Thermodynamic Properties of Aqueous Electrolyte Solutions.† 2. Vapor Pressure of Aqueous Solutions of NaBr, NaI, KCl, KBr, KI, RbCl, CsCl, CsBr, CsI, $MgCl_2$, $CaCl_2$, $CaBr_2$, CaI_2, $SrCl_2$, $SrBr_2$, SrI_2, $BaCl_2$, and $BaBr_2$

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A differential static method was used for the measurement of vapor pressures of aqueous solutions of NaBr, NaI, KCl, KBr, KI, RbCl, CsCl, CsBr, CsI, $MgCl_2$, $CaCl_2$, $CaBr_2$, CaI_2, $SrCl_2$, $SrBr_2$, SrI_2, $BaCl_2$, and $BaBr_2$ from 0.5 to 8.6 *m* and in the temperature range of 303.15-343.15 K. The experimental data for the binary solutions were fitted to the Antoine type of equation, $\log [P\,(\mathrm{kPa})] = A(m) + B(m)/[T\,(\mathrm{K})] + C(m)/[T\,(\mathrm{K})]^2$, where *A*, *B*, and *C* are constants and are concentration dependent. Vapor pressure data were used to calculate activity and osmotic coefficients in the temperature range studied for understanding the nonideal behavior of these solutions.

Introduction

The thermodynamic properties of aqueous electrolyte solutions have been under investigation for many years. Extensive data exist for a wide variety of aqueous electrolytes at 298.15 K. A need for thermodynamic data at temperatures above 298.15 K has been felt in recent years, owing mainly to the interest in desalination processes and absorption heat pumps. Several electrolytes have been studied by different investigators at temperatures between 373.15 and 573.15 K. However, very few precise data are available for aqueous electrolytes in the range 303.15-373.15 K.

In continuation of the recent publication (*1*), exhaustive study has been undertaken in this laboratory on the measurements of vapor pressures of aqueous solutions of NaBr, NaI, KCl, KBr, KI, RbCl, CsCl, CsBr, CsI, $MgCl_2$, $CaCl_2$, $CaBr_2$, CaI_2, $SrCl_2$, $SrBr_2$, SrI_2, $BaCl_2$, and $BaBr_2$ with high precision in the temperature range 303.15-343.15 K for various concentrations. These results were fitted to an Antoine type of equation. The experimental data may be used to correlate the local composition theory on single-solute aqueous solutions up to very high concentration (up to 20 *m*), as well as over a range of temperatures (*2*, *3*). The activity and osmotic coefficients have been also calculated from the present data.

Experimental Section

Apparatus and Procedure. The differential static method has been used for the measurements of vapor pressures, which involves the difference between the vapor pressures of solution and pure water. The experimental method used and the procedure followed were described in a previous publication (*1*). The necessity of removing the last traces of air in all vapor pressure measurements is well-known. For this purpose, the procedure adopted was to freeze the liquids in both the bulbs by dipping them in liquid nitrogen. The bulbs were then evacuated. The procedure was repeated until further evacuation gave no lowering of the vapor pressure. The temperature of water thermostat was controlled to within ±0.002 °C and was measured with the help of a quartz thermometer (Hewlett Packard, Model 2804A). The differences in the manometer levels were measured with a cathetometer that could read down to 0.01 mm. The data on vapor pressures of water were obtained from the literature (*4*).

Materials. All the salts used were of analytical reagent grade and anhydrous with reported purities of +99%. NaBr (Aldrich), NaI and KI (E. Merck, Darmstadt), KCl and KBr (Guaranteed reagent grade from Sarabhai Chemicals Co.), CsCl (Lobu-Chemie Industrial Co.), RbCl (Fluka), CsBr and CsI (SAS Chemicals), $MgCl_2$ and $CaCl_2$ (Fluka), $CaBr_2$, CaI_2, and $BaBr_2$ (Fisons, Philadelphia) $SrCl_2$, $SrBr_2$, SrI_2, and $BaCl_2$ (John Baker Inc., Colorado). All salts were dried in a vacuum oven at 120 °C for several days and used without further purification. Stock solutions were prepared by using double-distilled, but previously deionized, water throughout the experimental work. The concentrations were determined by density measurement using a vibrating reed densimeter from Anton Paar Co., Ltd. (DMA 60/602). The reproducibility of the concentration measurements was within 0.35%.

Results and Discussion

Measurements on vapor pressures were made in the temperature range 303.15-343.15 K and concentration range 1.0-8.6 m with the binary systems NaBr-H_2O, NaI-H_2O, KCl-H_2O, KBr-H_2O, KI-H_2O, RbCl-H_2O, CsCl-H_2O, CsBr-H_2O, CsI-H_2O, $MgCl_2$-H_2O, $CaCl_2$-H_2O, $CaBr_2$-H_2O, CaI_2-H_2O, $SrCl_2$-H_2O, $SrBr_2$-H_2O, SrI_2-H_2O, $BaCl_2$-H_2O, and $BaBr_2$-H_2O. The data are summarized in Table I. These data may be correlated to the Antoine type of equation

$$\log [P\,(\mathrm{kPa})] = A(m) + B(m)/[T\,(\mathrm{K})] + C(m)/[T\,(K)]^2 \quad (1)$$

where the parameters *A*, *B*, and *C* are the cubic functions of concentration, *m*, of the electrolyte and are calculated from the relations

$$A(m) = A_0 + A_1 m + A_2 m^2 + A_3 m^3 \quad (2)$$

$$B(m) = B_0 + B_1 m + B_2 m^2 + B_3 m^3 \quad (3)$$

$$C(m) = C_0 + C_1 m + C_2 m^2 + C_3 m^3 \quad (4)$$

where the parameters $A_0 - A_3$, $B_0 - B_3$, and $C_0 - C_3$ were determined from the experimental vapor pressure data by the least-squares method. The calculated vapor pressures from eqs 1-4 were in good agreement with the experimental results for all the solutions, and the average deviation was within 1.0%. Table II summarizes the best-fit parameters in eqs 2-4.

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Table I. Vapor Pressures (P) of Aqueous Solutions

	P at various T, kPa						P at various T, kPa				
m	303.15 K	313.15 K	323.15 K	333.15 K	343.15 K	m	303.15 K	313.15 K	323.15 K	333.15 K	343.15 K
						NaBr					
2.003	3.94	6.85	11.45	18.49	28.92	4.989	3.38	5.87	9.78	15.75	24.62
2.994	3.73	6.50	10.89	17.61	27.56	5.801	3.20	5.55	9.27	14.95	23.34
4.012	3.55	6.18	10.32	16.67	26.06	7.981	2.60	4.59	7.78	12.69	20.15
						NaI					
1.004	4.10	7.13	11.92	19.25	30.10	3.958	3.50	6.08	10.16	16.43	25.72
1.673	3.99	6.93	11.58	18.71	29.25	5.073	3.24	5.63	9.40	15.19	23.79
2.158	3.89	6.77	11.31	18.25	28.65	6.693	2.84	4.95	8.26	13.35	20.91
3.303	3.65	6.34	10.59	17.12	26.83	8.398	2.46	4.28	7.16	11.57	18.06
						KCl					
1.275	4.10	7.13	11.89	19.21	30.13	2.917	3.88	6.71	11.23	18.12	28.41
2.010	3.99	6.92	11.58	18.69	29.33	3.687	3.80	6.56	10.93	17.60	27.57
2.555	3.93	6.80	11.36	18.32	28.71	4.286	3.68	6.37	10.63	17.18	26.97
						KBr					
1.255	4.04	7.05	11.81	19.08	29.92	3.021	3.82	6.62	11.08	17.90	28.10
1.608	4.01	6.98	11.67	18.86	29.56	3.810	3.71	6.42	10.75	17.36	27.29
2.220	3.93	6.82	11.43	18.45	28.94	4.349	3.53	6.13	10.32	16.78	26.47
						KI					
1.006	4.11	7.17	12.01	19.36	30.22	3.027	3.89	6.71	11.12	17.89	27.94
1.523	4.07	7.06	11.80	19.02	29.67	4.059	3.73	6.43	10.65	17.14	26.74
2.003	4.01	6.96	11.59	18.67	29.18	4.747	3.57	6.21	10.25	16.63	25.90
2.351	3.97	6.86	11.44	18.42	28.78	5.648	3.42	5.95	9.87	15.86	24.75
						RbCl					
1.493	4.04	7.03	11.76	19.00	29.73	4.463	3.62	6.32	10.59	17.09	26.67
2.968	3.83	6.67	11.17	18.02	28.19	5.966	3.37	5.92	9.96	16.08	25.11
3.550	3.74	6.54	10.94	17.66	27.63	6.949	3.15	5.58	9.41	15.25	23.82
						CsCl					
1.774	3.95	6.88	11.55	18.65	29.26	5.492	3.53	6.13	10.19	16.42	25.58
2.471	3.85	6.72	11.30	18.27	28.66	6.444	3.41	5.91	9.84	15.83	24.63
3.522	3.75	6.53	10.92	17.65	27.58	7.435	3.24	5.66	9.41	15.14	23.57
4.402	3.66	6.35	10.63	17.12	26.72	8.590	2.91	5.18	8.80	14.27	22.37
						CsBr					
1.570	4.02	7.00	11.75	19.01	29.62	3.485	3.83	6.62	11.03	17.84	27.85
2.244	3.95	6.86	11.47	18.54	28.98	4.320	3.75	6.48	10.77	17.35	27.09
2.768	3.91	6.77	11.30	18.23	28.52	5.888	3.59	6.22	10.32	16.57	25.88
						CsI					
1.345	4.08	7.07	11.82	19.12	29.86	2.014	3.99	6.91	11.56	18.67	29.25
1.546	4.05	7.01	11.73	18.98	29.68	2.595	3.87	6.80	11.35	18.33	28.62
1.799	4.02	6.95	11.62	18.79	29.39						
						$MgCl_2$					
1.047	3.98	6.94	11.63	18.80	29.45	3.167	2.98	5.22	8.81	14.32	22.51
1.303	3.85	6.74	11.31	18.35	28.80	3.737	2.74	4.80	8.07	13.08	20.59
2.006	3.60	6.29	10.57	17.17	26.91	4.343	2.32	4.09	6.93	11.33	17.91
2.449	3.33	5.86	9.87	16.04	25.33	4.801	1.99	3.52	6.04	9.93	15.77
						$CaCl_2$					
1.002	3.99	6.94	11.61	18.77	29.39	4.951	2.15	3.82	6.52	10.75	17.18
2.249	3.58	6.22	10.43	16.87	26.46	6.019	1.70	3.06	5.27	8.77	14.15
3.017	3.18	5.55	9.34	15.17	23.89	6.786	1.45	2.63	4.56	7.66	12.41
3.887	2.70	4.74	8.03	13.12	20.77	7.885	1.20	2.20	3.85	6.50	10.61
						$CaBr_2$					
1.006	3.95	6.92	11.59	18.74	29.36	3.022	3.03	5.31	8.96	14.59	23.04
1.238	3.87	6.76	11.36	18.37	28.84	3.376	2.83	4.97	8.40	13.69	21.64
1.709	3.70	6.46	10.83	17.54	27.60	3.949	2.51	4.43	7.51	12.26	19.40
2.254	3.44	6.02	10.11	16.48	25.93	4.596	2.17	3.84	6.57	10.75	17.05
						CaI_2					
1.138	3.94	6.91	11.59	18.72	29.34	2.273	3.58	6.24	10.45	16.88	26.41
1.464	3.84	6.72	11.25	18.20	28.47	2.915	3.22	5.63	9.45	15.32	24.06
1.875	3.69	6.46	10.83	17.50	27.46						
						$SrCl_2$					
0.662	4.10	7.13	11.92	19.25	30.09	1.797	3.72	6.49	10.88	17.59	27.61
0.871	4.08	7.08	11.84	19.12	29.82	2.213	3.59	6.26	10.49	16.98	26.64
1.299	3.92	6.87	11.40	18.36	28.87	2.693	3.39	5.91	9.93	16.11	25.28
1.503	3.81	6.65	11.19	18.13	28.44	3.203	3.07	5.41	9.12	14.89	23.48
						$SrBr_2$					
0.800	3.97	6.98	11.74	18.99	29.71	1.345	3.88	6.78	11.31	18.27	28.51
1.013	3.95	6.92	11.59	18.76	29.26	1.746	3.73	6.50	10.88	17.55	27.43

Table I (Continued)

	P at various T, kPa						P at various T, kPa				
m	303.15 K	313.15 K	323.15 K	333.15 K	343.15 K	m	303.15 K	313.15 K	323.15 K	333.15 K	343.15 K
1.996	3.59	6.29	10.50	17.05	26.66	2.656	3.27	5.70	9.59	15.52	24.31
2.395	3.44	6.00	10.04	16.25	25.40	3.340	2.91	5.11	8.58	13.93	21.89
						SrI_2					
0.970	3.97	6.91	11.57	18.72	29.31	2.370	3.37	5.89	9.89	16.02	25.09
1.264	3.86	6.73	11.29	18.27	28.63	2.933	3.11	5.42	9.08	14.69	22.95
1.534	3.77	6.57	11.00	17.79	27.84	3.517	2.76	4.83	8.10	13.10	20.50
1.960	3.58	6.25	10.49	16.98	26.58	4.156	2.37	4.19	7.08	11.54	18.13
						$BaCl_2$					
0.504	4.07	7.15	12.03	19.44	30.44	1.214	3.90	6.85	11.53	18.67	29.27
0.738	4.03	7.07	11.88	19.23	30.10	1.388	3.85	6.77	11.42	18.54	29.05
0.975	3.98	6.97	11.72	18.97	29.68						
						$BaBr_2$					
1.001	3.98	6.96	11.69	18.88	29.54	1.888	3.70	6.48	10.85	17.54	27.43
1.265	3.91	6.84	11.47	18.55	28.95	2.245	3.59	6.29	10.54	17.01	26.61
1.445	3.85	6.73	11.31	18.27	28.53	2.503	3.50	6.14	10.26	16.53	25.90
1.706	3.76	6.59	11.05	17.89	27.95	3.398	3.11	5.58	9.23	14.98	25.56

Table II. Parameters in Equations 2-4

	$KCl + H_2O$	$KBr + H_2O$	$KI + H_2O$		$KCl + H_2O$	$KBr + H_2O$	$KI + H_2O$
A_0	7.626 0110	6.086 2080	5.486 5980	B_2	−166.5893	132.1589	127.8404
A_2	−0.426 4450	0.999 9371	1.252 8540	B_3	18.8654	−12.5391	−1.2463
A_2	0.208 8903	−0.235 9758	−0.190 7485	C_0	−27 305.940	−198 207.300	−275 912.900
A_3	−0.023 0629	0.024 0659	0.001 5253	C_1	−68 353.780	90 661.930	141 167.700
B_0	−2022.4850	−995.1476	−565.9023	C_2	32 669.500	−16 890.200	−21 502.850
B_1	339.4568	−616.6810	−845.7852	C_3	−3771.469	1370.040	247.165
	$CsCl + H_2O$	$CsBr + H_2O$	$CsI + H_2O$		$CsCl + H_2O$	$CsBr + H_2O$	$CsI + H_2O$
A_0	8.510 3620	4.023 5550	13.845 3600	B_2	−206.4201	352.0935	−5659.5240
A_1	−1.205 5230	2.447 0970	−13.283 3600	B_3	16.0836	−23.9989	1185.6090
A_2	0.292 7137	−0.547 3995	8.742 4280	C_0	65 296.600	−425 155.800	610 472.900
A_3	−0.022 8582	0.037 5162	−1.830 0890	C_1	−144 555.900	258 012.000	−1396 017.000
B_0	−2599.6630	369.7632	−5994.1790	C_2	36 297.510	−56 506.730	919 810.900
B_1	830.9444	−1595.1460	8583.0890	C_3	−2827.031	3832.014	−192 615.200
	$NaBr + H_2O$	$NaI + H_2O$	$RbCl + H_2O$		$NaBr + H_2O$	$NaI + H_2O$	$RbCl + H_2O$
A_0	7.208 1640	6.641 8220	7.089 4480	B_2	−19.9145	63.0511	16.9304
A_1	−0.067 5379	0.491 4986	0.020 2094	B_3	0.8825	−3.2720	0.7410
A_2	−0.000 3880	−0.100 8282	−0.030 7190	C_0	−61 252.4500	−146 462.900	−98 560.310
A_3	0.001 0449	0.005 1828	−0.000 6476	C_1	−30 106.550	51 849.160	307.495
B_0	−1782.1310	−1340.4910	−1631.0570	C_2	6662.861	−10 123.010	−2047.276
B_1	106.4015	−323.2146	−14.3337	C_3	−418.569	525.534	−195.086
	$CaCl_2 + H_2O$	$CaBr_2 + H_2O$	$CaI_2 + H_2O$		$CaCl_2 + H_2O$	$CaBr_2 + H_2O$	$CaI_2 + H_2O$
A_0	7.133 9460	5.061 9340	5.865 7030	B_2	−10.1648	428.0288	183.7660
A_1	0.066 6601	2.306 5260	0.931 1616	B_3	1.9557	−35.5699	−29.9868
A_2	0.017 1253	−0.684 1989	−0.345 4942	C_0	−101 301.800	−309 687.000	−217 515.900
A_3	−0.003 0351	0.057 0572	0.056 9615	C_1	16 194.170	234 931.300	69 980.930
B_0	−1647.3340	−328.2416	−848.7688	C_2	−640.718	−68 599.570	−17 450.280
B_1	−65.8949	−1472.7120	−559.4583	C_3	−176.317	5633.943	2568.411
	$SrCl_2 + H_2O$	$SrBr_2 + H_2O$	$SrI_2 + H_2O$		$SrCl_2 + H_2O$	$SrBr_2 + H_2O$	$SrI_2 + H_2O$
A_0	7.352 3180	5.312 8390	7.479 4540	B_2	−407.5421	380.6414	−152.2275
A_1	−0.815 0023	1.566 6820	−0.488 4127	B_3	77.3810	−44.3367	22.7994
A_2	0.570 4963	−0.528 8308	0.148 9571	C_0	−61 019.430	−310 093.800	−41 393.050
A_3	−0.109 2873	0.059 7050	−0.024 1059	C_1	−106 639.700	200 127.700	−82 610.700
B_0	−1830.6650	−410.3850	−1938.9650	C_2	73 013.390	−70 100.460	32 319.110
B_1	579.8124	−1121.6660	410.7994	C_3	−13 895.060	8282.056	−4821.754
	$BaCl_2 + H_2O$	$BaBr_2 + H_2O$	$MgCl_2 + H_2O$		$BaCl_2 + H_2O$	$BaBr_2 + H_2O$	$MgCl_2 + H_2O$
A_0	4.980 3270	6.210 0830	6.852 9260	B_2	1900.9680	212.0607	−7.8757
A_1	4.014 0250	0.676 4170	0.163 6174	B_3	−392.1857	−36.6102	−0.1009
A_2	−3.060 8950	−0.411 6864	−0.065 6395	C_0	−324 645.600	−180 287.900	−99 192.550
A_3	0.667 0547	0.070 8084	0.008 6453	C_1	409 351.600	43 730.630	−23 502.530
B_0	−253.9579	−1093.9780	−1545.4780	C_2	−297 548.100	−25 558.640	10 382.470
B_1	−2563.5440	−363.3954	0.7887	C_3	58 009.080	4354.658	−1127.883

The activity of water, a_{H_2O}, was calculated from the equation

$$\ln a_{H_2O} = \ln (P/P^\circ) \quad (5)$$

where P and P° are the vapor pressures of the solution and pure water, respectively.

The osmotic coefficients of the electrolyte solutions were calculated from the relation

$$\phi = -1000(\ln a_{H_2O})/\nu mM \quad (6)$$

where ν is the number of moles of ions formed from 1 mol of

Table III. Osmotic Coefficients of Aqueous Solutions and Activity Coefficients for Water

	T = 303.15 K		313.15 K		323.15 K		333.15 K		343.15 K	
m	ϕ	γ	ϕ	γ	ϕ	γ	ϕ	γ	ϕ	γ
					NaBr					
2.003	1.02	0.963	1.03	0.962	1.04	0.961	1.03	0.962	1.04	0.961
2.994	1.19	0.927	1.18	0.928	1.16	0.930	1.14	0.932	1.14	0.932
4.012	1.23	0.898	1.23	0.898	1.24	0.897	1.23	0.897	1.24	0.897
4.989	1.26	0.869	1.27	0.867	1.29	0.864	1.31	0.862	1.31	0.861
5.801	1.35	0.834	1.36	0.831	1.37	0.830	1.37	0.829	1.38	0.827
7.981	1.70	0.701	1.65	0.711	1.60	0.721	1.57	0.729	1.52	0.739
					NaI					
1.004	0.93	0.984	0.95	0.984	0.96	0.983	0.95	0.984	0.97	0.983
1.673	1.01	0.969	1.04	0.967	1.05	0.967	1.04	0.968	1.05	0.967
2.158	1.11	0.953	1.11	0.953	1.12	0.952	1.13	0.952	1.08	0.955
3.303	1.26	0.912	1.28	0.910	1.29	0.909	1.27	0.911	1.26	0.912
3.958	1.34	0.884	1.36	0.883	1.36	0.882	1.35	0.884	1.35	0.884
5.073	1.47	0.834	1.48	0.833	1.49	0.831	1.48	0.832	1.48	0.833
6.693	1.66	0.751	1.66	0.752	1.66	0.750	1.66	0.751	1.66	0.752
8.398	1.80	0.668	1.80	0.668	1.80	0.668	1.80	0.669	1.80	0.667
					KCl					
1.275	0.73	0.989	0.75	0.988	0.81	0.986	0.79	0.987	0.74	0.989
2.010	0.84	0.975	0.89	0.972	0.88	0.972	0.88	0.972	0.84	0.975
2.555	0.82	0.970	0.89	0.964	0.90	0.963	0.91	0.962	0.89	0.963
2.917	0.84	0.963	0.91	0.957	0.90	0.958	0.90	0.957	0.88	0.959
3.687	0.82	0.956	0.89	0.948	0.91	0.945	0.93	0.942	0.92	0.943
4.286	0.92	0.935	0.95	0.930	0.97	0.928	0.96	0.929	0.94	0.932
					KBr					
1.255	1.07	0.974	1.01	0.977	0.97	0.979	0.95	0.979	0.91	0.982
1.608	0.96	0.973	0.96	0.973	0.96	0.973	0.94	0.974	0.92	0.976
2.220	0.95	0.964	0.99	0.961	0.96	0.963	0.96	0.963	0.93	0.966
3.021	0.96	0.950	1.00	0.946	0.99	0.947	0.98	0.947	0.95	0.951
3.810	0.97	0.935	1.02	0.930	1.00	0.931	1.00	0.931	0.97	0.936
4.349	1.17	0.898	1.18	0.896	1.14	0.902	1.09	0.908	1.04	0.916
					KI					
1.006	0.86	0.987	0.80	0.989	0.75	0.991	0.79	0.990	0.85	0.987
1.523	0.75	0.986	0.81	0.983	0.82	0.982	0.84	0.981	0.90	0.978
2.003	0.77	0.980	0.81	0.977	0.87	0.973	0.90	0.971	0.91	0.970
2.351	0.78	0.976	0.86	0.969	0.89	0.966	0.92	0.964	0.94	0.962
3.027	0.79	0.967	0.87	0.959	0.95	0.950	0.99	0.947	1.00	0.945
4.059	0.88	0.944	0.94	0.935	1.01	0.926	1.03	0.923	1.05	0.921
4.747	1.01	0.914	1.01	0.913	1.08	0.902	1.06	0.906	1.08	0.902
5.648	1.06	0.889	1.06	0.888	1.10	0.881	1.12	0.877	1.13	0.875
					RbCl					
1.493	0.90	0.978	0.90	0.978	0.89	0.979	0.88	0.979	0.88	0.979
2.968	0.95	0.952	0.95	0.952	0.93	0.954	0.94	0.953	0.94	0.953
3.550	0.98	0.938	0.94	0.943	0.94	0.943	0.94	0.943	0.94	0.943
4.463	0.98	0.922	0.96	0.925	0.95	0.927	0.95	0.927	0.97	0.924
5.996	1.07	0.880	1.03	0.888	1.00	0.894	1.00	0.894	1.01	0.892
6.949	1.19	0.836	1.12	0.851	1.08	0.858	1.07	0.861	1.07	0.860
					CsCl					
1.774	1.11	0.961	1.10	0.962	1.04	0.966	1.03	0.966	0.99	0.969
2.471	1.08	0.948	1.05	0.951	0.99	0.956	0.97	0.958	0.94	0.960
3.522	0.97	0.941	0.96	0.941	0.96	0.941	0.95	0.942	0.96	0.941
4.402	0.93	0.932	0.95	0.929	0.94	0.930	0.96	0.928	0.97	0.925
5.492	0.93	0.915	0.94	0.913	0.97	0.907	0.98	0.906	1.00	0.902
6.444	0.94	0.898	0.96	0.894	0.98	0.890	0.99	0.887	1.01	0.882
7.435	1.00	0.867	0.99	0.870	1.01	0.865	1.02	0.862	1.04	0.857
8.590	1.22	0.793	1.14	0.811	1.09	0.823	1.08	0.827	1.07	0.829
					CsBr					
1.570	0.94	0.975	0.93	0.975	0.87	0.979	0.83	0.981	0.90	0.977
2.244	0.88	0.969	0.90	0.967	0.90	0.967	0.89	0.968	0.90	0.967
2.768	0.81	0.968	0.87	0.963	0.88	0.961	0.89	0.961	0.89	0.961
3.485	0.81	0.960	0.87	0.953	0.89	0.950	0.88	0.952	0.90	0.950
4.320	0.79	0.953	0.84	0.946	0.87	0.941	0.89	0.939	0.90	0.937
5.888	0.78	0.937	0.81	0.932	0.84	0.925	0.87	0.920	0.88	0.918
					CsI					
1.345	0.79	0.986	0.89	0.981	0.89	0.981	0.85	0.983	0.89	0.981
1.546	0.82	0.982	0.92	0.976	0.91	0.977	0.87	0.979	0.88	0.979
1.799	0.82	0.979	0.93	0.972	0.93	0.972	0.90	0.974	0.91	0.973
2.014	0.84	0.975	0.91	0.970	0.90	0.971	0.89	0.971	0.88	0.972
2.595	0.98	0.955	0.88	0.964	0.89	0.963	0.89	0.963	0.91	0.961

Table III (Continued)

	T = 303.15 K		313.15 K		323.15 K		333.15 K		343.15 K	
m	φ	γ	φ	γ	φ	γ	φ	γ	φ	γ
					$MgCl_2$					
1.047	1.12	0.956	1.09	0.958	1.05	0.960	1.02	0.962	1.00	0.963
1.303	1.37	0.929	1.29	0.935	1.24	0.938	1.17	0.943	1.12	0.946
2.006	1.51	0.880	1.47	0.883	1.43	0.888	1.37	0.893	1.35	0.895
2.449	1.83	0.820	1.74	0.829	1.69	0.835	1.64	0.841	1.57	0.848
3.167	2.06	0.743	2.02	0.748	1.97	0.755	1.93	0.760	1.89	0.765
3.737	2.16	0.690	2.13	0.694	2.10	0.698	2.08	0.702	2.05	0.705
4.343	2.57	0.590	2.51	0.598	2.46	0.606	2.41	0.613	2.36	0.620
4.801	2.91	0.510	2.85	0.518	2.75	0.532	2.68	0.542	2.63	0.550
					$CaCl_2$					
1.002	1.12	0.958	1.13	0.957	1.13	0.958	1.10	0.959	1.09	0.960
2.249	1.39	0.879	1.41	0.877	1.39	0.879	1.37	0.881	1.35	0.883
3.017	1.77	0.791	1.75	0.793	1.71	0.798	1.67	0.803	1.63	0.808
3.887	2.15	0.681	2.11	0.687	2.05	0.696	1.99	0.705	1.93	0.713
4.951	2.54	0.552	2.46	0.564	2.39	0.575	2.31	0.588	2.23	0.600
6.019	2.81	0.444	2.71	0.460	2.61	0.473	2.52	0.488	2.43	0.503
6.786	2.93	0.384	2.81	0.400	2.71	0.415	2.61	0.432	2.51	0.447
7.885	2.96	0.323	2.84	0.340	2.73	0.356	2.63	0.373	2.53	0.389
					$CaBr_2$					
1.006	1.30	0.948	1.19	0.955	1.15	0.956	1.12	0.958	1.10	0.959
1.238	1.37	0.933	1.31	0.936	1.24	0.941	1.21	0.943	1.16	0.946
1.709	1.47	0.900	1.44	0.902	1.41	0.905	1.38	0.908	1.32	0.913
2.254	1.71	0.844	1.67	0.849	1.63	0.853	1.55	0.861	1.51	0.866
3.022	2.06	0.754	2.01	0.759	1.96	0.766	1.91	0.772	1.85	0.779
3.376	2.21	0.708	2.17	0.714	2.11	0.722	2.05	0.729	2.00	0.736
3.949	2.45	0.634	2.39	0.643	2.33	0.652	2.27	0.659	2.22	0.667
4.596	2.70	0.554	2.63	0.563	2.54	0.576	2.48	0.584	2.43	0.592
					CaI_2					
1.138	1.19	0.948	1.07	0.956	1.02	0.958	1.01	0.959	0.99	0.961
1.464	1.25	0.930	1.19	0.935	1.17	0.936	1.14	0.938	1.15	0.937
1.875	1.37	0.900	1.31	0.905	1.29	0.907	1.28	0.908	1.25	0.911
2.273	1.38	0.879	1.37	0.880	1.35	0.882	1.35	0.882	1.35	0.882
2.915	1.75	0.799	1.72	0.803	1.69	0.806	1.67	0.809	1.65	0.812
					$SrCl_2$					
0.662	0.94	0.979	0.96	0.978	0.97	0.977	0.95	0.978	0.99	0.977
0.871	0.82	0.977	0.88	0.974	0.88	0.975	0.87	0.975	0.94	0.972
1.299	1.12	0.946	1.02	0.953	1.13	0.945	1.16	0.943	1.09	0.948
1.503	1.31	0.923	1.28	0.925	1.21	0.931	1.16	0.935	1.13	0.937
1.797	1.35	0.906	1.32	0.908	1.29	0.910	1.28	0.912	1.25	0.914
2.213	1.39	0.880	1.37	0.882	1.36	0.884	1.33	0.886	1.31	0.889
2.693	1.54	0.838	1.53	0.840	1.49	0.844	1.46	0.848	1.44	0.850
3.203	1.87	0.766	1.79	0.775	1.75	0.782	1.68	0.791	1.63	0.797
					$SrBr_2$					
0.800	1.52	0.950	1.29	0.959	1.15	0.965	1.11	0.967	1.11	0.967
1.013	1.29	0.949	1.18	0.955	1.15	0.956	1.10	0.959	1.16	0.956
1.345	1.22	0.937	1.17	0.941	1.20	0.939	1.19	0.939	1.23	0.937
1.746	1.36	0.907	1.35	0.908	1.33	0.909	1.34	0.909	1.35	0.908
1.996	1.54	0.877	1.48	0.883	1.50	0.881	1.44	0.887	1.45	0.886
2.395	1.62	0.846	1.60	0.848	1.59	0.849	1.57	0.851	1.58	0.850
2.656	1.81	0.808	1.80	0.809	1.76	0.814	1.74	0.816	1.73	0.817
3.340	2.09	0.728	2.04	0.734	2.01	0.737	1.98	0.741	1.96	0.745
					SrI_2					
0.970	1.26	0.953	1.26	0.953	1.23	0.954	1.19	0.956	1.17	0.957
1.264	1.37	0.931	1.35	0.933	1.30	0.936	1.27	0.938	1.24	0.939
1.534	1.42	0.914	1.40	0.915	1.39	0.916	1.36	0.918	1.36	0.918
1.960	1.60	0.874	1.57	0.877	1.53	0.880	1.51	0.883	1.50	0.883
2.370	1.79	0.829	1.76	0.832	1.73	0.836	1.70	0.839	1.69	0.839
2.933	1.96	0.772	1.95	0.773	1.94	0.775	1.92	0.776	1.93	0.775
3.517	2.26	0.692	2.23	0.696	2.21	0.698	2.20	0.699	2.20	0.699
4.156	2.59	0.601	2.52	0.611	2.47	0.617	2.43	0.623	2.41	0.625
					$BaCl_2$					
0.504	1.50	0.969	1.16	0.978	0.93	0.984	0.90	0.985	0.87	0.985
0.738	1.27	0.963	1.08	0.971	0.95	0.976	0.88	0.978	0.88	0.979
0.975	1.20	0.955	1.08	0.961	0.98	0.966	0.93	0.969	0.93	0.969
1.214	1.27	0.940	1.14	0.948	1.03	0.955	0.99	0.958	0.96	0.960
1.388	1.29	0.931	1.15	0.940	1.03	0.949	0.96	0.954	0.94	0.955
					$BaBr_2$					
1.001	1.17	0.958	1.08	0.960	1.00	0.964	0.99	0.965	0.99	0.965
1.265	1.19	0.943	1.11	0.948	1.07	0.951	1.04	0.952	1.08	0.950
1.445	1.24	0.932	1.18	0.936	1.12	0.940	1.11	0.941	1.13	0.939

Table III (Continued)

	T = 303.15 K		313.15 K		323.15 K		333.15 K		343.15 K	
m	φ	γ	φ	γ	φ	γ	φ	γ	φ	γ
1.706	1.30	0.914	1.23	0.920	1.20	0.923	1.17	0.926	1.18	0.924
1.888	1.34	0.902	1.27	0.908	1.26	0.909	1.25	0.910	1.25	0.910
2.245	1.37	0.881	1.32	0.887	1.30	0.889	1.30	0.888	1.30	0.888
2.503	1.42	0.868	1.36	0.869	1.36	0.869	1.38	0.867	1.37	0.868
3.398	1.60	0.778	1.62	0.788	1.58	0.794	1.55	0.798	1.52	0.802

electrolyte, m is the molality of the solution, and M is the molecular weight of water. The activity coefficients of water were obtained from

$$\gamma = a_{H_2O}/x \quad (7)$$

where x is the mole fraction of water. Osmotic coefficients of electrolyte solutions and the activity coefficients of water were calculated from experimental vapor pressure data and are tabulated in Table III. From Table III it may be observed that the activity coefficients of water are always less than unity. This means that these electrolyte solutions exhibit nonideal behavior.

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Glossary

A, B, C	constants of the Antoine equation
A_0, A_1, A_2, A_3	parameters in eq 2
B_0, B_1, B_2, B_3	parameters in eq 3
C_0, C_1, C_2, C_3	parameters in eq 4
m	molality of electrolyte, mol/kg
M	molecular weight
P	vapor pressure, kPa
T	temperature, K
ϕ	osmotic coefficient
ν	number of moles of ions formed from 1 mol of electrolyte
γ	activity coefficient of water

Registry No. NaBr, 7647-15-6; NaI, 7681-82-5; KCl, 7447-40-7; KBr, 7758-02-3; KI, 7681-11-0; RbCl, 7791-11-9; CsCl, 7647-17-8; CsBr, 7787-69-1; CsI, 7789-17-5; $MgCl_2$, 7786-30-3; $CaCl_2$, 10043-52-4; $CaBr_2$, 7789-41-5; CaI_2, 10102-68-8; $SrCl_2$, 10476-85-4; $SrBr_2$, 10476-81-0; SrI_2, 10476-86-5; $BaBr_2$, 10553-31-8; $BaCl_2$, 10361-37-2.

Literature Cited

(1) Patil, K. R.; Tripathi, A. D.; Pathak, G.; Katti, S. S. *J. Chem. Eng. Data* **1990**, *35*, 166.
(2) Chen, C. C.; Evans, L. B. *AIChE J.* **1986**, *32*, 444.
(3) Ananth, M. S.; Ramchandran, S. *AIChE J.* **1990**, *36*, 370.
(4) Keenan, J. H.; Keyes, F. G.; Moore, J. G. *Thermodynamic Properties of Water Including Vapor, Liquid and Solid Phases*; John Wiley and Sons: New York, 1969.

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