Hindawi
Journal of Chemistry
Volume 2019, Article ID 1541508, 7 pages
https://doi.org/10.1155/2019/1541508

Research Article

Phase Equilibria and Phase Diagrams for the Ternary Aqueous System Containing Lithium, Sodium, and Pentaborate Ions at 298.15 and 323.15 K and 101.325 kPa

Panpan Li,[1] Kaiyu Zhao,[1] Shangqing Chen,[1] Jiayin Hu ,[1] Yafei Guo ,[1] Mingli Li,[2] Ji Duo,[2] and Tianlong Deng [1]

[1]*Tianjin Key Laboratory of Marine Resources and Chemistry, College of Chemical Engineering and Materials Science, Tianjin University of Science and Technology, Tianjin 300457, China*
[2]*Central Laboratory of Tibet Autonomous Region Bureau of Geological & Mineral Resources, Lasa 850033, China*

Correspondence should be addressed to Yafei Guo; guoyafei@tust.edu.cn and Tianlong Deng; tldeng@tust.edu.cn

Received 20 February 2019; Accepted 14 May 2019; Published 31 July 2019

Academic Editor: Elena Gomez

Phase equilibria and phase diagrams for the ternary aqueous system containing lithium, sodium, and pentaborate ions at 298.15 and 323.15 K and 101.325 kPa were investigated by the methods of isothermal dissolution equilibrium. From the experimental data, the phase diagrams and the diagrams of physicochemical properties versus composition of lithium pentaborate in the equilibrium systems were plotted, respectively. The phase diagrams of the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at two temperatures contain one invariant point, two univariant curves, and two crystallization regions corresponding to sodium pentaborate pentahydrate ($NaB_5O_8{\cdot}5H_2O$) and lithium pentaborate pentahydrate ($LiB_5O_8{\cdot}5H_2O$). Due to the different dissolution behaviors of pentaborate salts in the aqueous systems, the component of LiB_5O_8 has a relatively strong effect on the solubility of NaB_5O_8. It was found that this system belongs to a simple eutectic type at two temperatures, and neither double salts nor solid solutions were formed. The densities and refractive indices in the ternary system at 298.15 and 323.15 K are as similar as changing regularly with the increase of LiB_5O_8 concentration. On the basis of empirical equations of the density and refractive index in electrolytes, the calculated values of density and refractive index agreed well with the experimental values at two temperatures.

1. Introduction

Borates not only occupy an important role in the modern inorganic salt industry but also have been widely used in electronic manufacturing, new type of electrode materials, and nonlinear optical materials for their excellent characteristics, so the demand for borates is sharply increasing nowadays [1–3]. Due to the rapid depletion of solid boron mineral resources, the comprehensive exploitation for brine resources such as salt lake brines, underground brines, and geothermal waters has become the research hotspots around the world at present [4]. The phase diagram and phase equilibrium as well as the corresponding physicochemical properties are essential to give a theoretical guidance for exploiting the available brine resources and describing the thermodynamic behaviors for the salt minerals. It is well known that salt lake brine located in the Qaidam Basin of Qinghai-Tibet Plateau is famous for its high concentrations of lithium, sodium, potassium, and boron. Therefore, it is highly desirable to study the phase equilibria and phase diagram for the systems containing lithium, sodium, and boron [5, 6].

In recent years, lots of phase diagram containing borates including $LiBO_2 + CaB_2O_4 + H_2O$ at 288.15 and 298.15 K [7], $MgCl_2 + MgSO_4 + MgB_6O_{10} + H_2O$ at 323.15 K [8], $MgB_4O_7 + Na_2B_4O_7 + Li_2B_4O_7 + H_2O$ at 288 K [9], $K_2B_4O_7 + Na_2B_4O_7 + Li_2B_4O_7 + H_2O$ at 273 K [10], $MgCl_2 + MgB_6O_{10} + H_2O$ and $MgSO_4 + MgB_6O_{10} + H_2O$ at 323.15 K [11], and $Li_2B_4O_7 + MgB_4O_7 + H_2O$ and $K_2B_4O_7 + MgB_4O_7 + H_2O$ at 273 K [12] have been reported. The existed forms of borates in the reported phase diagrams are mainly concentrated on BO_2^-, $B_4O_7^{2-}$, and $B_6O_{10}^{2-}$. However, the solubility data containing $B_5O_8^-$ are still lacking in the literature. In order to make comprehensive utilization and give a theoretical guidance for the actual production of salt lake brines containing pentaborate ions, the solubilities and corresponding physicochemical properties of the ternary systems $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K were reported for the first time in this paper.

2. Experimental

2.1. Reagents and Apparatus. The chemicals used in this work are shown in Table 1. And, $LiB_5O_8{\cdot}5H_2O$ and $NaB_5O_8{\cdot}5H_2O$ were successfully synthesized in our laboratory based on the method described previously in detail [13]. In brief, according to the molar ratio of $LiOH{\cdot}H_2O : H_3BO_3 : H_2O = 1:5:10$ and $Na_2B_4O_7{\cdot}10H_2O : H_3BO_3 : H_2O = 1:5:10$, a certain amount of $LiOH{\cdot}H_2O$ or $Na_2B_4O_7{\cdot}10H_2O$, H_3BO_3, and fresh CO_2-free deionized distilled water (DDW) were added in two beakers to synthesize $LiB_5O_8{\cdot}5H_2O$ and $NaB_5O_8{\cdot}5H_2O$, respectively. Then, they were stirred for homogeneity at room temperature, and then transferred into two reactors to react for 7 d at 60°C under stirring with 200°rmp, respectively. Finally, $LiB_5O_8{\cdot}5H_2O$ and $NaB_5O_8{\cdot}5H_2O$ were produced after separation, filtration, washing and recrystallization, and drying at 35°C for use. And the synthetic samples were analyzed by chemical analysis and identified by the X-ray diffraction, and the results are shown in Table 1 and Figures 1 and 2, respectively. From the XRD patterns, it is shown that the peak positions and intensities of the synthesized chemicals $LiB_5O_8{\cdot}5H_2O$ and $NaB_5O_8{\cdot}5H_2O$ agree well with that of the standard samples. The DDW produced using a deionizer (ULUP-II-10T Sichuan Ulupure Co. Ltd., China) with conductivity less than $1 \times 10^{-4}\,S{\cdot}m^{-1}$ and $pH = 6.60$ at 298.15 K was used during the whole experiment [14].

A magnetic stirring thermostatic water bath (HXC-500-6A, Beijing Fortune Joy Science Technology Co. Ltd, China) was employed for controlling the temperature with a precision of ±0.1 K for the phase equilibrium experiments. The refractive indices (n_D) were measured by an Abbe refractometer (Abbemat 550, Anton Paar, Austria) with an uncertainty of ±0.0003. The densities (ρ) were measured using a digital U-tube densimeter (DMA 4500, Anton Paar, Austria) with an uncertainty of ±0.5 $mg{\cdot}cm^{-3}$. The standard uncertainties $u(x)$ for pressure, temperature, and composition are $u(p) = 5$ kPa, $u(T) = 0.1$ K, $u(LiB_5O_8) = 0.00063$, and $u(NaB_5O_8) = 0.00060$. An X-ray diffractometer (MSAL XD-3, Beijing Purkinje Instrument Co. Ltd, China) was used to identified the solid phase [15].

2.2. Experimental Methods. The solid-liquid-phase equilibrium of the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K was studied by the isothermal dissolution equilibrium method as described previously [16]. On the basis of the binary solubility, a series of artificial synthetic complexes were prepared by mixing lithium pentaborate and sodium pentaborate with DDW. Then, complexes were put into the sealed polyethylene plastic bottles, which were placed in magnetic stirring thermostatic water baths with continuous stirring in order to accelerate the establishment of equilibrium states, and the temperatures were automatically controlled for $T = 298.15 \pm 0.1$ and 323.15 ± 0.1 K using magnetic stirring thermostatic water baths, respectively. Then, the composition of the liquid phase in the bottle was for quantitative chemical analysis at seven-day intervals. If the composition of the liquid phase became constant, it indicated that the solid-liquid-phase equilibrium was achieved. Generally, the equilibration time is about 90 days. After equilibrium was achieved, the magnetic stirrer was stopped to separate the solid phase from the liquid phase for 6 hours. When the complexes in bottles were clarified, the liquid phases were taken out for quantitative chemical analysis and physicochemical properties measurements (density and refractive index). In addition, the equilibrium solid phase was identified by X-ray diffraction [17].

2.3. Analytical Methods. The borate ion concentration was determined by the mannitol gravimetric method with sodium hydroxide standard solution and the mixture indicator of methyl red and phenolphthalein with an uncertainty of 0.0005 in mass fraction. The concentration of Li+ and Na+ was measured using an inductively coupled plasma optical emission spectrometer (ICP-OES, Prodigy, Leman Corporation, America. Precision: ±0.01), and then evaluated using ion balance [18].

3. Results and Discussion

In order to evaluate and test the reliability of the experimental method in this work, a comparison of the solubilites in the boundary subsystems $NaB_5O_8 + H_2O$ at 298.15 and 323.15 K in literature [19] is summarized in Table 2. The results show that the experimental results in this work agree well with previous reports, demonstrating that our experimental procedure and results are rational reliable and rational. The experimental solubilities and the relevant physicochemical properties including density and refractive index for the ternary systems $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K and 101.325 kPa are presented in Table 3, respectively. The composition of the liquid phase was expressed in mass fraction.

3.1. Solubilities of the Binary Systems $LiB_5O_8 + H_2O$ and $NaB_5O_8 + H_2O$ at 298.15 and 323.15 K. The solubilities of binary systems $LiB_5O_8 + H_2O$ and $NaB_5O_8 + H_2O$ at 298.15 and 323.15 K were firstly obtained by the isothermal dissolution equilibrium method in this work. As shown in Table 2, the solubilities of lithium pentaborate in the binary systems $LiB_5O_8 + H_2O$ at 298.15 and 323.15 K in mass fraction of $100w$ were 14.00 and 22.19, respectively. Analogously, the solubilities of sodium pentaborate in the binary systems $NaB_5O_8 + H_2O$ at 298.15 and 323.15 K in mass fraction of $100w$ were 12.23 and 20.73, respectively.

Table 1: Chemical samples used in this study.

Chemical	Source	Initial mass fraction	Purification method	Final mass fraction	Analytical method
H_3BO_3	[b]A.R.	0.99	No further purification	—	Gravimetric method for $B(OH)_3$
$LiOH{\cdot}H_2O$	[a]A.R.	0.99	No further purification	—	Titration method for OH^-
$Na_2B_4O_7{\cdot}10H_2O$	[b]A.R.	0.99	No further purification	—	Gravimetric method for $B_4O_7^{2-}$
$LiB_5O_8{\cdot}5H_2O$	[c]A.R.	0.99	Recrystallization	0.998	Gravimetric method for $B_5O_8^-$
$NaB_5O_8{\cdot}5H_2O$	[c]A.R.	0.99	Recrystallization	0.998	Gravimetric method for $B_5O_8^-$

[a]A.R. from the Shanghai Macklin Biochemical Co. Ltd. [b]A.R. from the Simopharm Chemical Reagent Co. Ltd. [c]A.R. synthesized in our laboratory.

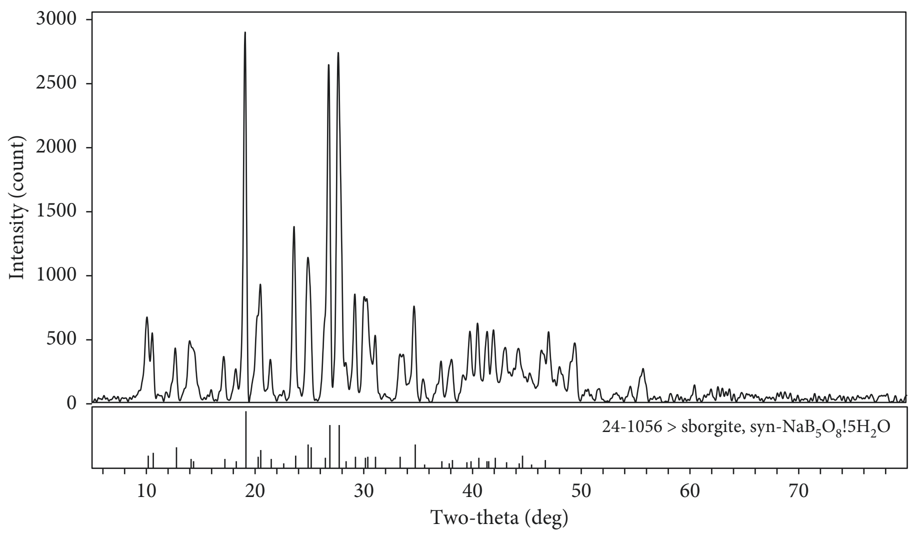


Figure 1: X-ray diffraction pattern of $NaB_5O_8{\cdot}5H_2O$.

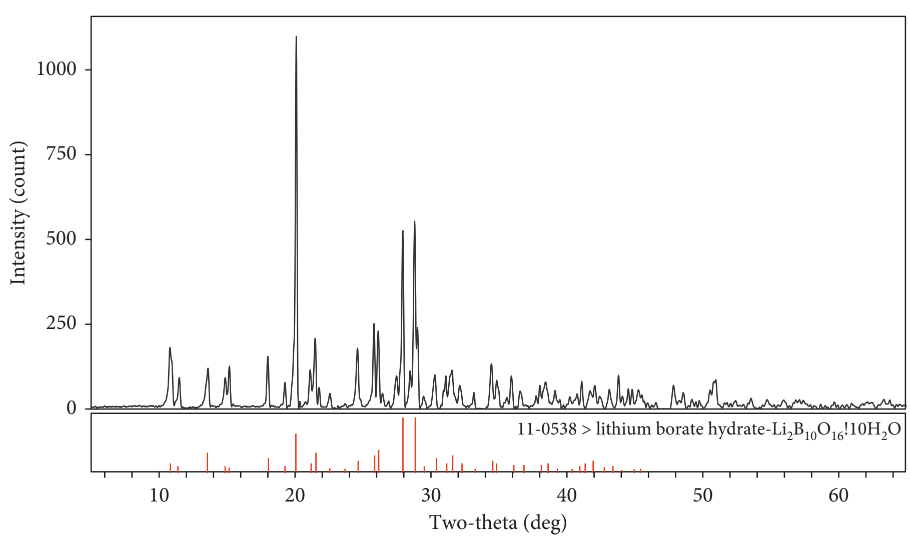


Figure 2: X-ray diffraction pattern of $LiB_5O_8{\cdot}5H_2O$.

Table 2: Solubilities in the binary subsystems $NaB_5O_8 + H_2O$ at 298.15 and 323.15 K and 0.1 MPa[a].

Binary system	T (K)	Solubility ($100w^b$)	Ref.
$NaB_5O_8 + H_2O$	298.15	12.20	19
		12.23	This work
	323.15	21.80	19
		20.73	This work

[a]Standard uncertainties u are $u(T) = 0.1$ K and $u(p) = 5$ kPa. $u(w)$ for NaB_5O_8 is 0.00060 in mass fraction. [b]w is the mass fraction.

Table 3: Solubilities, refractive indices, and densities for ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$[a].

No.	Composition of liquid phase ($100w^b$)		Density, ρ ($g\cdot cm^{-3}$)			Refractive index (n_D)			Equilibrium solid phase[c]
	LiB_5O_8	NaB_5O_8	Exp. Value	Cal. Value	Relative error (%)	Exp. Value	Cal. Value	Relative error (%)	
					$T = 298.15$ K and $p = 0.1$ MPa				
1,A	14.00	0.00	1.10136	1.096286	0.46	1.353170	1.352497	0.05	LB5
2	13.71	1.92	1.10231	1.108264	−0.54	1.353425	1.354508	−0.08	LB5
3	13.12	2.57	1.10473	1.108647	−0.35	1.353711	1.354481	−0.06	LB5
4	11.77	3.78	1.10618	1.107469	−0.12	1.353998	1.354067	−0.01	LB5
5,E	9.87	4.69	1.10757	1.099968	0.69	1.354261	1.352483	0.13	LB5 + NB5
6	4.52	8.88	1.09087	1.090923	0.00	1.349830	1.350084	−0.02	NB5
7	3.48	9.64	1.08973	1.088776	0.09	1.349583	1.349549	0.00	NB5
8	0.96	12.12	1.08658	1.088226	−0.15	1.348849	1.349059	−0.02	NB5
9,B	0.00	12.23	1.08213	1.081964	0.02	1.347858	1.347821	0.00	NB5
					$T = 323.15$ K and $p = 0.1$ MPa				
1,A	0.00	20.73	1.14023	1.130639	0.84	1.356293	1.354688	0.12	NB5
2	5.12	18.17	1.14082	1.151091	−0.90	1.356541	1.358206	−0.12	NB5
3	9.82	13.20	1.14404	1.150421	−0.56	1.357015	1.358158	−0.08	NB5
4	12.96	9.46	1.14623	1.146839	0.05	1.357495	1.357601	0.01	NB5
5,E	14.80	7.60	1.15309	1.147217	0.51	1.358599	1.357689	0.07	LB5 + NB5
6	15.70	6.04	1.15109	1.142560	0.74	1.358417	1.356919	0.11	LB5
7	17.55	5.21	1.14925	1.150696	0.13	1.358121	1.358310	−0.01	LB5
8	19.11	3.68	1.14793	1.151369	−0.30	1.357911	1.358444	−0.04	LB5
9,B	22.19	0.00	1.14747	1.147767	0.03	1.357777	1.357883	−0.01	LB5

[a]Standard uncertainties u are $u(T) = 0.1$ K and $u(p) = 5$ kPa. $u(w)$ for LiB_5O_8 and NaB_5O_8 are 0.00063 and 0.00060 in mass fraction. $u(x)$ for ρ and n_D are 0.5 $mg\cdot cm^{-3}$ and 0.0003, respectively. [b]w is the mass fraction. [c]NB5, $NaB_5O_8\cdot 5H_2O$; LB5, $LiB_5O_8\cdot 5H_2O$.

Obviously, the solubilities of single salts of LiB_5O_8 or NaB_5O_8 are increased with the increasing of temperature.

3.2. Phase Diagrams of the Ternary System $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K. From the experimental data in Table 2, the phase diagrams and part enlargement diagrams for the ternary system at 298.15 and 323.15 K are shown in Figures 3 and 4. In Figures 3 and 4, it can be clearly seen that they are all in one invariant point corresponding to E_1 at 298.15 K and E_2 at 323.15 K, i.e., cosaturated with $LiB_5O_8\cdot 5H_2O$ and $NaB_5O_8\cdot 5H_2O$, two univariant solubility curves of A_1E_1 and B_1E_1 at 298.15 K, A_2E_2 and B_2E_2 at 323.15 K, and two crystallization regions corresponding to $LiB_5O_8\cdot 5H_2O$ and $NaB_5O_8\cdot 5H_2O$, respectively. In addition, due to the difference of the solubilities, the area of crystallization region for $NaB_5O_8\cdot 5H_2O$ is relatively larger than that for $LiB_5O_8\cdot 5H_2O$ at both temperatures. The composition for the two invariant points of LiB_5O_8 and NaB_5O_8 in the liquid phase in mass fraction of $100w$ is 9.87 and 4.69 at 298.15 K and 14.80 and 7.60 at 323.15 K, respectively. The points A_1, A_2 and B_1, B_2 present the solubilities of the binary systems $LiB_5O_8 + H_2O$ and $NaB_5O_8 + H_2O$ at two temperatures, respectively. At both temperatures, the component of NaB_5O_8 in the ternary system is decreased sharply with the increase of jLiB_5O_8 concentration in the solution, so it indicates that the component of lithium pentaborate existing in the solution has a strong salting-out effect of NaB_5O_8. The same coexisted equilibrium solid phases in the invariant points E_1 and E_2 identified by the powder X-ray diffraction are presented in Figure 5. A comparison for the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K shows is in Figure 6. It can be clearly seen that the solubilities for the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ increased with the increase of temperature, but the crystallization regions for $LiB_5O_8\cdot 5H_2O$ and $NaB_5O_8\cdot 5H_2O$ did not change obviously with changing temperature. And, this ternary system at two temperatures belongs to a simple eutectic type, and neither double salts nor solid solutions were formed.

3.3. Refractive Index and Density Calculation. According to the semiempirical formulas of electrolyte aqueous solution with density and refractive index employed by Deng et al. [20], shown as equations (1) and (2), the density and refractive index of the experimental solution were calculated, and the results are listed in Table 3.

$$\ln \frac{\rho}{\rho_0} = \sum A_i \times w_i, \tag{1}$$

$$\ln \frac{n_D}{n_{D_0}} = \sum B_i \times w_i, \tag{2}$$

where ρ and ρ_0 are the density of solution and pure water at the same temperature and n_D and n_{D0} represent the refractive index of the solution and pure water at the same temperature, respectively. The ρ_0 values at 298.15 and 323.15 K are 0.997041 and 0.988038 $g\cdot cm^{-3}$, respectively; the n_{D0} values at 298.15 and 323.15 K are 1.33250 and 1.32904, respectively; and w_i is the component same as Table 2. A_i and B_i represent the coefficients for the solid phase i in this system. The A_i and B_i for LiB_5O_8 and NaB_5O_8 are shown in Table 4, and the maximal relative deviation of density

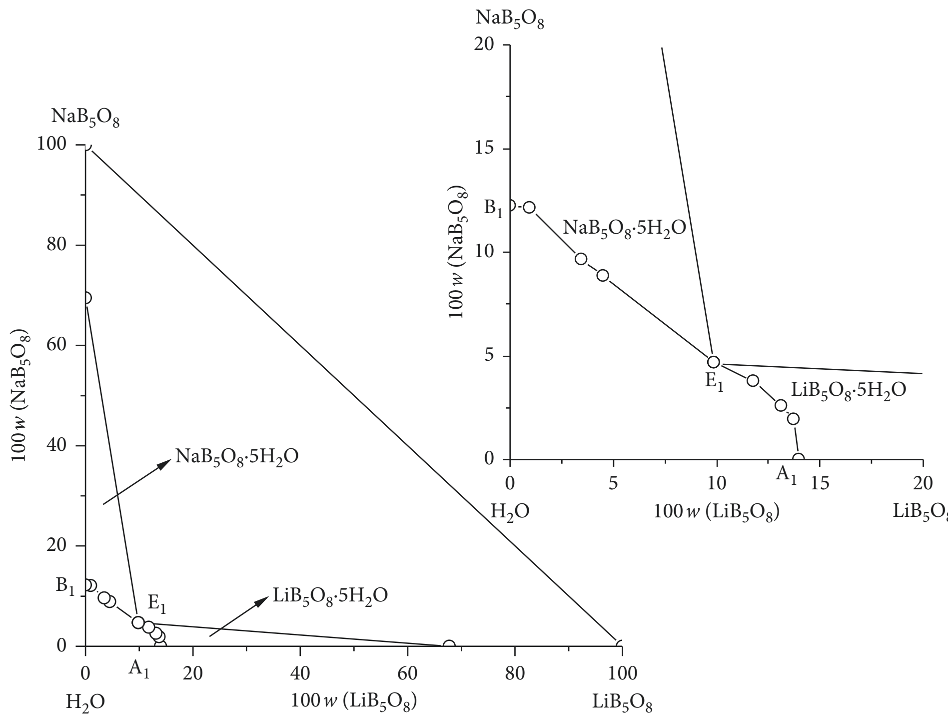


Figure 3: Phase diagram and part enlargement of the compositions of the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 K; ○, experimental points at 298.15 K; —, solubility curve at 298.15 K.

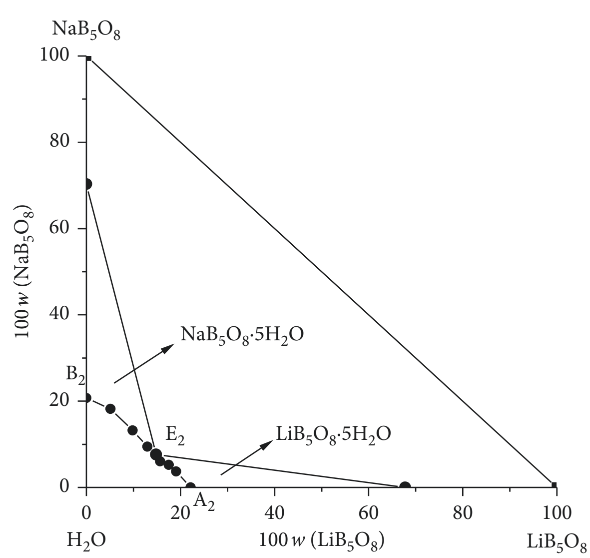


Figure 4: Phase diagram for the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 323.15 K; •, experimental points at 323.15 K; —, solubility curve at 323.15 K.

between experimental and calculated values was 0.0084, as for the refractive index, the deviation was less than 0.0013, which indicates that the physicochemical properties obtained are reliable. On the basis of the data of physicochemical property (including densities and refractive indices) in Table 2, the diagrams of physicochemical properties (density and refractive index) versus the composition of lithium pentaborate in the solution are plotted in Figures 7 and 8, respectively. It could be clearly seen that the density and refractive index changed regularly with the changing of lithium pentaborate concentration in the ternary system at two temperatures, which was increased, and then decreased as the increasing of the concentration of lithium pentaborate concentration, and show a similar changing tendency.

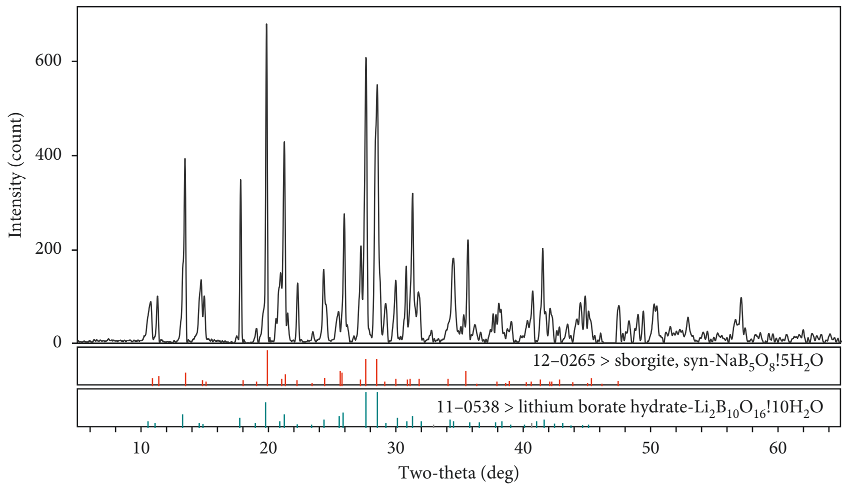


FIGURE 5: X-ray diffraction patterns of the solid phase at invariant point E_1 $LiB_5O_8{\cdot}5H_2O + NaB_5O_8{\cdot}5H_2O$.

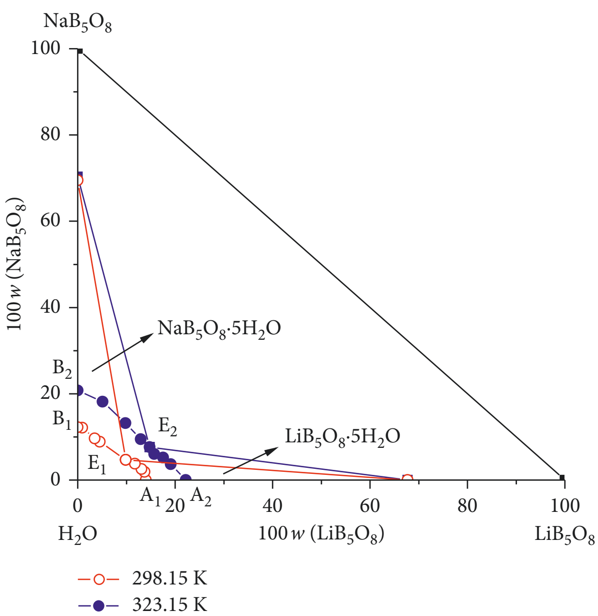


FIGURE 6: Comparison of phase diagram of the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K; ○, experimental points at 298.15 K; ●, experimental points at 323.15 K; —, solubility curve at 298.15 and 323.15 K.

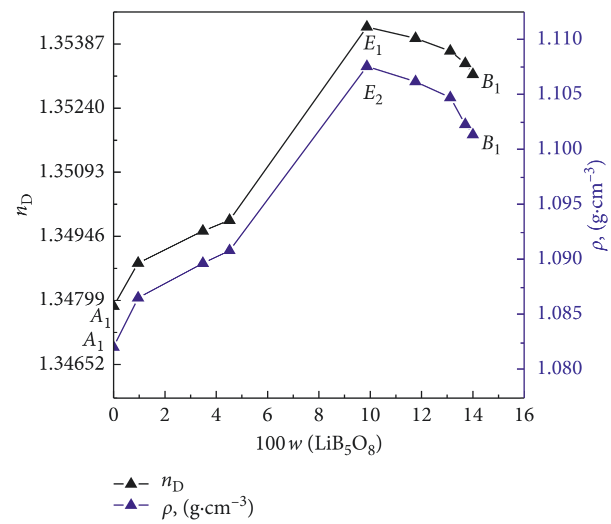


FIGURE 7: Comparison of physicochemical properties versus composition diagram of the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 K.

TABLE 4: Coefficients of densities and refractive indices in the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K and 0.1 MPa.

T (K)	Coefficients	LiB_5O_8	NaB_5O_8
298.15	A_i	0.006777954	0.006683650
	B_i	0.001063948	0.000934748
323.15	A_i	0.006753151	0.006503464
	B_i	0.000967555	0.000922052

[a]Standard uncertainties $u(x)$ are $u(T) = 0.1$ K and $u(p) = 5$ kPa.

4. Conclusions

Phase equilibria and phase diagrams for the ternary systems of $LiB_5O_8 + NaB_5O_8 + H_2O$ at 298.15 and 323.15 K were studied by the isothermal dissolution equilibrium method, and the solubilities and relevant physicochemical properties including density and refractive index were firstly obtained. For this system at two temperatures, the phase diagrams contain one invariant point, two univariant solubility curves, and two crystallization regions corresponding to $LiB_5O_8{\cdot}5H_2O$ and $NaB_5O_8{\cdot}5H_2O$, and the area of crystallization region of $NaB_5O_8{\cdot}5H_2O$ at each temperature is relatively larger than that of $LiB_5O_8{\cdot}5H_2O$. This ternary system at two temperatures belongs to simple eutectic type, and

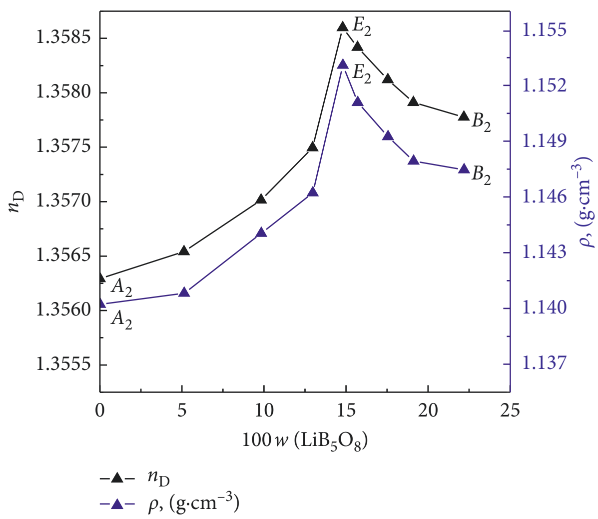


FIGURE 8: Comparison of physicochemical properties versus composition diagram of the ternary system $LiB_5O_8 + NaB_5O_8 + H_2O$ at 323.15 K.

neither double salts nor solid solution was found. The density and refractive index in the two ternary systems at 298.15 and 323.15 K increased firstly and then decreased with increasing of LiB_5O_8 concentration. In addition, the density and refractive index for salt-water electrolytes were theoretically calculated by empirical equations, which agree well with the experimental values.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

Financial supports from the National Natural Science Foundation of China (U1607123 and 21773170), the Key Projects of Natural Science Foundation of Tianjin (18JCZDJC10040), the Major Special Projects of Tibet Autonomous Region (XZ201801-GB-01), and the Yangtze Scholars and Innovative Research Team of the Chinese University (IRT_17R81) are acknowledged.

References

[1] J. E. Teeple, *The Industrial Development of Searles Lake Brines with Equilibrium Data*, Chemical Catalog, New York, NY, USA, 1929.

[2] B. L. Liu, D. Liu, H. F. Ji, W. D. Wang, and H. L. Xu, "Development of borate functional materials," *Guangzhou Chemical Industry*, vol. 42, no. 23, pp. 12–14, 2014.

[3] S. Y. Gao, P. S. Song, S. P. Xia, and M. P. Zheng, *The Chemistry of Salt Lakes*, Chinese Science Press, Beijing, China, 2007.

[4] G. Feng, Z. M. Ping, N. Zhen, L. J. Hua, and S. P. Sheng, "Brine lithium resource in the salt lake and advances in its exploitation," *Acta Geoscientica Sinica*, vol. 32, no. 4, pp. 483–492, 2011.

[5] P. S. Song, "Salt lakes and their exploiting progresses on the relatively resources," *Journal of Salt Lake Research*, vol. 8, no. 1, pp. 1–16, 2000.

[6] X. Y. Zheng, M. G. Zhang, Y. Xu, and B. X. Li, *Salt Lakes in China*, Chinese Science Press, Beijing, China, 2002.

[7] S. Wang, Y. Guo, W. Liu, and T. Deng, "Phase equilibria in the aqueous ternary system ($LiBO_2 + CaB_2O_4 + H_2O$) at 288.15 and 298.15 K," *Journal of Solution Chemistry*, vol. 44, no. 7, pp. 1545–1554, 2015.

[8] L. Meng, D. Li, Y. Guo, and T. Deng, "Stable phase equilibrium of the aqueous quaternary system ($MgCl_2 + MgSO_4 + MgB_6O_{10} + H_2O$) at 323.15 K," *Journal of Chemical & Engineering Data*, vol. 56, no. 12, pp. 5060–5065, 2011.

[9] J. Peng, S. H. Sang, and F. Wei, "Metastable phase equilibria of MgB_4O_7-$Na_2B_4O_7$-$Li_2B_4O_7$-H_2O quaternary system at 288 K," *Industry Mineral Process*, vol. 2, pp. 11–13, 2007.

[10] S. H. Sang, H. A. Yin, S. J. Ni, and C. J. Zhang, "Metastable equilibrium solubilities of solutions in the quaternary system of $K_2B_4O_7$-$Na_2B_4O_7$-$Li_2B_4O_7$-H_2O at 273 K," *Acta Physico-Chimica Sinica*, vol. 23, no. 8, pp. 1285–1287, 2007, in Chinese.

[11] L.-Z. Meng, T.-L. Deng, Y.-F. Guo, and D. Li, "The phase diagrams of the systems $MgCl_2 + MgB_6O_{10} + H_2O$ and $MgSO_4 + MgB_6O_{10} + H_2O$ at 323.15 K and Pitzer model," *Russian Journal of Physical Chemistry A*, vol. 86, no. 10, pp. 1526–1532, 2012.

[12] C. Fu, S.-H. Sang, M.-F. Zhou, Q.-Z. Liu, and T.-T. Zhang, "Phase equilibria in the ternary systems $Li_2B_4O_7$-MgB_4O_7-H_2O and $K_2B_4O_7$-MgB_4O_7-H_2O at 273 K," *Journal of Chemical & Engineering Data*, vol. 61, no. 3, pp. 1071–1077, 2016.

[13] S.-H. Sang and J. Peng, "(Solid + liquid) equilibria in the quinary system at 288 K," *Calphad*, vol. 34, no. 1, pp. 64–67, 2010.

[14] M. L. Li, J. Duo, X. D. Yu, and Y. Zeng, "Stable phase equilibrium of the aqueous ternary system Li^+, Mg^{2+}//borate-H_2O at 323 K," *Journal of Salt Chemical Industry*, vol. 10, pp. 16–19, 2014, in Chinese.

[15] Y. Z. Jia, S. Y. Gao, and S. P. Xia, "FT–IR spectroscopic study of borate in supersaturated solution of sodium pentaborate," *Chinese Journal of Inorganic Chemistry*, vol. 15, no. 6, pp. 766–772, 1999.

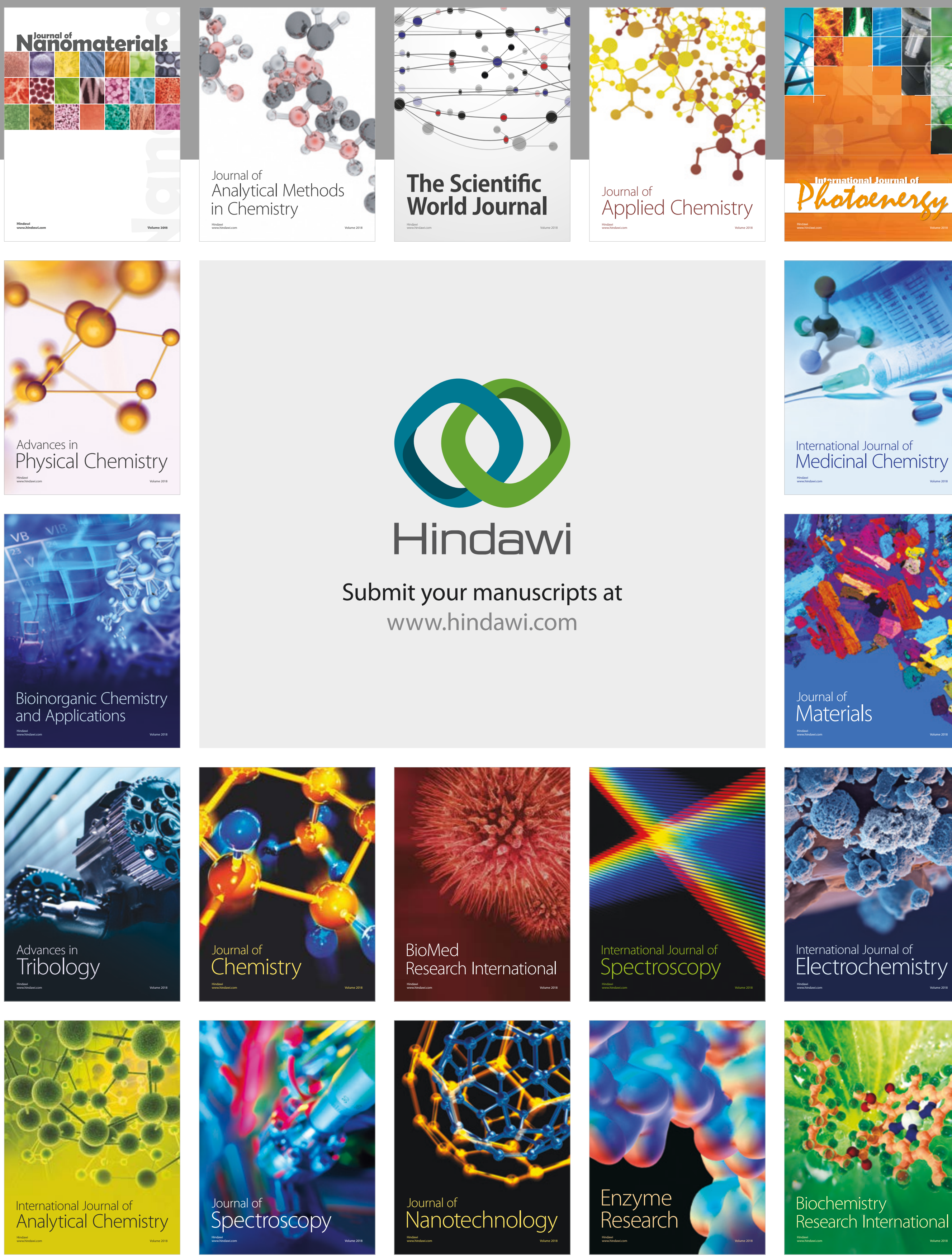
[16] A. V. Churikov, K. V. Zapsis, V. V. Khramkov, M. A. Churikov, and I. M. Gamayunova, "Temperature-induced transformation of the phase diagrams of ternary systems $NaBO_2 + NaOH + H_2O$ and $KBO_2 + KOH + H_2O$," *Journal of Chemical & Engineering Data*, vol. 56, no. 3, pp. 383–389, 2011.

[17] G. Y. Xie, S. M. Ma, and Q. Feng, "The phase diagram of $NaBO_2$-H_2O_2-H_2O at 0°C and 25°C," *Journal of Fudan University*, vol. 27, pp. 21–26, 1988.

[18] Analytical Department of Qinghai Institute of Salt-lake, Chinese Academy of Sciences, *The Analytical Methods of Brines and Salts*, Chinese Science Press, Beijing, China, 1988.

[19] C. B. Walter and M. S. Cyril, "The Solubility Curves of Boric Acid and the Borates of Sodium," *The Chemical Laboratory of the University of California*, vol. 61, pp. 917–920, 1939.

[20] T. L. Deng, L. Z. Meng, and B. Sun, "Metastable phase equilibria of the reciprocal quaternary system containing sodium, potassium, chloride, and borate Ions at 308.15 K," *Journal of Chemical and Engineering Data*, vol. 53, no. 1, pp. 704–709, 2008.


Journal of Nanomaterials
Journal of Analytical Methods in Chemistry
The Scientific World Journal
Journal of Applied Chemistry
International Journal of Photoenergy
Advances in Physical Chemistry
Hindawi
Submit your manuscripts at
www.hindawi.com
International Journal of Medicinal Chemistry
Bioinorganic Chemistry and Applications
Journal of Materials
Advances in Tribology
Journal of Chemistry
BioMed Research International
International Journal of Spectroscopy
International Journal of Electrochemistry
International Journal of Analytical Chemistry
Journal of Spectroscopy
Journal of Nanotechnology
Enzyme Research
Biochemistry Research International