Activity Coefficients at Infinite Dilution of Organic Solutes in 1-Ethyl-3-methylimidazolium Tetrafluoroborate Using Gas−Liquid Chromatography

Ming-Lan Ge,[†] Li-Sheng Wang,* Jun-Sheng Wu, and Qing Zhou

School of Chemical Engineering & Environment, Beijing Institute of Technology, Beijing 100081, People's Republic of China

---

The activity coefficients at infinite dilution, γ_i^∞, for 25 organic solutes, alkanes, alkenes, alkyl benzenes, acetonitrile, acetone, 1,4-dioxane, tetrahydrofuran, ethyl acetate, and chloromethanes, in the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate ([EMIM][BF_4]) have been measured by the gas−liquid chromatographic method at temperatures from (303.15 to 363.15) K. The partial molar excess enthalpies at infinite dilution, $H_i^{E,\infty}$, of the solutes in the ionic liquid were also derived from the temperature dependence of the γ_i^∞ values.

Introduction

This work continues our studies on the determination of activity coefficients at infinite dilution, γ_i^∞, of various solutes (*i*) by the gas−liquid chromatographic method (GLC) for hydrophilic ionic liquids (ILs).[1–7] Heintz et al.[8–16] and Letcher et al.[17–25] measured γ_i^∞ of various solutes in a number of ILs. 1-Ethyl-3-methylimidazolium tetrafluoroborate ([EMIM][BF_4]) was synthesized in 1992, which is the first of the new ILs with air and moisture stability.[26] In this work, the activity coefficients at infinite dilution, γ_i^∞, for 25 polar and nonpolar solutes in [EMIM][BF_4] at temperature from (303.15 to 363.15) K have been measured. The partial molar excess enthalpies at infinite dilution, $H_i^{E,\infty}$, of the solutes in the ionic liquid were also derived from the temperature dependence of the γ_i^∞ values.

Experimental section

Materials. The organic solutes including alkanes, alkenes, alkyl benzenes, acetonitrile, acetone, 1,4-dioxane, tetrahydrofuran, ethyl acetate, and chloromethanes were purchased from Beijing Chemical Reagents Company. Their mass fraction purities were above 99 %. All chemicals were used without further purification. The ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate ([EMIM][BF_4]) was prepared via the traditional two steps. First, 1-ethyl-3-methylimidazolium bromide was synthesized with equimolar amounts of 1-methylimidazole and ethyl bromide. Second, [EMIM][BF_4] was prepared by anion metathesis in water using $NaBF_4$. NaBr precipitate was removed by filtration, and the remaining water was removed by rotary evaporation. The crude product was dissolved in dichloromethane, and the solution was washed with a small amount of cooled deionized water five times until the aqueous solution did not form any precipitate with $AgNO_3$ solution. The solvent dichloromethane was removed by rotary evaporation, and the [EMIM][BF_4] was dried under high vacuum at 343 K for 8 h to remove volatile impurities. Water mass fractions analyzed by Karl Fischer analysis were less than 10^{-3}. The chemical shifts for ^{1}H NMR spectra (parts per million, D_2O) appear as follows: δ 8.646 [s, 1H, H(2)], 7.437 [s, 1H, H(4)], 7.370 [s, 1H, H(5)], 4.202 [m, 2H, NCH_2], 3.838 [s, 3H, NCH_3], and 1.464 [t, 3H, CH_3]. Impurity peaks were not observed in the ^{1}H NMR. Before use, the IL was subjected to vacuum evaporation at (323 to 333) K over 24 h to remove possible traces of solvents and moisture.

Table 1. Relative Uncertainties in the Measured and Derived Quantities

parameters	relative uncertainty
$t_r - t_G$	± 2.8 %
U_0	± 0.5 %
P_i	± 0.6 %
P_o	± 0.02 %
J	± 1 %
P_i^0	± 0.01 % to ± 0.30 %
n_3	± 0.6 %
γ_i^∞	± 5 %

Apparatus and Procedure. The GLC apparatus, column preparation, packing method, experimental process, and the method of checking the stability of the experimental conditions have been described in our previous work.[1–3] In this work, dry nitrogen was used as the carrier gas, and dichloromethane was used as solvent to coat the ionic liquid onto the solid support. The volume of the samples injected into the GC probes was from (0.1 to 2) μL. The experiments were carried out over a temperature range from (303.15 to 363.15) K.

The γ_i^∞ values were obtained by the equation proposed by Cruickshank et al.[27] and Everett.[28] The way of deducing γ_i^∞ from the experiments was given in our previous work.[1–3] The data needed for the equations have been obtained in the following way. Molar volumes of solutes, V_i^0, were estimated using their experimental densities,[29] and partial molar volumes of solute at infinite dilution, V_i^∞, have been assumed to be equal to V_i^0. Values of the vapor pressure of the pure liquid solute *i*, P_i^0, for all solutes were calculated from the Antoine equation, with Antoine coefficients given by Boublik et al.[30] B_{11} is the second virial coefficient of the solute (1), and B_{12} is the cross second virial coefficient of the solute (1) with the carrier gas (2). B_{11} and B_{12} have been estimated according to the equations suitable for polar liquids by Tsonopolous's method.[31] Critical

---

* Corresponding author. E-mail: lishengwang@btamail.net.cn.

[†] Present address: Department of Chemical Engineering, Beijing Institute of Petrochemical Technology, Beijing 102617, People's Republic of China. E-mail: geminglan@bipt.edu.cn.

10.1021/je800218g CCC: $40.75

Table 2. Experimental Activity Coefficients at Infinite Dilution, γ_i^∞, for Various Solutes in the Ionic Liquid 1-Ethyl-3-methylimidazolium Tetrafluoroborate at Temperatures of (303.15 to 363.15) K

solutes (i)	T/K = 303.15	T/K = 313.15	T/K = 323.15	T/K = 333.15	T/K = 343.15	T/K = 353.15	T/K = 363.15
			Alkanes				
pentane	68.78	62.52	57.64	53.85	49.03	45.66	42.12
hexane	101.4	95.27	90.60	85.28	77.40	74.47	69.46
heptane	153.5	138.1	124.1	111.3	104.2	96.00	90.39
octane	216.5	200.7	186.9	172.8	157.8	148.7	139.8
nonane	319.1	293.9	271.9	254.2	248.2	234.8	223.8
decane	1112.5	984.3	861.4	751.4	642.8	544.7	455.8
cyclohexane	70.55	60.88	49.73	39.65	31.17	27.46	21.90
methylcyclohexane	92.97	79.67	67.65	58.92	51.36	43.32	32.26
2,2,4-trimethylpentane	158.31	142.56	123.82	112.29	101.48	85.84	75.30
			Alkenes				
cyclohexene	21.81	19.65	16.64	14.39	12.75	10.51	9.13
styrene	3.375	3.443	3.489	3.558	3.620	3.654	3.734
			Alkyl Benzenes				
benzene	2.127	2.107	2.087	2.052	2.018	1.986	1.963
toluene	3.678	3.659	3.615	3.560	3.516	3.482	3.399
ethylbenzene	6.49	6.30	6.11	5.89	5.58	5.44	5.31
o-xylene	4.73	4.69	4.64	4.58	4.50	4.41	4.34
m-xylene	5.88	5.71	5.57	5.32	5.17	4.98	4.83
p-xylene	5.41	5.30	5.14	5.03	4.96	4.88	4.76
			Solvents				
acetonitrile	0.892	0.875	0.853	0.832	0.814	0.792	0.769
acetone	1.232	1.257	1.266	1.293	1.313	1.330	1.334
1,4-dioxane	1.346	1.397	1.423	1.436	1.467	1.485	1.511
tetrahydrofuran	1.872	1.852	1.834	1.817	1.796	1.766	1.735
ethyl acetate	2.938	2.920	2.892	2.867	2.835	2.795	2.755
			Chloromethanes				
dichloromethane	1.123	1.161	1.206	1.255	1.319	1.360	1.385
trichloromethane	1.361	1.375	1.390	1.409	1.426	1.460	1.495
tetrachloromethane	4.31	4.41	4.56	4.66	4.80	4.89	4.98

Table 3. Comparison of Activity Coefficients at Infinite Dilution, γ_i^∞, with the Values in the Literature

	γ_i^∞					
	T/K = 303.15		T/K = 323.15		T/K = 343.15	
solutes (i)	this work	lit.[33]	this work	lit.[33]	this work	lit.[33]
hexane	101.4	124.88	90.60	113.21	77.40	64.75
heptane	153.5	201.52	124.1	172.56	104.2	138.52
cyclohexane	70.55	53.72	49.73	46.17	31.17	38.89
2,2,4-trimethylpentane	158.31	221.60	123.82	167.85	101.48	162.38
benzene	2.127	2.42	2.087	2.51	2.018	2.47
toluene					3.516	4.03
ethylbenzene			6.11	7.05	5.58	6.87
acetone			1.266	1.11	1.313	1.14
ethyl acetate			2.892	3.08	2.835	3.32
trichloromethane			1.390	0.73	1.426	0.84

Table 4. Coefficients a and b of Equation 1, γ_i^∞ at 298.15 K Calculated Using Equation 1, Values of $H_i^{E,\infty}$ Derived from Equation 1, Standard Deviation σ

solute (i)	a	b/K	$\gamma^\infty_{i\ 298.15\mathrm{K}}$	$H_i^{\mathrm{E},\infty}$/kJ·mol^{-1}	σ
		Alkanes			
pentane	1.3015	889.17	72.51	7.39	0.0088
hexane	2.3208	701.02	106.9	5.83	0.0158
heptane	1.7812	983.58	160.8	8.18	0.0125
octane	2.6843	819.21	228.6	6.81	0.0090
nonane	3.6562	634.63	325.3	5.28	0.0152
decane	1.6989	1625.70	1276	13.52	0.0416
cyclohexane	−2.9046	2187.17	84.03	18.18	0.0411
methylcyclohexane	−1.4466	611.90	1.83	5.09	0.0658
2,2,4-trimethylpentane	0.6437	1349.23	175.7	11.22	0.0323
		Alkenes			
cyclohexene	−2.2131	1618.94	24.95	13.46	0.0352
styrene	1.8112	−180.55	3.34	−1.50	0.0029
		Alkyl Benzenes			
benzene	0.2536	153.73	2.16	1.04	0.0036
toluene	0.8411	142.03	3.73	1.18	0.0060
ethyl benzene	0.6065	385.59	6.68	3.21	0.0089
o-xylene	1.0376	158.82	4.81	1.32	0.0070
m-xylene	0.5614	369.75	6.06	3.07	0.0078
p-xylene	0.9272	230.75	5.48	1.92	0.0039
		Solvents			
acetonitrile	−0.9972	269.70	0.91	2.24	0.0059
acetone	0.7169	−153.78	1.22	−1.28	0.0044
1,4-dioxane	0.9575	−197.51	1.34	−1.64	0.0063
tetrahydrofuran	0.1879	134.58	1.90	1.12	0.0055
ethylacetate	0.6965	117.25	2.97	0.97	0.0048
		Chloromethanes			
dichloromethane	1.4568	−408.16	1.09	−3.39	0.0077
trichloromethane	0.7119	−122.92	1.35	−1.02	0.0014
tetrachloromethane	2.3630	−274.01	4.24	−2.28	0.0033

parameters needed for the calculations were available from the literature.[31] The cross critical properties P_{cij}, T_{cij}, V_{cij}, and Z_{cij} and acentric factor ω_{ij} were calculated using equations given in the literature.[31,32] From a propagation of error analysis, the γ_i^∞ values in this work are estimated to have an uncertainty within ± 5 %. The uncertainties in the measured and derived quantities are listed in Table 1.

Results and Discussion

Experimental results of γ_i^∞ for 25 solutes in [EMIM][BF$_4$] at different temperatures are presented in Table 2. The γ_i^∞ values for the linear *n*-alkanes increase with increasing chain length. The branching of the alkane skeleton reduces the values of γ_i^∞ in comparison with the corresponding linear alkanes. Introduction of the double bond in the six-membered ring (cyclohexene) causes a reduction of γ_i^∞. For the aromatic compounds, the values of γ_i^∞ are distinctly lower in comparison with those of the alkanes and alkenes, and the values of γ_i^∞ increase with increasing size of the alkyl group.

The γ_i^∞ values of polar solutes were in the order of ethylacetate > tetrahydrofuran > 1,4-dioxane > acetone > acetonitrile. The γ_i^∞ values of dichloromethane and trichloromethane are similar and clearly lower than that for tetrachlo-

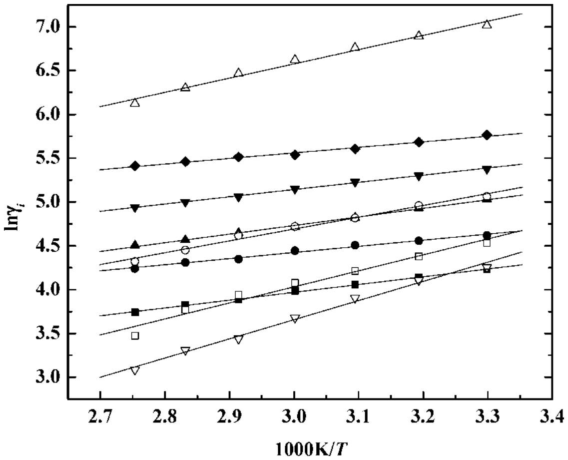

Figure 1. Plot of ln γ_i^∞ vs 1/*T* for the solutes together with a linear correlation of the data: ■, pentane; ●, hexane; ▲, heptane; ▼, octane; ◆, nonane; Δ, decane; ▽, cyclohexane; □, methylcyclohexane; ○, 2,2,4-trimethylpentane; —, linear fit.

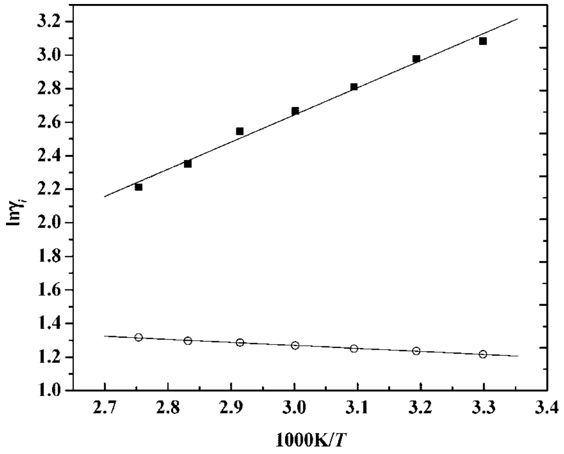

Figure 2. Plot of ln γ_i^∞ vs 1/*T* for the solutes together with a linear correlation of the data: ■, cyclohexane; ○, styrene; —, linear fit.

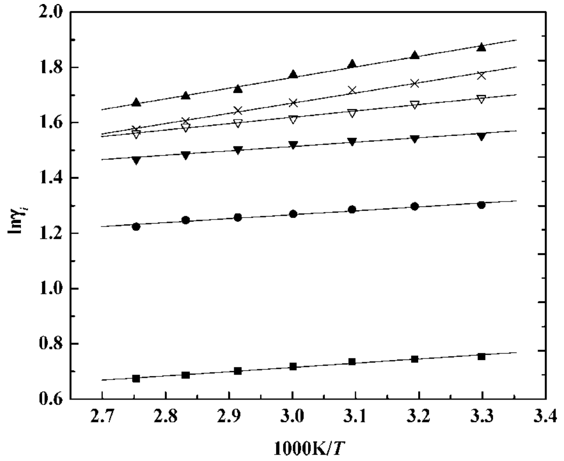

Figure 3. Plot of ln γ_i^∞ vs 1/*T* for the solutes together with a linear correlation of the data: ■, benzene; ●, toluene; ▼, *o*-xylene; ▽, *p*-xylene; ×, *m*-xylene; ▲, ethyl benzene; —, linear fit.

Table 5. Selectivity, S_{ij}^∞, at Infinite Dilution for Different Ionic Liquids at 298.15 K

ionic liquids	hexane (*i*)/ benzene (*j*)	cyclohexane (*i*)/ benzene (*j*)
[EMIM][N(CF_3SO_2)$_2$][a]	23.1	13.2
[EMIM][N(CF_3SO_2)$_2$][b]	24.5[d]	13.8[d]
[EMIM][$EtSO_4$][b]	40.8[d]	21.7[d]
[EMIM][TFA][c]	30.7	14.4
[EMIM][BF_4] (this work)	49.5	38.9

[a] Ref 10. [b] Ref 36. [c] Ref 37. [d] The values of γ_i^∞ from the dilutor technique.

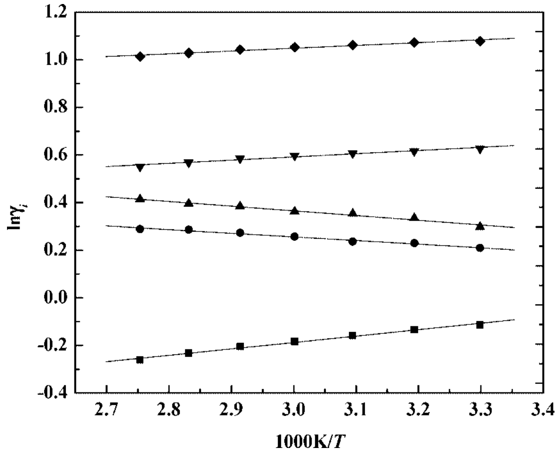

Figure 4. Plot of ln γ_i^∞ vs 1/*T* for the solutes together with a linear correlation of the data: ■, acetonitrile; ●, acetone; ▲, 1,4-dioxane; ▼, tetrahydrofuran; ◆, ethylacetate; —, linear correlation.

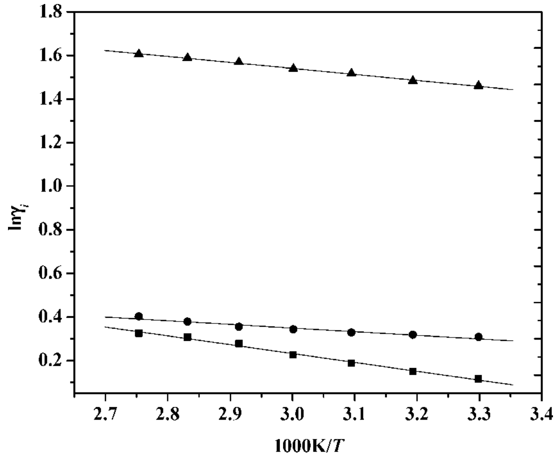

Figure 5. Plot of ln γ_i^∞ vs 1/*T* for the solutes together with a linear correlation of the data: ■, dichloromethane; ●, trichloromethane; ▲, tetrachloromethane; —, linear correlation.

romethane. This behavior indicates that more polar solutes have better solubilities in the ionic liquid because of the preferred attractive interaction of polar molecules with the charged ions of the IL, and they were prone to strongly retain in the IL stationary phase.

Bottini et al.[33] have measured γ_i^∞ for some solutes in [EMIM][BF_4] at T = (303, 323, and 343) K using inverse gas chromatography. Table 3 lists the γ_i^∞ values reported by these authors. For comparison, the γ_i^∞ values for the same solutes in this work have also been included in Table 3. The γ_i^∞ values except for cyclohexane at T = (303 and 323) K, acetone, and trichloromethane in this work are lower than that Bottini et al. reported, and there is an average discrepancy of the order of (20 to 30) % between both sets of data. The differences of the experimental method and calculation equation may result in the discrepancy in the results. Furthermore, there is the possibility of interfacial adsorption for the solutes onto the solid support, which may result in the γ_i^∞ values having a tendency of underestimation in particular for hydrocarbons and low polarity solutes.[34]

Experimental results of γ_i^∞ at different temperatures are correlated with temperature by the following equation

$$\ln \gamma_i^\infty = a + \frac{b}{(T/\mathrm{K})} \qquad (1)$$

The coefficients a and b, the standard deviation σ of the fitted equations, and the values of γ_i^∞ at 298.15 K are listed in Table 4. The plots of measured ln γ_i^∞ vs $1/T$ values and the linear fit of their data are given in Figures 1 to 5, which showed a fairly good fitting quality of eq 1. According to the Gibbs−Helmholtz equation, the values for the partial molar excess enthalpy at infinite dilution, $H_i^{\mathrm{E},\infty}$, of solute i can be obtained from the slope of a straight line derived from eq 1, which were listed in Table 4. For the linear alkanes, cyclohexene, and alkyl benzenes, $H_i^{\mathrm{E},\infty}$ was positive. The value of $H_i^{\mathrm{E},\infty}$ for styrene, acetone, 1,4-dioxane, and chloromethanes $H_i^{\mathrm{E},\infty}$ became negative. This is most probably due to the high polarizibility of the oxygen and chlorine atoms and the special strength of ion-induced dipole interactions. The relative uncertainties of $H_i^{\mathrm{E},\infty}$ is about ± 10 %.

The selectivity, Sij^∞, is defined as $Sij^\infty = \gamma_{i,\mathrm{IL}}^\infty/\gamma_{j,\mathrm{IL}}^\infty$[35] (where i,j refers to the solutes to be separated). The Sij^∞ calculated from experimental γ_i^∞ values at 298.15 K for hexane (i)/benzene (j) and cyclohexane (i)/benzene (j) are presented in Table 5. The results indicated that [EMIM][BF$_4$] can play an important role for the separation of hexane and cyclohexane from benzene. The values of Sij^∞ for three isomeric xylenes at 298.15 K were 1.26 (*m*-xylene/*o*-xylene), 1.10 (*m*-xylene/*p*-xylene), and 1.14 (*p*-xylene/*o*-xylene), respectively. The results indicated that [EMIM][BF$_4$] was not an ideal extraction solvent for separation of xylenes.

Literature Cited

(1) Zhou, Q.; Wang, L.-S. Activity Coefficients at Infinite Dilution of Alkanes, Alkenes, and Alkyl benzenes in 1-Butyl-3-methylimidazolium Tetrafluoroborate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2006**, *51*, 1698–1701.

(2) Zhou, Q.; Wang, L.-S.; Wu, J.-S.; Li, M.-Y. Activity Coefficients at Infinite Dilution of Polar Solutes in 1-Butyl-3-methylimidazolium Tetrafluoroborate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2007**, *52*, 131–134.

(3) Ge, M.-L.; Wang, L.-S.; Li, M.-Y.; Wu, J.-S. Activity Coefficients at Infinite Dilution of Alkanes, Alkenes, and Alkyl Benzenes in 1-Butyl-3-methylimidazolium Trifluoromethanesulfonate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2007**, *52*, 2257–2260.

(4) Wang, M.-H.; Wu, J.-S.; Wang, L.-S.; Li, M.-Y. Activity Coefficients at Infinite Dilution of Alkanes, Alkenes, and Alkyl benzenes in 1-Propyl-2,3-dimethylimidazolium Tetrafluoroborate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2007**, *52*, 1488–1491.

(5) Ge, M.-L.; Wang, L.-S. Activity Coefficients at Infinite Dilution of Polar Solutes in 1-Butyl-3-methylimidazolium Trifluoromethanesulfonate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2008**, *53*, 846–849.

(6) Ge, M.-L.; Wu, J.-S.; Wang, M.-H.; Wang, L.-S. Activity Coefficients at Infinite Dilution of Polar Solutes in 1-Propyl-2,3-dimethylimidazolium Tetrafluoroborate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2008**, *53*, 871–873.

(7) Yang, X.-J.; Wu, J.-S.; Ge, M.-L.; Wang, L.-S.; Li, M.-Y. Activity Coefficients at Infinite Dilution of Alkanes, Alkenes, and Alkyl benzenes in 1-Hexyl-3-methylimidazolium Trifluoromethanesulfonate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2008**, *53*, 1220–1222.

(8) Heintz, A.; Kulikov, D. V.; Verevkin, S. P. Thermodynamic Properties of Mixtures Containing Ionic Liquids. 1. Activity Coefficients at Infinite Dilution of Alkanes, Alkenes, and Alkylbenzenes in 4-Methyl-*n*-butylpyridinium Tetrafluoroborate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2001**, *46*, 1526–1529.

(9) Heintz, A.; Kulikov, D. V.; Verevkin, S. P. Thermodynamic Properties of Mixtures Containing Ionic Liquids. Activity Coefficients at Infinite Dilution of Polar Solutes in 4-Methyl-*N*-butylpyridinium Tetrafluoroborate Using Gas−Liquid Chromatography. *J. Chem. Thermodyn.* **2002**, *34*, 1341–1347.

(10) Heintz, A.; Kulikov, D. V.; Verevkin, S. P. Thermodynamic Properties of Mixtures Containing Ionic Liquids. 2. Activity Coefficients at Infinite Dilution of Hydrocarbons and Polar Solutes in 1-Methyl-3-ethyl-imidazolium Bis(trifluoromethyl-sulfonyl) Amide and in 1,2-Dimethyl-3-ethyl-imidazolium Bis(trifluoromethyl-sulfonyl) Amide Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2002**, *47*, 894–899.

(11) Verevkin, S. P.; Vasiltsova, T. V.; Bich, E.; Heintz, A. Thermodynamic Properties of Mixtures Containing Ionic Liquid Activity Coefficients of Aldehydes and Ketones in 1-Methyl-3-ethyl-imidazolium Bis(trifluoromethyl-sulfonyl) Imide Using the Transpiration Method. *Fluid Phase Equilib.* **2004**, *218*, 165–175.

(12) Vasiltsova, T. V.; Verevkin, S. P.; Bich, E.; Heintz, A. Thermodynamic Properties of Mixtures Containing Ionic Liquids. Activity Coefficients of Ethers and Alcohols in 1-Methyl-3-ethylimidazolium Bis(Trifluoromethyl-sulfonyl) Imide Using the Transpiration Method. *J. Chem. Eng. Data* **2005**, *50*, 142–148.

(13) Heintz, A.; Casás, L. M.; Nesterov, I. A.; Emeyanenko, V. N.; Verevkin, S. P. Thermodynamic Properties of Mixtures Containing Ionic Liquids. 5. Activity Coefficients at Infinite Dilution of Hydrocarbons, Alcohols, Esters, and Aldehydes in 1-Methyl-3-butylimidazolium Bis(trifluoromethylsulfonyl) Imide Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2005**, *50*, 1510–1514.

(14) Heintz, A.; Verevkin, S. P. Thermodynamic Properties of Mixtures Containing Ionic Liquids. 6. Activity Coefficients at Infinite Dilution of Hydrocarbons, Alcohols, Esters, and Aldehydes in 1-Methyl-3-octylimidazolium Tetrafluoroborate Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2005**, *50*, 1515–1519.

(15) Heintz, A.; Verevkin, S. P. Thermodynamic Properties of Mixtures Containing Ionic Liquids. 8. Activity Coefficients at Infinite Dilution of Hydrocarbons, Alcohols, Esters, and Aldehydes in 1-Hexyl-3-methylimidazolium Bis(trifluoromethylsulfonyl) Imide Using Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2006**, *51*, 434–437.

(16) Heintz, A.; Vasiltsova, T. V.; Safarov, J.; Bich, E.; Verevkin, S. P. Thermodynamic Properties of Mixtures Containing Ionic Liquids. 9. Activity Coefficients at Infinite Dilution of Hydrocarbons, Alcohols, Esters, and Aldehydes in Trimethylbutylammonium Bis(trifluoromethylsulfonyl) Imide Using Gas−Liquid Chromatography and Static Method. *J. Chem. Eng. Data* **2006**, *51*, 648–655.

(17) Letcher, T. M.; Soko, B.; Reddy, P. Determination of Activity Coefficients at Infinite Dilution of Solutes in the Ionic Liquid 1-Hexyl-3-methylimidazolium Tetrafluoroborate Using Gas−Liquid Chromatography at the Temperatures 298.15 and 323.15 K. *J. Chem. Eng. Data* **2003**, *48*, 1587–1590.

(18) Deenadayalu, N.; Letcher, T. M.; Reddy, P. Determination of Activity Coefficients at Infinite Dilution of Polar and Nonpolar Solutes in the Ionic Liquid 1-Ethyl-3-methylimidazolium Bis(trifluoromethylsulfonyl) Imidate Using Gas−Liquid Chromatography at the Temperature 303.15 or 318.15 K. *J. Chem. Eng. Data* **2005**, *50*, 105–108.

(19) Letcher, T. M.; Soko, B.; Ramjugernath, D. Activity Coefficients at Infinite Dilution of Organic Solutes in 1-Hexyl-3-methylimidazolium Hexafluorophosphate from Gas−Liquid Chromatography. *J. Chem. Eng. Data* **2003**, *48*, 708–711.

(20) David, W.; Letcher, T. M.; Ramjugernath, D.; Raal, J. D. Activity Coefficients of Hydrocarbon Solutes at Infinite Dilution in the Ionic Liquid, 1-Methyl-3-octyl-imidazolium Chloride from Gas−Liquid Chromatography. *J. Chem. Thermodyn.* **2003**, *35*, 1335–1341.

(21) Letcher, T. M.; Reddyb, P. Determination of Activity Coefficients at Infinite Dilution of Organic Solutes in the Ionic Liquid, Trihexyl(tetradecyl)-phosphonium Tris(pentafluoroethyl) Trifluorophosphate, by Gas−Liquid Chromatography. *Fluid Phase Equilib.* **2005**, *235*, 11–17.

(22) Letcher, T. M.; Marciniak., A.; Marciniak, M. Determination of Activity Coefficients at Infinite Dilution of Solutes in the Ionic Liquid 1-Butyl-3-methylimidazolium Octyl Sulfate Using Gas−Liquid Chromatography at a Temperature of 298.15 K, 313.15 K, or 328.15 K. *J. Chem. Eng. Data* **2005**, *50*, 1294–1298.

(23) Letcher, T. M.; Domańska, U.; Marciniak, M.; Marciniak, A. Activity Coefficients at Infinite Dilution Measurements for Organic Solutes in the Ionic Liquid 1-Butyl-3-methyl-imidazolium 2-(2-Methoxyethoxy) Ethyl Sulfate Using G.L.C. at T = (298.15, 203.15, and 308.15) K. *J. Chem. Thermodyn.* **2005**, *37*, 587–593.

(24) Letcher, T. M.; Marciniak, A.; Marciniak, M.; Domańska, U. Activity Coefficients at Infinite Dilution Measurements for Organic Solutes in the Ionic Liquid 1-Hexyl-3-methylimidazolium Bis(trifluoromethylsulfonyl)-imide Using G.L.C. at T = (298.15, 313.15, and 333.15) K. *J. Chem. Thermodyn.* **2005**, *37*, 1327–1331.

(25) Deenadayalu, N.; Thango, S. H.; Letcher, T. M.; Ramjugernath, D. Measurement of Activity Coefficients at Infinite Dilution Using Polar and Non-polar Solutes in the Ionic Liquid 1-Methyl-3-octyl-imidazolium Diethyleneglycolmonomethylethersulfate at T = (288.15, 298.15, and 313.15) K. *J. Chem. Thermodyn.* **2006**, *38*, 542–546.

(26) Wilkes, J. S.; Zaworotko, J. M. Air and water stable 1-ethyl-3-methylimidazolium based ionic liquids. *J. Chem. Soc., Chem. Commun.* **1992**, *13*, 965–967.

(27) Cruickshank, A. J. B.; Windsor, M. L.; Young, C. L. The Use of Gas−Liquid Chromatography to Determine Activity Coefficients and

Second Virial Coefficients of Mixtures. *Proc. R. Soc. London* **1966**, *A295*, 259–270.

(28) Everett, D. H. Effects of Gas Imperfections on GLC Measurements: a refined method for determining activity coefficients and second Virial coefficients. *Trans. Faraday Soc.* **1965**, *61*, 1637–1645.

(29) Lu, H.-Z. *The Handbook of Petrolia Chemical Engineering Data*; Chemical Industrial Press: Beijing, China, 1992.

(30) Boublik, T.; Fried, V.; Hala, E. The Vapor Pressure of Pure Substances. *Physical Science Data 17*; Elsevier: Amsterdam, Netherlands, 1984.

(31) Poling, B. E.; Prausnitz, J. M.; O'Connell, J. P. *The Properties of Gases and Liquids*, 5th ed.; McGraw-Hill Chemical Engineering Series: New York, 2000.

(32) Prausnitz, J. M.; Lichtenthaler, R. N.; Azevedo, E. G. *Molecular Thermodynamics of Fluid Phase Eqilibria*, 2nd ed.; Prentice Hall: New York, 1986.

(33) Foco, G. M.; Bottini, S. B.; Quezada, N.; de la Fuente, J. C.; Peters, C. J. Activity Coefficients at Infinite Dilution in 1-Alkyl-3-methylimidazolium Tetrafluoroborate Ionic Liquids. *J. Chem. Eng. Data* **2006**, *51*, 1088–1091.

(34) Mutelet, F.; Jaubert, J.-N. Accurate Measurements of Thermodynamic Properties of Solutes in Ionic Liquids Using Reverse Gas Chromatography. *J. Chromatogr. A* **2006**, *1102*, 256–267.

(35) Tiegs, D.; Gmehling, J.; Medina, A.; Soares, M.; Bastos, J.; Alessi, P.; Kikic, I. *DECHEMA Chemistry Data Series IX*, Part 1; DECHEMA: Frankfurt/Main, 1986.

(36) Krummen, M.; Wasserscheid, P.; Gmehling, J. Measurement of Activity Coefficients at Infinite Dilution in Ionic Liquids Using the Dilutor Technique. *J. Chem. Eng. Data* **2002**, *47*, 1411–1417.

(37) Domanska, U.; Marciniak, A. Activity Coefficients at Infinite Dilution Measurements for Organic Solutes and Water in the Ionic Liquid 1-Ethyl-3-methylimidazolium Trifluoroacetate. *J. Phys. Chem. B* **2007**, *111*, 11984–11988.

Received for review March 28, 2008. Accepted May 5, 2008.

JE800218G