, molar mass of the sample; W/g, mass of the sample. The results of energy of combustion were given in Table 3.

Table 3 Individual values of the molar energy of combustion $\Delta_c U_m$, molar enthalpy of combustion $\Delta_c H^0_m$ and molar enthalpy of formation $\Delta_f H^0_m$ for aspirin

$-\Delta_c U_m$/kJ mol^{-1}	$-\Delta_c H^0_m$/kJ mol^{-1}	$-\Delta_f H^0_m$/kJ mol^{-1}
3943.78	3943.78	737.89
3946.35	3946.35	735.32
3948.87	3948.87	732.80
3945.40	3945.40	736.27
3941.92	3941.92	739.75
	Mean value and standard deviation of the mean	
3945.26 2.63	3945.26 2.63	736.41 1.30

The standard molar enthalpy of combustion ($\Delta_c H_m^0$, at 298.15 K) and standard molar enthalpy of formation ($\Delta_f H_m^0$) of aspirin were derived by the following formulas:

$$C_9H_8O_4(S)+9O_2(g)=9CO_2(g)+4H_2O(l)$$

$$\Delta_c H_m^0=\Delta_c U_m+\Delta n\, RT$$

$$\Delta_f H_m^0\ (C_9H_8O_4,\ S)=[9\Delta_f H_m^0(CO_2,\ g)+4\Delta_f H_m^0(H_2O,\ l)]-\Delta_c H_m^0$$

where $\Delta n=n_g(\text{product})-n_g(\text{reactant})$; R=8.314 J mol^{-1} K^{-1}; T=298.15 K; $\Delta_f H_m^0(CO_2,\ g)=-(393.51\pm0.13)$ kJ mol^{-1} [23]; $\Delta_f H_m^0(H_2O,\ l)=-(285.830\pm0.042)$ kJ mol^{-1} [23]. The results are also presented in Table 3.

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References

1 R. Altman, A. Scazziota and J. C. Fu, Thromb Res., 51 (1988) 259.
2 G. P. McMahon and M. T. Kelly, Analytical Chemistry, 70 (1998) 409.
3 J. Wang and R. H. Zhang, Yaoxue Xuebao, 35 (2000) 461.
4 O. M. N. Al-Gohary and R. S. Al-Kassas, Pharm. Acta Helv., 74 (2000) 351.
5 N. A. Chronos, D. J. Wilson and S. L. Janes, Clin. Sci., 87 (1994) 575.
6 S. Wissing, D. Q. M. Craig, S. A. Barker and W. D. Moore, International J. Pharmaceutics, 199 (2000) 141.
7 J. Zhang, S. J. Wu and D. H. Chen, J. South-Central Uni. Nationalities (Nat. Sci. Edition), 21 (2002) 21.
8 M. J. Habib and J. A. Roger, International J. Pharmaceutics, 44 (1988) 235.
9 H. Kawaji, M. Takematsu, T. Tojo, T. Atake, A. Hirano and R. Kanno, J. Therm. Anal. Cal., 68 (2002) 833.
10 N. Sakisato, A. Inaba and T. Matsuo, J. Therm. Anal. Cal., 70 (2002) 353.
11 Xu, L. X. Sun, Z. C. Tan, Z. D. Nan, P. Yu and T. Zhang, J. Therm. Anal. Cal., 74 (2003) 335.
12 Chinese Pharmacopoeia, 2000, p. 327.
13 Z. C. Tan, G. Y. Sun, Y. Sun, A. X. Yin, W. B. Wang, J. C. Ye and L. X. Zhou, J. Thermal Anal., 45 (1995) 59.
14 B. P. Liu, Z. C. Tan, Z. D. Nan, P. Liu, L. X. Sun, F. Xu and X. Z. Lan, J. Therm. Anal. Cal., 71 (2003) 623.
15 L. Wang, Z. C. Tan, S. H. Meng, D. B. Liang, S. J. Ji and Z. K. Hei, J. Therm. Anal. Cal., 66 (2001) 409.
16 Z. C. Tan, B. Xue, S.-W. Lu, S.-H. Meng, X.-H. Yuan and Y.-J. Song, J. Therm. Anal. Cal., 63 (2000) 297.
17 B. P. Liu, Z. C. Tan, J. l. Lu, X. Z. Lan, L.X. Sun, F. Xu, P. Yu and Jun Xing, Thermochim. Acta, 397 (2003) 67.
18 Z. C. Tan, L. X. Sun, S. Meng, L. Li, F. Xu, P. Yu, B. P. Liu and J. B. Zhang, J. Chem. Thermodyn., 34 (2002) 1417.

19 D. A. Ditmars, S. Ishihara, S. S. Chang, G. Bernstein and E. D. West, J. Res. Nat. Bur. Stand., 87 (1982) 159.
20 L. M. Zhang, Z. C. Tan, S. D. Wang and D. Y. Wu, Thermochim. Acta, 299 (1997) 13.
21 X. M. Wu, Z. C. Tan, S. H. Meng, C. X. Sun, F. D. Wang and S. S. Qu, Thermochim. Acta, 359 (2000) 103.
22 D. D. Waeman, W. H. Evans and V. B. Paskes, The NBS Tables of Chemical Thermodynamic Properties, J. Phys. Ref. Data, 1982, II (Suppl. 2).
23 J. D. Cox, J. Chem. Thermodyn., 10 (1978) 903.