

Densities, Viscosities, and Conductivities of Mixtures of Benzene with the Lewis Acidic Aluminum Chloride + 1-Methyl-3-ethylimidazolium Chloride Molten Salt

Qing Liao and Charles L. Hussey*

Department of Chemistry, University of Mississippi, University, Mississippi 38677

The densities, kinematic viscosities, and specific conductances of mixtures of benzene with the Lewis acidic room-temperature chloroaluminate molten salt aluminum chloride + 1-methyl-3-ethylimidazolium chloride ($\text{AlCl}_3 + \text{MeEtimCl}$) were determined at 298.2 K. Benzene was added to melts containing 51.00, 60.00, and 66.67 mol % AlCl_3 . Simple polynomial equations were fitted to the experimental results as a function of the mass fraction of benzene. The addition of small amounts of benzene resulted in a decrease in the kinematic viscosity and an increase in the specific conductance of the mixture. However, the addition of benzene beyond 35 mass % caused the specific conductance to decrease due to a decrease in the concentration of charge-carrying ions.

Introduction

The combination of anhydrous aluminum chloride and the unsymmetrical quaternary ammonium chloride salt 1-methyl-3-ethylimidazolium chloride (MeEtimCl) results in a molten salt that is liquid at room temperature. The synthesis, purification, and physical properties of this molten salt system have been described at length (Wilkes et al., 1982; Fannin et al., 1984b). The $\text{AlCl}_3 + \text{MeEtimCl}$ molten salt system displays adjustable Lewis acidity; melts containing more than 50 mol % AlCl_3 are acidic because they contain chloride ion acceptors such as Al_2Cl_7^- , whereas those prepared with less than 50 mol % AlCl_3 contain chloride ion that is not covalently bound to aluminum and are thus Lewis basic. The Lewis acidic $\text{AlCl}_3 + \text{MeEtimCl}$ molten salt is of particular interest because, unlike the basic melt, aluminum and many aluminum alloys can be electroplated from this ionic liquid. Furthermore, the acidic melt is under exploration as an industrial solvent for the liquefaction of coal and as a catalyst for the polymerization of butenes. However, development of these applications is hindered by the rather modest electrical conductivity and the relatively high viscosity of the $\text{AlCl}_3 + \text{MeEtimCl}$ molten salt at room temperature.

In a recent article (Perry et al., 1995), we demonstrated that the addition of cosolvents such as acetonitrile, benzene, and dichloromethane to basic melts produces ternary cosolvent (1) + AlCl_3 (2) + MeEtimCl (3) mixtures with viscosities lower than and conductivities higher than those of the pure melt. The addition of these cosolvents apparently acts to decrease ion-pairing or ion aggregation by solvating one or more of the interacting ions. Although the basic melt is miscible with and nonreactive toward many of the organic compounds that are commonly used as solvents, the acidic melt is another matter. In this case, there are relatively few candidates for cosolvents because of the strong acceptor nature of this melt (Zawodzinski and Osteryoung, 1989). However, simple aromatic hydrocarbons such as benzene, chlorobenzene, and toluene do seem to be useful cosolvents for melts with $x_2 > 0.50$, where x_2 is the mole fraction of AlCl_3 in the melt before the addition of cosolvent (Robinson, 1979; Moy and Emmenegger, 1992; Papageorgiou and Emmenegger, 1993). We have found benzene to be quite stable when dissolved in acidic AlCl_3

+ MeEtimCl, provided that precautions were taken to remove all traces of moisture from the benzene and protic impurities from the melt. Furthermore, our preliminary studies indicate that mixtures of benzene and Lewis acidic $\text{AlCl}_3 + \text{MeEtimCl}$ are excellent solvents for the electrodeposition of pure aluminum. In this article, we report the densities, electrical conductivities, and viscosities of such mixtures at 298.2 K.

Experimental Section

Materials. The procedures used for the purification of AlCl_3 and the preparation and purification of MeEtimCl were identical to those described in a previous publication (Perry et al., 1995). Benzene (Aldrich, HPLC grade) was distilled from potassium hydride and stored over molecular sieves in a nitrogen-filled glovebox before use. The protic impurities were removed from the $\text{AlCl}_3 + \text{MeEtimCl}$ melt by reduction with aluminum foil. Small pieces of foil were stirred in the melt for several days. At the end of this time, the melt was filtered through a coarse porosity glass frit. Melt + benzene samples were prepared by weighing inside the glovebox and were stored in tightly capped glass vials with Teflon-lined closures. For convenience, the melt compositions reported herein are given as the mole fraction of AlCl_3 , x_2 , in the AlCl_3 (2) + MeEtimCl (3) melt before the addition of benzene. Ternary benzene (1) + AlCl_3 (2) + MeEtimCl (3) mixtures are described in terms of the mass fraction, w_1 , or mole fraction, x_1 , of benzene in the three component mixture. Because acidic $\text{AlCl}_3 + \text{MeEtimCl}$ reacts vigorously with moisture, all experiments were carried out in such a way so as to eliminate all direct contact between the atmosphere and the melt.

Density. Melt densities were determined inside the glovebox with calibrated 5-mL volumetric flasks. The volumes of these flasks had been determined with mercury and were known to $\pm 0.0001 \text{ cm}^3$. These flasks were filled above the calibration line with melt, capped, and submerged in a sand bath, which was maintained at a temperature of $(25.0 \pm 0.1)^\circ\text{C}$, for 1 h. At the end of this thermal equilibration period, the cap was removed and extra melt above the calibration line was withdrawn carefully with a Pasteur pipet. The flasks were then weighed to the nearest 0.1 mg with a precision balance,

Table 1. Comparison of AlCl₃-MeEtimCl Density, Viscosity, and Conductivity Data at 298.2 K

property	present work	lit. ^a	% diff
	$x_2 = 0.5100$		
$\rho/\text{g}\cdot\text{cm}^{-3}$	1.3025	1.2993	0.24
$100\nu/\text{cm}^2\cdot\text{s}^{-1}$	13.28	13.48	-1.5
$\kappa/\text{S}\cdot\text{m}^{-1}$	2.186	2.229	-1.9
	$x_2 = 0.6000$		
$\rho/\text{g}\cdot\text{cm}^{-3}$	1.3541	1.3491	0.37
$100\nu/\text{cm}^2\cdot\text{s}^{-1}$	11.92	11.36	4.9
$\kappa/\text{S}\cdot\text{m}^{-1}$	1.694	1.714	-1.2
	$x_2 = 0.6667$		
$\rho/\text{g}\cdot\text{cm}^{-3}$	1.3974	1.3888	0.62
$100\nu/\text{cm}^2\cdot\text{s}^{-1}$	9.87	9.62	2.6
$\kappa/\text{S}\cdot\text{m}^{-1}$	1.423	1.452	-2.0

^a Fannin et al., 1984b.

which was also placed inside the glovebox. The estimated experimental uncertainty of these measurements was $\pm 0.0001 \text{ g}\cdot\text{cm}^{-3}$.

Kinematic Viscosity. Measurements of the kinematic viscosity, ν , were carried out by using a modified No. 200 Cannon-Fenske viscometer attached to a vertical turntable; the turntable was immersed in a water bath maintained at $(25.00 \pm 0.05)^\circ\text{C}$ with a Braun Model 1420 Thermomix immersion controller. The construction and operation of the viscometer and turntable were described in a previous article (Sanders et al., 1986). The viscometer was filled with 10.00 cm^3 of melt or benzene + melt in the glovebox with a pipet, sealed gastight, and then removed from the glovebox and attached to the turntable. The viscometer was calibrated with distilled water, 1-propanol (Baker, reagent grade), 1-butanol (Baker, reagent grade), and freshly distilled ethylene glycol (Baker, reagent grade). The viscosities of pure water, 1-propanol, and 1-butanol were taken from the *TRC Databases for Chemistry and Engineering-TRC Thermodynamic Tables*, Texas Engineering Station, Texas A&M University, whereas that for pure ethylene glycol was taken from I. Mellan (*Polyhydric Alcohols*; Spartan Books: Washington, DC, 1962). Efflux times were measured to 0.01 s with a digital stopwatch. The estimated uncertainty in ν is $\pm 0.01 \text{ cm}^2\cdot\text{s}^{-1}$.

Specific Conductance. Conductivity measurements were carried out with a Stanford Research Systems Model SR720 LCR meter and a homemade conductivity cell similar to that described in the literature (Moynihan, 1967). This cell was fashioned from two 14/20 female

ground glass joints sealed on the end opposite from the joint; these tubes were joined together at a point approximately 0.5 cm from the closed end by a 4-cm length of 3-mm diameter capillary tubing. The electrodes for this conductivity cell were crafted from 14/35 male ground glass joints with reduced tubes on one end (ACE, 7640-06). The large end of these tubes was cut off about 0.5 cm above the joint. Tungsten wires were sealed into the ends of the small tubes and protruded approximately 1 cm below the seal and ca. 2 cm above the top of the large tube. Bright platinum flags (area = 1.5 cm^2) were spot welded to short lengths of platinum wire; these wires were mechanically joined to the tungsten wires just below the seal. When the male joints were coated very lightly with vacuum grease and inserted into the female receptacles, the cell was gastight. The cell was filled in the glovebox with enough melt to just cover the platinum flag electrodes, sealed, and then immersed in the water bath described above to a level just below the joints. The conductivity cell was calibrated with 0.02, 0.04, 0.06, 0.08, 0.10, 0.15, and 0.20 mol dm^{-3} aqueous KCl solutions according to IUPAC recommendations (Juhász and Marsh, 1981). Resistance measurements were made with the bridge described above in the *C-R* mode with a drive potential of 100 mV. The measured cell resistance was found to be independent of frequency over the range from 100 Hz to 10 kHz when the cell was filled with either molten salt or aqueous KCl; therefore resistance measurements were typically performed at 1 kHz. The specific conductance, κ , was calculated from the measured resistance for each sample and the cell constant, which was 6.5391. The estimated uncertainty in κ is $\pm 0.001 \text{ S}\cdot\text{m}^{-1}$.

Results and Discussion

The experimental values of ρ , ν , and κ of the neat AlCl₃ (2) + MeEtimCl (3) melt ($x_2 = 0.5100$, 0.6000, and 0.6667) that were measured during this study are compared to the literature values (Fannin et al., 1984b) in Table 1. Taken together, the values of ρ , ν , and κ resulting from the present study are in very good agreement with the literature values, the largest deviation being 4.9% for ν measured in the $x_2 = 0.6000$ melt.

Experimental values of ρ , ν , and κ for several different benzene (1) + AlCl₃ (2) + MeEtimCl (3) mixtures are listed in Tables 2–4. These results are grouped according to the value of x_2 of the AlCl₃ + MeEtimCl melt *prior* to the addition of benzene.

Table 2. Densities of Benzene (1) + AlCl₃ (2) + MeEtimCl (3) at 298.2 K

$x_2^a = 0.5100$			$x_2 = 0.6000$			$x_2 = 0.6667$		
w_1^b	x_1^c	$\rho/\text{g}\cdot\text{cm}^{-3}$	w_1	x_1	$\rho/\text{g}\cdot\text{cm}^{-3}$	w_1	x_1	$\rho/\text{g}\cdot\text{cm}^{-3}$
0.000 00	0.000 00	1.3025	0.000 00	0.000 0	1.3541	0.000 00	0.000 00	1.3974
0.020 13	0.035 47	1.2949	0.019 95	0.034 87	1.3407	0.020 00	0.034 74	1.3845
0.040 00	0.069 42	1.2826	0.039 97	0.068 82	1.3275	0.040 01	0.068 47	1.3659
0.059 95	0.102 47	1.2764	0.060 00	0.101 76	1.3141	0.060 00	0.101 18	1.3559
0.070 18	0.119 04	1.2693	0.069 96	0.117 79	1.3100	0.070 01	0.117 20	1.3499
0.079 98	0.134 67	1.2627	0.080 00	0.133 71	1.3041	0.079 99	0.132 95	1.3434
0.089 99	0.150 41	1.2579	0.090 00	0.149 33	1.3000	0.090 00	0.148 52	1.3344
0.100 15	0.166 14	1.2542	0.099 97	0.164 69	1.2939	0.099 99	0.163 83	1.3269
0.149 92	0.239 97	1.2292	0.149 79	0.238 22	1.2659	0.150 00	0.237 35	1.2988
0.200 14	0.309 37	1.2079	0.200 03	0.307 39	1.2382	0.200 00	0.305 99	1.2685
0.249 94	0.373 65	1.1832	0.249 90	0.371 59	1.2119	0.250 00	0.370 22	1.2331
0.299 12	0.433 12	1.1609	0.299 91	0.431 93	1.1825	0.300 00	0.430 46	1.2051
0.349 57	0.490 36	1.1388	0.350 00	0.488 68	1.1595	0.350 00	0.487 08	1.1725
0.399 76	0.543 86	1.1198	0.399 98	0.541 95	1.1327	0.400 00	0.540 38	1.1488
0.449 62	0.593 91	1.0957	0.450 08	0.592 28	1.1090	0.450 00	0.590 65	1.1234
0.500 20	0.641 79	1.0709	0.500 37	0.639 97	1.0800	0.499 58	0.637 76	1.0880

^a x_2 = mole fraction of AlCl₃ without benzene. ^b w_1 = mass fraction of benzene. ^c x_1 = mole fraction of benzene.

Table 3. Kinematic Viscosities of Benzene (1) + AlCl₃ (2) + MeEtimCl (3) at 298.2 K

$x_2^a = 0.5100$			$x_2 = 0.6000$			$x_2 = 0.6667$		
w_1^b	x_1^c	$10^2\nu/\text{cm}^2\cdot\text{s}^{-1}$	w_1	x_1	$10^2\nu/\text{cm}^2\cdot\text{s}^{-1}$	w_1	x_1	$10^2\nu/\text{cm}^2\cdot\text{s}^{-1}$
0.000 00	0.000 0	13.28	0.000 00	0.000 00	11.92	0.000 00	0.000 00	9.87
0.020 13	0.035 47	12.07	0.019 95	0.034 87	10.77	0.020 00	0.034 74	8.88
0.040 00	0.069 42	10.98	0.039 97	0.068 82	9.87	0.040 01	0.068 47	8.06
0.059 95	0.102 47	10.28	0.060 00	0.101 76	8.99	0.060 00	0.101 18	7.59
0.070 18	0.119 04	9.87	0.069 96	0.117 79	8.64	0.070 01	0.117 20	7.19
0.079 98	0.134 67	9.48	0.080 00	0.133 71	8.26	0.079 99	0.132 95	6.78
0.089 99	0.150 41	9.05	0.090 00	0.149 33	8.01	0.090 00	0.148 52	6.56
0.100 15	0.166 14	8.70	0.099 97	0.164 69	7.62	0.099 99	0.163 83	6.28
0.149 92	0.239 97	7.24	0.149 79	0.238 22	6.32	0.150 00	0.237 35	5.45
0.200 14	0.309 37	6.14	0.200 03	0.307 39	5.35	0.200 00	0.305 99	4.54
0.249 94	0.373 65	5.27	0.249 90	0.371 59	4.56	0.250 00	0.370 22	3.82
0.299 12	0.433 12	4.64	0.299 91	0.431 93	3.96	0.300 00	0.430 46	3.32
0.349 57	0.490 36	3.90	0.350 00	0.488 68	3.43	0.350 00	0.487 08	2.81
0.399 76	0.543 86	3.51	0.399 98	0.541 95	2.98	0.400 00	0.540 38	2.50
0.449 62	0.593 91	2.99	0.450 08	0.592 28	2.62	0.450 00	0.590 65	2.18
0.500 20	0.641 79	2.63	0.500 37	0.639 97	2.29	0.499 58	0.637 76	1.89

^a x_2 = mole fraction of AlCl₃ without benzene. ^b w_1 = mass fraction of benzene. ^c x_1 = mole fraction of benzene.

Table 4. Specific Conductances of Benzene (1) + AlCl₃ (2) + MeEtimCl (3) at 298.2 K

$x_2^a = 0.5100$			$x_2 = 0.6000$			$x_2 = 0.6667$		
w_1^b	x_1^c	$\kappa/\text{S}\cdot\text{cm}^{-1}$	w_1	x_1	$\kappa/\text{S}\cdot\text{cm}^{-1}$	w_1	x_1	$\kappa/\text{S}\cdot\text{cm}^{-1}$
0.000 00	0.000 00	2.186	0.000 00	0.000 00	1.694	0.000 00	0.000 00	1.423
0.020 13	0.035 47	2.274	0.019 95	0.034 87	1.784	0.020 00	0.034 74	1.501
0.040 00	0.069 42	2.364	0.039 97	0.068 82	1.866	0.040 01	0.068 47	1.595
0.059 95	0.102 47	2.419	0.060 00	0.101 76	1.948	0.060 00	0.101 18	1.656
0.070 18	0.119 04	2.451	0.069 96	0.117 79	1.987	0.070 01	0.117 20	1.717
0.079 98	0.134 67	2.500	0.080 00	0.133 71	2.024	0.079 99	0.132 95	1.763
0.089 99	0.150 41	2.539	0.090 00	0.149 33	2.059	0.090 00	0.148 52	1.806
0.100 15	0.166 14	2.573	0.099 97	0.164 69	2.077	0.099 99	0.163 83	1.825
0.149 92	0.239 97	2.728	0.149 79	0.238 22	2.248	0.150 00	0.237 35	2.053
0.200 14	0.309 37	2.874	0.200 03	0.307 39	2.406	0.200 00	0.305 99	2.211
0.249 94	0.373 65	2.973	0.249 90	0.371 59	2.542	0.250 00	0.370 22	2.391
0.299 12	0.433 12	3.043	0.299 91	0.431 93	2.629	0.300 00	0.430 46	2.465
0.349 57	0.490 36	3.075	0.350 00	0.488 68	2.676	0.350 00	0.487 08	2.538
0.399 76	0.543 91	3.033	0.399 98	0.541 95	2.650	0.400 00	0.540 38	2.530
0.449 62	0.593 91	2.929	0.450 08	0.592 28	2.567	0.450 00	0.590 65	2.439
0.500 20	0.641 79	2.692	0.500 37	0.639 97	2.351	0.499 58	0.637 76	2.237

^a x_2 = mole fraction of AlCl₃ without benzene. ^b w_1 = mass fraction of benzene. ^c x_1 = mole fraction of benzene.

Plots of ρ versus w_1 are shown in Figure 1. Polynomial equations of the form

$$\rho/\text{g}\cdot\text{cm}^{-3} = \sum_{i=0}^n a_i(w_1)^i \quad (1)$$

were fitted to the density data in Table 2 by using the linear regression feature of LOTUS software. The parameters resulting from these fits are collected in Table 5. The solid lines in Figure 1 were calculated from the parameters listed in Table 5 and eq 1. The squares of the correlation coefficients (R^2) resulting from each fit of eq 1 to the ρ versus w_1 data in Table 2 are very close to 1.00, indicating that eq 1 provides an excellent representation of the experimental data.

Plots of ν versus w_1 are shown in Figure 2. In a previous investigation (Perry et al., 1995), polynomial expressions of the type

$$\ln(10^2\nu/\text{cm}^2\cdot\text{s}^{-1}) = \sum_{i=0}^n a_i(w_1)^i \quad (2)$$

were found to provide an excellent representation of the experimental viscosity data for mixtures of benzene with the Lewis basic AlCl₃ + MeEtimCl melt. Therefore, the expression shown in eq 2 was fitted to the data appearing in Table 3 and Figure 2. The fitted parameters that resulted are collected in Table 5; the values of R^2 that

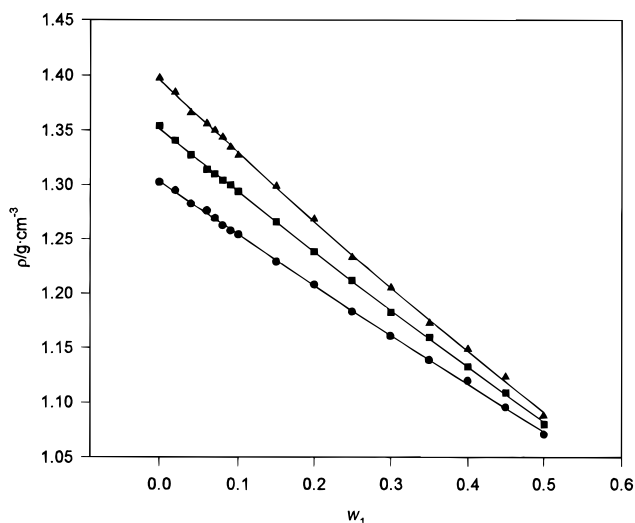


Figure 1. Variation of the density, ρ , of the AlCl₃ + MeEtimCl melt with the mass fraction of benzene, w_1 , at 298.2 K: (●) $x_2 = 0.5100$, (■) $x_2 = 0.6000$, (▲) $x_2 = 0.6667$. The solid lines were calculated with eq 1 and the fitted parameters in Table 5.

resulted from these fits indicate that eq 2 provides an excellent representation of the experimental data. The solid lines that appear in Figure 2 were calculated from eq 2 and the fitted parameters in Table 5.

Table 5. Fitted Parameters for Eqs 1–3

x_2	a_0	a_1	a_2	a_3	a_4	a_5	R^2	$S_{y/x}^a$
Density (Eq 1)								
0.5100	1.3031	-0.4928	0.0659				0.9996	0.0016
0.6000	1.3515	-0.5869	0.0972				0.9997	0.0016
0.6667	1.3960	-0.6786	0.1387				0.9994	0.0026
Kinematic Viscosity (Eq 2)								
0.5100	2.5839	-4.6043	4.6418	-3.8199			0.9997	0.0098
0.6000	2.4753	-4.9104	5.4037	-4.3468			1.0000	0.0038
0.6667	2.2767	-4.6623	4.6623	-3.8104			0.9994	0.0143
Specific Conductance (Eq 3)								
0.5100	2.1825		6.8515	-20.1512	46.8784	-42.4309	0.9992	0.0098
0.6000	1.6886		7.8806	-26.3288	60.2746	-51.0798	0.9996	0.0078
0.6667	1.4303		3.5227		12.9337	-23.6273	0.9990	0.0138

^a Standard error of the y estimate.

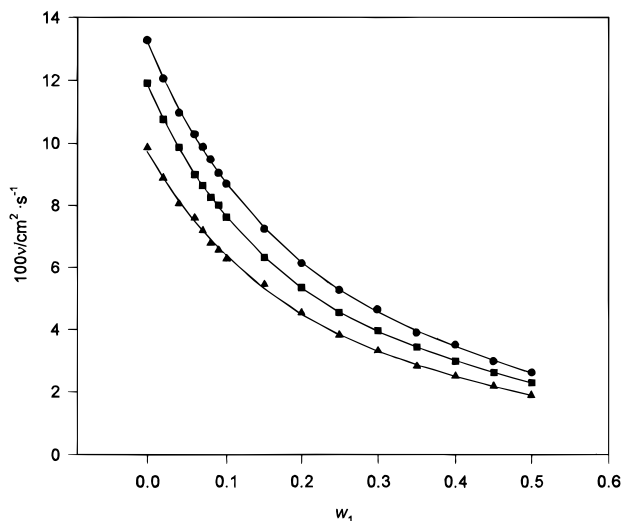


Figure 2. Variation of the kinematic viscosity, ν , of the AlCl_3 + MeEtimCl melt with the mass fraction of benzene, w_1 , at 298.2 K: (●) $x_2 = 0.5100$, (■) $x_2 = 0.6000$, (▲) $x_2 = 0.6667$. The solid lines were calculated with eq 2 and the fitted parameters in Table 5.

Plots of κ versus w_1 are shown in Figure 3. In keeping with previous results for basic melts (Perry et al., 1995), polynomial expressions similar to that shown in eq 3 were

$$\kappa/\text{S}\cdot\text{m}^{-1} = \sum_{i=0}^n a_i(w_1)^{i/2} \quad (3)$$

investigated as correlating expressions for this data. The parameters resulting from the fits of eq 3 to the data in Table 4 are collected in Table 5; the R^2 values resulting from these fits indicate that this equation provides an excellent representation of the experimental κ versus w_1 data. However, not all of the terms in eq 3 are needed. The solid lines appearing in Figure 3 were calculated from eq 3, and the fitted parameters are listed in Table 5.

As was the case for combinations of various cosolvents with the basic AlCl_3 + MeEtimCl melt (Perry et al., 1995), the addition of benzene to acidic melt results in substantial modification of both ν and κ , the former decreasing and the latter increasing and passing through a maximum and finally decreasing as w_1 is increased. The favored explanation for the changes in both of these transport properties is that the cosolvent "solvates" the constituent ions, thereby decreasing ion-pairing or ion aggregation. The maxima seen in the plots of κ versus w_1 are simply due to the fact that the addition of benzene beyond $w_1 \sim 0.35$ progressively decreases the concentration of free ions in the solution, resulting in a decrease in κ . No maximum was obtained during the addition of benzene to basic AlCl_3 + MeEtimCl;

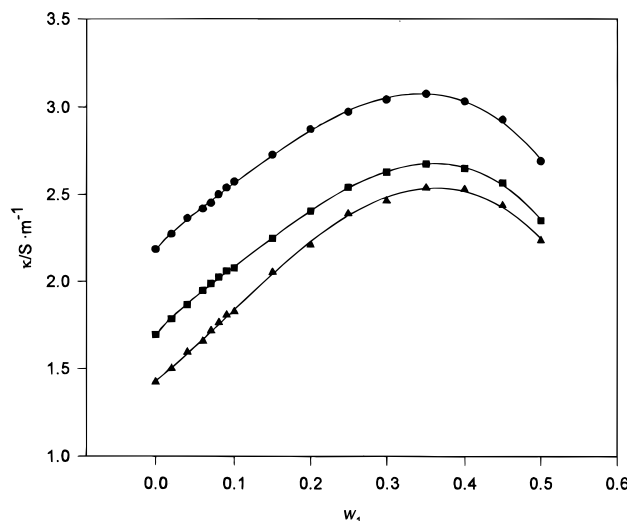


Figure 3. Variation of the specific conductance, κ , of the AlCl_3 + MeEtimCl melt with the mass fraction of benzene, w_1 , at 298.2 K: (●) $x_2 = 0.5100$, (■) $x_2 = 0.6000$, (▲) $x_2 = 0.6667$. The solid lines were calculated with eq 3 and the fitted parameters in Table 5.

however, the range of w_1 that was examined during this previous investigation was somewhat smaller than that explored here and did not extend beyond $w_1 = 0.35$. In addition, NMR studies (Fannin et al., 1984a) indicate that ion-ion interactions are much weaker in acidic melt than in basic melt. Thus, a solvent with a low relative permittivity such as benzene ($\epsilon_r(20^\circ\text{C}) = 2.28$) may be more effective at disrupting ion-ion interactions in acidic melt than in basic melt, leading to the maximum observed in the plots of κ versus w_1 .

Literature Cited

- Fannin, A. A., Jr.; King, L. A.; Levisky, J. A.; Wilkes, J. S. Properties of 1,3-Dialkylimidazolium Chloride-Aluminum Chloride Ionic Liquids. 1. Ion Interactions by Nuclear Magnetic Resonance Spectroscopy. *J. Phys. Chem.* **1984a**, *88*, 2609–2614.
- Fannin, A. A., Jr.; Floreani, D. A.; King, L. A.; Landers, J. S.; Piersma, B. J.; Stech, D. J.; Vaughn, R. L.; Wilkes, J. S.; Williams, J. L. Properties of 1,2-Dialkylimidazolium Chloride-Aluminum Chloride Ionic Liquids. 2. Phase Transitions, Densities, Electrical Conductivities, and Viscosities. *J. Phys. Chem.* **1984b**, *88*, 2614–2621.
- Juhász, E.; Marsh, K. N. Recommended Reference Materials for Physicochemical Properties: Electrolytic Conductance. *Pure Appl. Chem.* **1981**, *53*, 1841–1845.
- Moy, R.; Emmenegger, F.-P. Co-Solvents for Chloroaluminate Electrolytes. *Electrochim. Acta* **1992**, *37*, 1061–1068.
- Moynihan, C. T. A Low Temperature Fused Salt Experiment. The Conductivity, Viscosity, and Density of Molten Calcium Nitrate Tetrahydrate. *J. Chem. Educ.* **1967**, *44*, 531–535.
- Papageorgiou, N.; Emmenegger, F.-P. The Effect of Cosolvents and Additives on the Electrochemical Properties of $[(\text{Me})_3\text{PhN}][\text{Al}_2\text{Cl}_7]$ Melts. *Electrochim. Acta* **1993**, *38*, 245–252.
- Perry, R. L.; Jones, K. M.; Scott, W. D.; Liao, Q.; Hussey, C. L. Densities, Viscosities, and Conductivities of Mixtures of Selected

- Organic Cosolvents with the Lewis Basic Aluminum Chloride + 1-Methyl-3-ethylimidazolium Chloride Molten Salt. *J. Chem. Eng. Data* **1995**, *40*, 615–619.
- Robinson, J.; Bugle, R. C.; Chum, H. L.; Koran, D.; Osteryoung, R. A. ^1H and ^{13}C Nuclear Magnetic Resonance Spectroscopy Studies of Aluminum Halide-Alkylpyridinium Halide Molten Salts and Their Benzene Mixtures. *J. Am. Chem. Soc.* **1979**, *101*, 3776–3779.
- Sanders, J. R.; Ward, E. H.; Hussey, C. L. Aluminum Bromide-1-Methyl-3-ethylimidazolium Bromide Ionic Liquids I. Densities, Viscosities, Electrical Conductivities, and Phase Transitions. *J. Electrochem. Soc.* **1986**, *133*, 325–328, 1526.
- Wilkes, J. S.; Levisky, J. A.; Wilson, R. A.; Hussey, C. L. Dialkylimidazolium Chloroaluminate Melts: A New Class of Room-Temperature Ionic Liquids for Electrochemistry, Spectroscopy, and Synthesis. *Inorg. Chem.* **1982**, *21*, 1263–1264.
- Zawodzinski, T. A., Jr.; Osteryoung, R. A. Donor-Acceptor Properties of Ambient Temperature Chloroaluminate Melts. *Inorg. Chem.* **1989**, *28*, 1710–1715.

Received for review April 1, 1996. Accepted July 1, 1996.® Support of this research by the National Science Foundation, Grant No. CHE-9411165, is gratefully acknowledged.

JE960123S

® Abstract published in *Advance ACS Abstracts*, August 1, 1996.