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Synthesis and thermochemistry of two zinc borates, $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$

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ABSTRACT

Two pure zinc borates, $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$ have been synthesized and characterized by XRD, FT-IR, DTA–TG techniques and chemical analysis. The molar enthalpies of solution of $Zn_2B_6O_{11}\cdot 7H_2O(s)$ and $Zn_3B_{10}O_{18}\cdot 14H_2O(s)$ in 1 mol dm^{-3} HCl(aq) were measured to be 15.42 ± 0.03 kJ mol^{-1} and 57.78 ± 0.11 kJ mol^{-1}, respectively. The molar enthalpy of solution of ZnO(s) in $(HCl + H_3BO_3)$(aq) was determined to be -80.01 ± 0.15 kJ mol^{-1}. With incorporation of the previously determined enthalpy of solution of $H_3BO_3(s)$ in 1 mol dm^{-3} HCl(aq), and the standard molar enthalpies of formation for ZnO(s), $H_3BO_3(s)$, and $H_2O(l)$, the standard molar enthalpies of formation of -6738.1 ± 4.8 kJ mol^{-1} for $Zn_2B_6O_{11}\cdot 7H_2O$ and $-11{,}786.4 \pm 8.0$ kJ mol^{-1} for $Zn_3B_{10}O_{18}\cdot 14H_2O$ were obtained.

1. Introduction

There are many kinds of zinc borates [1] found in nature as well as synthesized in the laboratory. Some of these borates have useful properties. For example, zinc borates with different chemical formula such as $2ZnO\cdot 3B_2O_3\cdot nH_2O$($n$ = 3, 7), $4ZnO\cdot B_2O_3\cdot H_2O$, and $2ZnO\cdot 3B_2O_3$ are the fire retardant materials used in plastics [2].

Thermodynamic properties play very important roles in scientific research and industrial applications. As for the thermochemistry of borates, the standard molar enthalpies of formation of many alkaline, and alkaline-earth metal borates have been measured [3–11]. However, studies of the thermochemistry of the transition metal borates, such as zinc borates, are not reported in the literature. This paper reports the determination of standard molar enthalpies of formation of two zinc borates, $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$, by using a heat conduction microcalorimeter.

2. Experimental

2.1. Synthesis and characterization of samples

All reagents used in the synthesis were of analytic grade (made in Xi'an Chemical Factory, China).

$Zn_2B_6O_{11}\cdot 7H_2O$ was prepared by the following procedure: 6.671 g of $Na_2B_4O_7\cdot 10H_2O$, 0.203 g of ZnO are added to a solution of 5.032 g of $ZnSO_4\cdot 7H_2O$ in 77.5 ml of distilled water. The mixture was put into the flask and was refluxed at the boiling point. After 11 h, the mixture was stored at room temperature for several days. The solids were separated and washed thoroughly with distilled water, and then with alcohol and ether, and finally dried at room temperature to a constant mass.

$Zn_3B_{10}O_{18}\cdot 14H_2O$ was prepared by the following procedure: 3.048 g of $Na_2B_4O_7\cdot 10H_2O$ is added to a solution of 4.945 g of H_3BO_3 in 50 ml of distilled water. A solution of 2.304 g of $ZnSO_4\cdot 7H_2O$ in 10 ml of distilled water was added and the solution was left in a closed beaker. The mixture was stirred for 1 h at room temperature. After several days, the resulting white precipitate was filtered, then washed with absolute alcohol and absolute ether, and finally, dried at room temperature to constant mass.

The two synthetic samples were characterized by X-ray powder diffraction (XRD, Rigaku D/MAX-IIIC with Cu target at 8° min^{-1}), FT-IR spectroscopy (Nicolet NEXUS 670 FT-IR spectrometer with KBr pellets at room temperature), and TG–DTA (TA-SDT Q600 simultaneous thermal analyzer at a heating rate of 10 K min^{-1} in flowing N_2). The chemical compositions of the samples were determined by EDTA titration for Zn^{2+}, by NaOH standard solution in the presence of mannitol for B_2O_3, and by the mass loss in the TG curve for H_2O.

2.2. Calorimetric experiment

$Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$ can be regarded as the products of the following reactions (I) and (II), respectively:

$$2ZnO(s) + 6H_3BO_3(s) = Zn_2B_6O_{11}\cdot 7H_2O(s) + 2H_2O(l) \quad (I)$$

$$3ZnO(s) + 10H_3BO_3(s) = Zn_3B_{10}O_{18}\cdot 14H_2O(s) + H_2O(l) \quad (II)$$

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The 1 mol dm^{-3} HCl(aq) solvent can rapidly dissolve all components of reactions (I) and (II). The solution was prepared from analytical grade hydrochloric acid and deionized water, and its concentration, 1.0004 mol dm^{-3}, was determined by titration with standard sodium carbonate.

The thermochemical cycles used are given in Tables 4 and 5. The molar enthalpies of solution of H_3BO_3(s), $Zn_2B_6O_{11}\cdot 7H_2O$(s) and $Zn_3B_{10}O_{18}\cdot 14H_2O$(s) in 1 mol dm^{-3} HCl(aq) were measured, respectively. The calculated amount of ZnO(s) was dissolved in (hydrochloric acid + boric acid) aqueous solution which consisted of 1 mol dm^{-3} HCl(aq) and the calculated amount of H_3BO_3(s). In all these determinations, strict control of the stoichiometry in each step of the calorimetric cycle must be observed, with the objective that the dissolution of the reactants give the same composition as those of the products in reactions (I) and (II). Applying Hess's law, the enthalpy of reaction (5) can be calculated according to the following expression:

$$\Delta_r H_m^\circ(5) = \Delta_r H_m^\circ(1) + \Delta_r H_m^\circ(2) - \Delta_r H_m^\circ(3) - \Delta_r H_m^\circ \qquad (4)$$

The standard molar enthalpies of formation of $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$ can be obtained from the value of $\Delta_r H_m^\circ$ (5) in combination with the molar enthalpies of formation of H_3BO_3(s), ZnO(s), and H_2O(l).

All the enthalpies of solution were measured with an RD496-III heat conduction microcalorimeter (Southwest Institute of Electron Engineering, China), which is a totally automatic instrument by using a computerized control that has been described in detail previously [9,12]. Total time required for the complete dissolution reaction was about 0.5 h. There were no solid residues observed after the reactions in each calorimetric experiment.

To check the performance of the calorimeter, the enthalpy of solution of KCl (mass fraction ≥0.9999) in deionized water was determined to be 17.563 ± 0.099 kJ mol^{-1}, which was in agreement with that of 17.524 ± 0.028 kJ mol^{-1} reported in the literature [13].

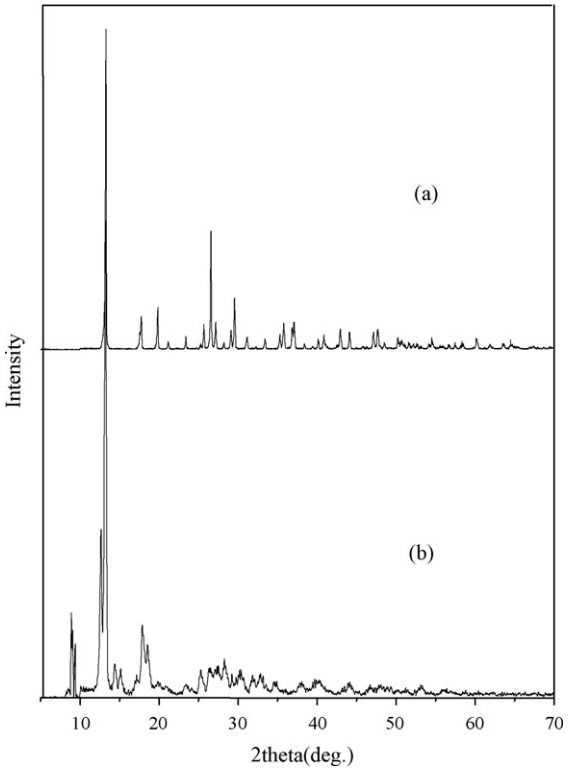

Fig. 1. X-ray powder diffraction patterns of samples. (a) $Zn_2B_6O_{11}\cdot 7H_2O$ and (b) $Zn_3B_{10}O_{18}\cdot 14H_2O$.

Table 1
XRD data of synthetic samples and corresponding JCPDS cards values[a].

Measured values			JCPDS cards values		
2θ (°)	d (Å)	I/I_0	2θ (°)	d (Å)	I/I_0
$Zn_2B_6O_{11}\cdot 7H_2O$					
13.280	6.6617	100	13.207	6.6984	100
17.779	4.9847	10.3	17.687	5.0106	31
19.875	4.4635	13.0	19.824	4.4750	25
23.422	3.7950	3.9	389	3.8003	7
25.704	3.4630	7.7	25.590	3.4782	34
26.600	3.3483	36.6	593	3.3492	47
27.217	3.2738	8.3	27.092	3.2887	37
29.141	3.0618	5.7	29.145	3.0615	13
29.617	3.0138	15.8	29.519	3.0235	61
31.218	2.8627	3.6	31.237	2.8611	9
33.443	2.6772	3.1	33.466	2.6754	9
35.361	2.5362	4.6	35.391	2.5342	14
35.841	2.5034	7.9	35.813	2.5053	30
36.918	2.4328	6.6	36.936	2.4317	17
37.156	2.4178	8.3	37.136	2.4190	43
43.019	2.1008	6.2	43.064	2.0987	25
44.176	2.0484	5.2	44.240	2.0457	12
47.759	1.9028	5.8	47.830	1.9001	23
$Zn_3B_{10}O_{18}\cdot 14H_2O$					
9.378	9.4226	10.5	10.813	9.5000	39
13.220	6.6918	100	15.218	6.7600	54
14.401	6.1455	5.1	16.415	.2700	23
15.160	5.8395	5.1	17.603	5.8500	25
18.541	4.7816	8.2	21.632	4.7700	31
23.420	3.7953	1.9	27.248	3.8000	39
25.280	3.5200	4.7	29.635	3.5000	21
26.380	3.3757	4.9	30.806	3.3700	22
28.280	3.1531	4.2	33.017	3.1500	23
30.400	2.9379	4.5	35.576	2.9300	100
31.877	2.8050	2.7	37.287	2.8000	26
32.840	2.7249	2.8	38.872	2.6900	54
38.138	2.3577	1.7	44.380	2.3700	62
34.900	2.5687	1.9	40.600	2.5800	57
53.218	1.7198	1.6	62.719	1.7200	85

[a] Data in JCPDS card (File No. 32–1461) obtained with Co target, and the others data obtained with Cu target.

3. Results and discussion

3.1. Chemical analysis of synthetic samples

The chemical analytical data of synthetic samples are (calcd./found, %), ZnO (32.70/32.37), B_2O_3 (41.96/41.76), H_2O (25.34/25.96) for sample of $Zn_2B_6O_{11}\cdot 7H_2O$ and ZnO (28.91/29.35), B_2O_3 (41.22/41.67), H_2O (29.87/31.53) for sample of $Zn_3B_{10}O_{18}\cdot 14H_2O$, which are consistent with the theoretical values.

3.2. X-ray powder diffraction

The XRD patterns of synthetic samples are given in Fig. 1. The data of XRD patterns of the synthetic samples and corresponding data in JCPDS cards are listed in Table 1. The main characteristic *d* values for samples of $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$ agree with those of JCPDS cards (File Nos. 72–1789 and 32–1461) and shows absence of other crystalline forms in the synthetic samples, respectively. It is worth noting that the determined XRD data obtained with Cu target for $Zn_3B_{10}O_{18}\cdot 14H_2O$ and corresponding XRD data in JCPDS card (File No. 32–1461) obtained with Co target, which leads to the different 2θ values between them.

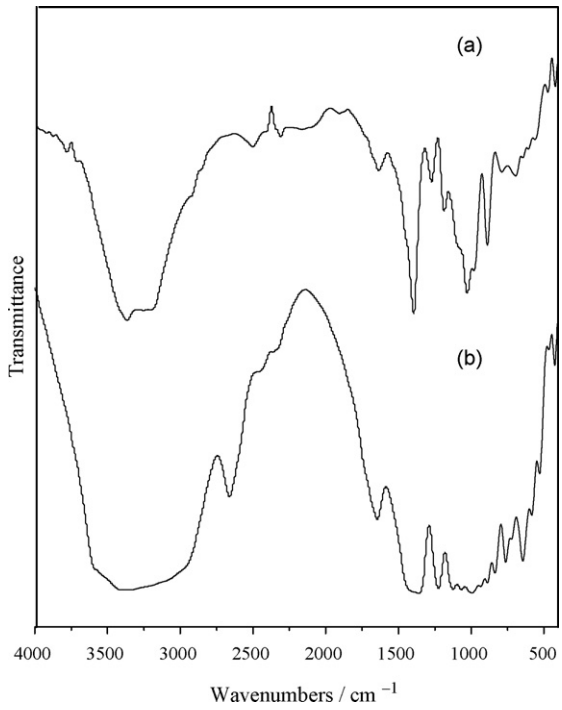

Fig. 2. FT-IR spectra of samples. (a) $Zn_2B_6O_{11}\cdot 7H_2O$ and (b) $Zn_3B_{10}O_{18}\cdot 14H_2O$.

3.3. FT-IR spectra

The FT-IR spectra (Fig. 2) of samples exhibited the following absorption bands and they were assigned referring to the literature [14].

For sample of $Zn_2B_6O_{11}\cdot 7H_2O$: the band at 3374 cm^{-1} is the stretching of O–H. The band at 2510 cm^{-1} is the O–H stretching because of hydrogen bond. The band at 1644 cm^{-1} is assigned to the H–O–H bending mode, which shows the compound containing the crystalline water. The bands at 1181 cm^{-1} and 1274 cm^{-1} might be the in-plane bending of B–O–H. The band at 1391 cm^{-1} is the asymmetric stretching of B(3)–O. The bands at 1022 cm^{-1} and 883 cm^{-1} are the asymmetric and symmetric stretching of B(4)–O. The band at 685 cm^{-1} is the out-of-plane bending mode of B(3)–O. The band at 433 cm^{-1} is the bending of B(4)–O.

For sample of $Zn_3B_{10}O_{18}\cdot 14H_2O$: the band at 3355 cm^{-1} is the stretching of O–H. The band at 2662 cm^{-1} is the O–H stretching because of hydrogen bond. The band at 1645 cm^{-1} is the H–O–H bending mode, which shows that the compound contains crystalline water. The band at 1224 cm^{-1} might be the in-plane bending of B–O–H. The peaks at 1122 cm^{-1}, 831 cm^{-1} and 762 cm^{-1} might be the asymmetric and symmetric stretching of B(4)–O. The band at 1358 cm^{-1} is the asymmetric stretching of B(3)–O. The peak at 644 cm^{-1} is the out-of-plane bending of B(3)–O. The peaks at 530 cm^{-1} and 590 cm^{-1} are the bending of B(3)–O. The peak at 432 cm^{-1} is the bending of B(4)–O.

3.4. Thermal analysis

The simultaneous TG–DTA curves of sample of $Zn_2B_6O_{11}\cdot 7H_2O$ (Fig. 3) indicate that the total mass loss is 25.96% from 423 K to 1023 K, which corresponds to the loss of seven water molecules and agrees with the calculated value of 25.34%. In the DTA curve, the endothermic peak appearing at 476 K is related to the elimination of crystalline water. The formed amorphous phase of $Zn_2B_6O_{11}$ recrystallizes as shown by the exothermic peak at 953 K.

The simultaneous TG–DTA curves of sample of $Zn_3B_{10}O_{18}\cdot 14H_2O$ (Fig. 4) indicate that the total mass loss is 31.53% from 356 K to 973 K, which corresponds to the loss of 14 water molecules and is near to the calculated value of 29.87%. This error might be resulted from the existence of moisture on the surface of this sample. In the DTA curve, the endothermic peak appearing at 420 K is related to the elimination of crystalline water. The formed amorphous phase of $Zn_3B_{10}O_{18}$ recrystallizes as shown by the exothermic peak at 970 K.

All of above results indicate that the synthetic samples are pure and suitable for the calorimetric experiments.

3.5. Results of calorimetric experiment

The molar enthalpies of solution of ZnO(s) in $(HCl + H_3BO_3)$(aq) at 298.15 K are listed in Table 2. The molar enthalpies of solution of $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$ in HCl(aq) at 298.15 K are listed in Table 3, in which m is the mass of sample, $\Delta_{sol}H_m$ is the molar enthalpy of solution of solute, and the uncertainty is estimated as twice the standard deviation of the mean with $n = 5$.

Tables 4 and 5 give the thermochemical cycles used for the derivation of the standard molar enthalpy of formation of

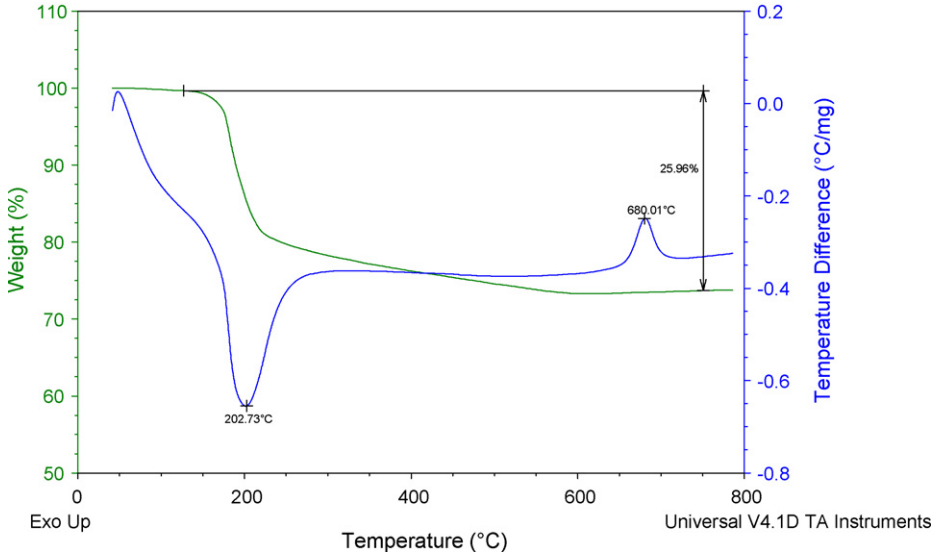

Fig. 3. Simultaneous TG–DTA curves of sample $Zn_2B_6O_{11}\cdot 7H_2O$.

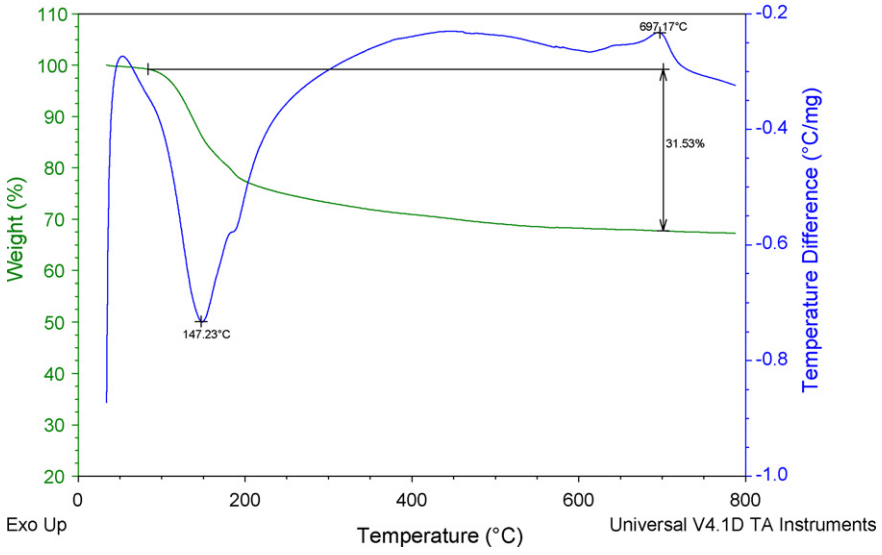

Fig. 4. Simultaneous TG–DTA curves of sample $Zn_3B_{10}O_{18}\cdot 14H_2O$.

Table 2
The molar enthalpies of solution of ZnO(s) in the mixed solvent that consisted of 1 mol dm^{-3} HCl(aq) and calculated amount of H_3BO_3 at 298.15 K[a].

No.	m (mg)	$\Delta_r H$ (mJ)	$\Delta_{sol}H_m$ (kJ mol^{-1})
1	2.29	−2253.758	−80.10
2	2.34	−2303.145	−80.10
3	2.24	−2305.434	−80.12
4	2.23	−2184.547	−79.72
5	2.23	−2194.896	−79.99
Mean			−80.01 ± 0.15[b]

[a] In each experiment, 2.00 cm^3 of HCl(aq) was used.
[b] Uncertainty is estimated as twice the standard deviation of the mean.

Table 3
The molar enthalpies of solution of $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$ in 1 mol dm^{-3} HCl(aq) at 298.15 K[a].

No.	m (mg)	$\Delta_r H$ (mJ)	$\Delta_{sol}H_m$ (kJ mol^{-1})
$Zn_2B_6O_{11}\cdot 7H_2O$			
1	7.08	219.388	15.42
2	7.10	220.050	15.43
3	7.12	220.862	15.44
4	7.08	218.614	15.36
5	7.18	222.581	15.43
Mean			15.42 ± 0.03[b]
$Zn_3B_{10}O_{18}\cdot 14H_2O$			
1	7.14	488.146	57.73
2	7.19	492.291	57.82
3	7.28	496.969	57.65
4	7.20	492.205	57.73
5	7.22	495.594	57.96
Mean			57.78 ± 0.11[b]

[a] In each experiment, 2.00 cm^3 of HCl(aq) was used.
[b] Uncertainty is estimated as twice the standard deviation of the mean.

$Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$. The molar enthalpy of solution of H_3BO_3(s) of 21.84 ± 0.05 kJ mol^{-1} in 1 mol dm^{-3} HCl(aq) was taken from our previous work [11]. The enthalpy of dilution of HCl(aq) was calculated from NBS tables [15]. The enthalpies change of −44.36 ± 0.43 kJ mol^{-1} for the formation of $Zn_2B_6O_{11}\cdot 7H_2O$ and −79.39 ± 0.68 kJ mol^{-1} for the formation of $Zn_3B_{10}O_{18}\cdot 14H_2O$ from the reagents in the solid phase (reactions (I) and (II)) were calculated on the basis of the thermochemical cycles. The standard

Table 4
Thermochemical cycle and results for the derivation of $\Delta_f H_m^\circ$ ($Zn_2B_6O_{11}\cdot 7H_2O$, 298.15 K)[a].

No.	Reaction	$\Delta_r H^\circ$ (kJ mol^{-1})	Ref.
1	$6H_3BO_3(s) + 140.062(HCl\cdot 54.561H_2O) = 6H_3BO_3(aq) + 140.062(HCl\cdot 54.561H_2O)$	131.04 ± 0.30	[11]
2	$2ZnO(s) + 6H_3BO_3(aq) + 140.062(HCl\cdot 54.561H_2O) = 2ZnCl_2(aq) + 6H_3BO_3(aq) + 136.062(HCl\cdot 56.180H_2O)$	−160.02 ± 0.30	This work
3	$140.062(HCl\cdot 54.561H_2O) + 2H_2O(l) = 140.062(HCl\cdot 54.575H_2O)$	−0.04 ± 0.01	[15]
4	$Zn_2B_6O_{11}\cdot 7H_2O(s) + 140.062(HCl\cdot 54.575H_2O) = 2ZnCl_2(aq) + 6H_3BO_3(aq) + 136.062(HCl\cdot 56.180H_2O)$	15.42 ± 0.03	This work
5	$2ZnO(s) + 6H_3BO_3(s) = Zn_2B_6O_{11}\cdot 7H_2O(s) + 2H_2O(l)$	−44.36 ± 0.43[b]	

[a] $\Delta_f H_m^\circ(Zn_2B_6O_{11}\cdot 7H_2O, s) = \Delta_r H_m^\circ(5) + 2\Delta_f H_m^\circ(ZnO, s) + 6\Delta_f H_m^\circ(H_3BO_3, s) - 2\Delta_f H_m^\circ(H_2O, l)$.
[b] Uncertainty of the combined reaction is estimated as the square root of the sum of the squares of uncertainty of each individual reaction.

Table 5
Thermochemical cycle and results for the derivation of $\Delta_f H_m^\circ$ ($Zn_3B_{10}O_{18}\cdot 14H_2O$, 298.15K)[a].

No.	Reaction	$\Delta_r H^\circ$ (kJ mol^{-1})	Ref.
1	$10H_3BO_3(s) + 233.365(HCl\cdot 54.561H_2O) = 10H_3BO_3(aq) + 233.365(HCl\cdot 54.561H_2O)$	218.40 ± 0.50	[11]
2	$3ZnO(s) + 10H_3BO_3(aq) + 233.365(HCl\cdot 54.561H_2O) = 3ZnCl_2(aq) + 10H_3BO_3(aq) + 227.365(HCl\cdot 56.014H_2O)$	−240.03 ± 0.45	This work
3	$233.365(HCl\cdot 54.561H_2O) + H_2O(l) = 233.365(HCl\cdot 54.565H_2O)$	−0.02 ± 0.01	[15]
4	$Zn_3B_{10}O_{18}\cdot 14H_2O(s) + 233.365(HCl\cdot 54.565H_2O) = 3ZnCl_2(aq) + 10H_3BO_3(aq) + 227.365(HCl\cdot 56.014H_2O)$	57.78 ± 0.11	This work
5	$3ZnO(s) + 10H_3BO_3(s) = Zn_3B_{10}O_{18}\cdot 14H_2O(s) + H_2O(l)$	−79.39 ± 0.68[b]	

[a] $\Delta_f H_m^\circ(Zn_3B_{10}O_{18}\cdot 14H_2O, s) = \Delta_r H_m^\circ(5) + 3\Delta_f H_m^\circ(ZnO, s) + 10\Delta_f H_m^\circ(H_3BO_3, s) - \Delta_f H_m^\circ(H_2O, l)$.
[b] Uncertainty of the combined reaction is estimated as the square root of the sum of the squares of uncertainty of each individual reaction.

molar enthalpies of formation of H_3BO_3(s) and H_2O(l) were taken from the CODATA Key Values[16], namely -1094.8 ± 0.8 kJ mol^{-1} and -285.830 ± 0.040 kJ mol^{-1}, respectively. The standard molar enthalpy of formation of ZnO(s) of -348.28 kJ mol^{-1} was taken from the NBS tables [15]. From these data, the standard molar enthalpies of formation for $Zn_2B_6O_{11}\cdot 7H_2O$ and $Zn_3B_{10}O_{18}\cdot 14H_2O$ were calculated to be -6738.1 ± 4.8 kJ mol^{-1} and $-11{,}786.4 \pm 8.0$ kJ mol^{-1}, respectively.

The very big values of standard molar enthalpies of formation show that the two zinc borates are quite thermodynamic stable. It also can be found that the bigger the molecular weight of zinc borate, the larger the $\Delta_f H_m^\circ$ of zinc borate, which shows that the total numbers of B(3)–O and B(4)–O groups in $Zn_3B_{10}O_{18}\cdot 14H_2O$ are more than those in $Zn_2B_6O_{11}\cdot 7H_2O$.

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References

[1] D.M. Schubert, F. Alam, M.Z. Visi, C.B. Knobler, Chem. Mater. 15 (2003) 866.
[2] A. Mergen, E. Tektas, G. Karakoc, M. Gunduz, CFI-Ceram. Forum Int. 80 (2003) 40.
[3] J. Li, B. Li, S.Y. Gao, J. Chem. Thermodyn. 30 (1998) 425.
[4] Z.H. Liu, S.Y. Li, M.C. Hu, J. Chem. Themodyn. 37 (2005) 1003.
[5] Z.H. Liu, P. Li, L.Q. Li, Q.X. Jia, Thermochim. Acta 454 (2007) 23.
[6] P. Li, Z.H. Liu, J. Chem. Eng. Data 52 (2007) 1811.
[7] J. Li, S.Y. Gao, Sh.P. Xia, B. Li, J. Chem. Themodyn. 29 (1997) 491.
[8] J. Li, S.Y. Gao, Sh.P. Xia, B. Li, R.Z. Hu, J. Chem. Thermodyn. 29 (1997) 1071.
[9] Z.H. Liu, M.C. Hu, Thermochim. Acta 414 (2004) 215.
[10] Z.H. Liu, Y.S. Li, C.F. Zuo, Thermochim. Acta 433 (2005) 196.
[11] Z.H. Liu, P. Li, C.F. Zuo, J. Chem. Eng. Data 51 (2006) 272.
[12] M. Ji, M.Y. Liu, Sh.L. Gao, Q.Zh. Shi, Instrum. Sci. Technol. 29 (1) (2001) 53.
[13] R. Rychlý, V. Pekárek, J. Chem. Themodyn. 9 (1977) 391.
[14] J. Li, S.P. Xia, S.Y. Gao, Spectrochim. Acta 51A (1995) 519.
[15] D.D. Wagman, W.H. Evans, V.B. Parker, R.H. Schumm, I. Halow, S.M. Bailey, K.L. Chumey, L.R. Nuttall, The NBS tables of chemical thermodynamic properties, J. Phys. Chem. Ref. Data 11 (Suppl. 2) (1982).
[16] J.D. Cox, D.D. Wagman, V.A. Medvedev, CODATA Key Values for Thermodynamics, Hemisphere, New York, 1989.