Densities, Ultrasonic Velocities, Viscosities, and Electrical Conductivities of Aqueous Solutions of $Mg(OAc)_2$ and $Mg(NO_3)_2$

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The ultrasonic velocities, densities, viscosities, and electrical conductivities of aqueous solutions of magnesium nitrate and magnesium acetate have been measured as functions of concentration ($0.0145 \le m/\text{mol·kg}^{-1} \le 6.545$) and temperature $273.15 \le T/\text{K} \le 323.15$. The results are in reasonable agreement with literature data where comparisons are possible. The viscosity and electrical conductivity data are consistent with greater ion association in $Mg(OAc)_2$ solutions.

Introduction

The behavior of electrolyte solutions is important in many areas of solution chemistry[1] as well as in living cells,[2] seawater,[3] and soils.[4−6] Industrial applications generally involve moderate to very high salt concentrations,[7] so reliable data on physicochemical properties over wide concentration and temperature ranges are desirable.

Densities,[8−10] viscosities,[9,10] and conductivities[11−13] of $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq) available in the literature are quite old and are limited with respect to temperature and concentration ranges. For example, the International Critical Tables of 1921,[11] to the best of our knowledge, is the only readily available source of conductivity data for $Mg(OAc)_2$(aq); while satisfactory values up to $\sim$5.5 mol·kg^{-1} exist at 298.15 K, there are large incremental gaps. For $Mg(NO_3)_2$(aq), the available literature data[12,13] differ by up to 34 %. No viscosity data appear to have been published for $Mg(OAc)_2$(aq), and there have been few reported measurements of speed of sound data for the solutions of either salt.[8,14]

Accordingly, this paper presents a systematic study of the ultrasonic velocities, densities, viscosities, and electrical conductivities of the aqueous solutions of $Mg(NO_3)_2$ and $Mg(OAc)_2$ as functions of concentration and temperature over wide ranges. A detailed interpretation of these results along with molecular dynamics simulations and Raman spectra have been presented elsewhere,[15] so discussion here is deliberately limited.

Experimental Section

$Mg(OAc)_2 \cdot 4H_2O$ (>99 %, SRL, India) and $Mg(NO_3)_2 \cdot 6H_2O$ (>99 %, SD Fine Chemicals, India) were recrystallized twice from double-distilled water and then dried and dehydrated in a vacuum desiccator over P_2O_5 for 2 weeks with replacement of desiccant in between. All solutions were prepared using double-distilled water and by successive dilution by volume of stock solutions. Concentrations were checked by complexometric titration against EDTA[16] and are accurate to within ± 0.3 %.

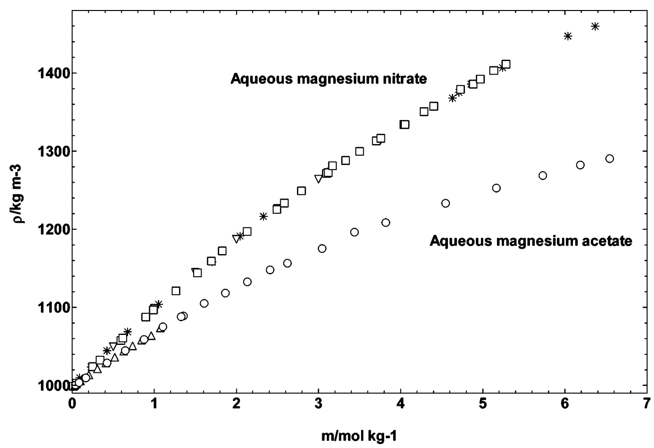

Figure 1. Density isotherms of $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq) as a function of concentration at 298.15 K: ○ and □ present results; △, ref 8; ▽, ref 9; and *, ref 10.

Ultrasonic velocities (u) were determined using a variable path ultrasonic interferometer, M-83 (Mittal Enterprises, India) at 3 MHz. Densities (ρ) of all solutions were measured with a single-stem graduated pycnometer of capacity $\sim$ 9 cm^3. Viscosities (η) were obtained with a Schott-Geräte AVS 310 unit equipped with an Ubbelohde viscometer. Electrical conductivities (κ) were measured using platinised platinum electrodes at a field frequency of 1 kHz with a Precision Component Analyser 6440A (Wayne Kerr, U.K.) employing a four-terminal connection. The cell constant of 1.237 cm^{-1}, with negligible temperature coefficient, was determined by using a 0.1 mol·kg^{-1} aqueous KCl solution at different temperatures.[17] The uncertainties in the ultrasonic velocities, densities, viscosities, and conductivities were estimated to be ± 0.01 %, ± 0.01 %, ± 0.5 %, and ± 0.4 % respectively.

Values of u, ρ, η, and κ for solutions of both salts were measured at temperatures from (273.15 to 323.15) K and concentrations over the range $0.0145 \le m/\text{mol·kg}^{-1} \le 6.545$.

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Table 1. Densities of Aqueous Solutions of Magnesium Acetate and Magnesium Nitrate as Functions of Concentration and Temperature

T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}	T/K	ρ/kg·m^{-3}
$Mg(OAc)_2$(aq)															
0.0414 mol·kg^{-1}		0.0831 mol·kg^{-1}		0.1671 mol·kg^{-1}		0.4247 mol·kg^{-1}		0.6460 mol·kg^{-1}		0.8751 mol·kg^{-1}		1.106 mol·kg^{-1}		1.327 mol·kg^{-1}	
323.15	990.94	324.10	993.76	322.30	1000.8	324.25	1018.8	323.75	1034.3	323.95	1048.7	323.05	1064.8	323.05	1077.2
320.85	991.94	319.40	995.82	320.00	1001.7	322.15	1019.9	321.40	1035.4	319.35	1050.8	320.95	1065.8	318.60	1079.4
318.50	992.99	316.95	996.85	315.20	1003.8	317.10	1021.9	319.15	1036.5	314.30	1052.9	316.05	1068.0	313.45	1081.7
316.25	994.01	314.35	997.91	312.55	1004.8	314.65	1022.9	316.70	1037.6	311.65	1054.0	313.50	1069.1	310.60	1082.8
313.35	995.14	311.85	998.98	309.70	1006.0	312.10	1024.0	314.25	1038.6	308.75	1055.2	310.70	1070.3	307.75	1084.0
310.85	996.10	308.90	1000.0	306.90	1007.0	309.25	1025.2	311.35	1039.6	305.95	1056.2	308.10	1071.4	304.70	1085.2
307.65	997.17	305.95	1001.0	303.30	1008.0	306.30	1026.1	308.65	1040.7	302.55	1057.4	304.95	1072.5	301.35	1086.4
304.45	998.24	302.50	1002.0	299.60	1009.1	302.75	1027.2	305.65	1041.8	298.95	1058.5	301.70	1073.7		
300.85	999.30	298.75	1003.1	295.40	1010.2	299.15	1028.4	302.25	1043.0	295.15	1059.6	298.05	1074.8		
						295.15	1029.4	298.85	1044.0						
1.354 mol·kg^{-1}		1.608 mol·kg^{-1}		1.866 mol·kg^{-1}		2.134 mol·kg^{-1}		2.411 mol·kg^{-1}		2.622 mol·kg^{-1}		3.043 mol·kg^{-1}		3.437 mol·kg^{-1}	
323.65	1078.3	324.05	1093.3	322.85	1107.1	323.95	1120.5	323.05	1135.8	323.50	1143.8	322.15	1162.9	323.75	1181.9
319.10	1080.6	319.50	1095.5	318.20	1109.3	319.50	1122.8	318.60	1138.3	319.25	1146.1	319.95	1164.1	319.65	1184.4
314.05	1082.8	317.15	1096.6	315.85	1110.4	317.30	1124.1	314.10	1140.6	317.05	1147.3	315.65	1166.4	315.25	1186.9
311.40	1083.9	314.70	1097.8	313.45	1111.6	314.75	1125.2	309.10	1142.9	314.85	1148.5	313.50	1167.6	313.15	1188.0
308.65	1085.0	312.15	1099.0	308.05	1114.0	312.45	1126.3	303.75	1145.4	312.55	1149.7	311.25	1168.8	310.85	1189.2
305.85	1086.1	309.60	1100.1	305.50	1115.1	309.80	1127.4	301.00	1146.5	309.95	1151.0	308.75	1170.1	308.70	1190.5
302.70	1087.4	306.55	1101.3	302.40	1116.3	307.25	1128.6	297.95	1147.7	307.50	1152.1	306.40	1171.3	306.40	1191.7
299.65	1088.4	303.65	1102.5	299.30	1117.5	304.55	1129.8	294.90	1149.0	304.80	1153.3	303.75	1172.5	303.90	1193.1
296.00	1089.6	300.60	1103.6	296.10	1118.6	301.55	1131.1			302.05	1154.6	301.05	1173.8	301.50	1194.2
						298.70	1132.2			299.20	1155.8	298.30	1175.0	298.80	1195.5
3.819 mol·kg^{-1}		4.547 mol·kg^{-1}		5.165 mol·kg^{-1}		5.732 mol·kg^{-1}		6.187 mol·kg^{-1}		6.545 mol·kg^{-1}					
325.75	1192.2	323.75	1217.1	324.25	1235.2	324.55	1250.4	328.55	1259.8	325.25	1269.9				
321.70	1194.7	319.95	1219.5	322.45	1236.5	320.85	1253.0	325.15	1262.4	323.45	1271.3				
317.70	1197.2	318.00	1220.8	318.85	1239.0	317.30	1255.6	321.55	1265.1	321.80	1272.5				
315.55	1198.5	314.00	1223.4	315.00	1241.7	313.55	1258.3	317.90	1267.7	319.95	1273.9				
313.45	1199.8	311.90	1224.6	310.95	1244.3	309.70	1260.8	316.05	1269.0	318.25	1275.3				
311.20	1201.0	309.70	1225.9	308.85	1245.6	305.85	1263.4	314.25	1270.4	316.35	1276.6				
308.95	1202.2	307.60	1227.3	306.65	1247.0	303.75	1264.8	312.30	1271.8	314.50	1278.1				
306.75	1203.4	305.35	1228.6	304.60	1248.3	301.75	1266.0	310.45	1273.1	312.70	1279.4				
304.40	1204.7	302.95	1229.9	302.40	1249.6	299.55	1267.4	308.45	1274.5	310.80	1280.7				
302.05	1205.9														
$Mg(NO_3)_2$(aq)															
0.0145 mol·kg^{-1}		0.0528 mol·kg^{-1}		0.2491 mol·kg^{-1}		0.3405 mol·kg^{-1}		0.5931 mol·kg^{-1}		0.6173 mol·kg^{-1}		0.8960 mol·kg^{-1}		0.9898 mol·kg^{-1}	
322.1	989.61	321.95	993.94	322.75	1013.6	320.9	1023.3	321.25	1047.4	323.4	1049.0	318.4	1077.9	323.95	1084.0
319.95	990.65	319.55	994.98	320.65	1014.7	315.95	1025.4	318.9	1048.4	319.05	1051.1	316.1	1079.0	321.75	1085.2
315.0	992.80	317.15	995.93	317.85	1016.9	313.7	1026.4	314.45	1050.6	316.75	1052.2	313.8	1080.2	317.5	1087.3
312.45	993.76	314.7	996.94	313.45	1017.9	308.55	1028.5	309.5	1052.8	314.45	1053.3	311.55	1081.3	315.25	1088.5
309.5	994.82	312.25	997.99	310.8	1019.0	305.85	1029.6	306.65	1054.0	312.1	1054.3	309.0	1082.4	310.7	1090.8
306.45	995.89	309.6	999.02	307.95	1020.1	302.55	1030.8	303.85	1055.1	309.5	1055.5	306.5	1083.6	308.35	1091.9
303.05	996.95	303.25	1001.1	305.0	1021.1	299.6	1031.8	300.95	1056.2	307.05	1056.6	303.9	1084.7	305.8	1093.0
299.15	998.05	299.35	1002.2	301.6	1022.3	295.75	1032.9	297.65	1057.4	304.15	1057.7	300.9	1085.9	300.5	1095.4
												318.4	1077.9		
1.262 mol·kg^{-1}		1.525 mol·kg^{-1}		1.694 mol·kg^{-1}		1.827 mol·kg^{-1}		2.131 mol·kg^{-1}		2.493 mol·kg^{-1}		2.584 mol·kg^{-1}		2.793 mol·kg^{-1}	
323.75	1107.8	323.5	1130.6	324.95	1144.5	324.25	1157.4	323.95	1182.5	321.6	1211.3	322.35	1219.2	322.25	1234.5
319.55	1110.2	319.35	1132.8	320.85	1146.9	320.3	1159.7	319.9	1184.8	317.35	1213.8	318.35	1221.6	320.25	1235.8
317.5	1111.2	317.25	1134.0	318.7	1148.1	318.15	1160.9	317.75	1186.0	313.5	1216.4	314.25	1224.2	316.1	1238.2
315.25	1112.4	315.05	1135.2	314.5	1150.4	316.15	1162.1	313.6	1188.5	309.3	1218.8	309.9	1226.7	314.1	1239.5
313.1	1113.5	312.95	1136.3	312.15	1151.6	311.75	1164.7	311.25	1189.9	305.05	1221.3	307.6	1228.1	312.15	1240.8
310.95	1114.7	308.4	1138.7	310.1	1152.8	309.65	1165.8	309.25	1191.0	302.55	1222.7	305.35	1229.4	307.8	1243.4
308.45	1116.0	305.95	1139.9	307.9	1154.0	307.25	1167.0	304.55	1193.6	300.35	1223.9	303.1	1230.7	305.5	1244.7
303.55	1118.2	303.5	1141.2	305.3	1155.3	305.0	1168.3	302.25	1194.8	298.1	1225.2	300.75	1232.0	303.1	1246.1
300.95	1119.4	301.1	1142.4	303.1	1156.4	302.6	1169.5	299.75	1196.1					300.95	1247.4
3.096 mol·kg^{-1}		3.118 mol·kg^{-1}		3.170 mol·kg^{-1}		3.501 mol·kg^{-1}		3.704 mol·kg^{-1}		3.757 mol·kg^{-1}		4.039 mol·kg^{-1}		4.051 mol·kg^{-1}	
321.35	1257.2	323.6	1256.7	323.55	1265.4	317.15	1287.7	322.45	1297.7	323.5	1300.1	322.45	1318.2	322.75	1318.5
317.25	1259.7	319.45	1259.2	319.5	1268.1	315.1	1288.9	318.25	1300.4	319.35	1302.8	320.3	1319.5	318.15	1321.2
313.15	1262.3	317.55	1260.5	315.3	1270.8	311.0	1291.7	314.15	1303.0	317.35	1304.1	316.25	1322.3	313.8	1324.0
310.9	1263.8	313.25	1263.3	311.05	1273.3	306.65	1294.4	309.95	1305.7	315.15	1305.4	311.9	1325.0	309.4	1326.7
308.85	1265.0	311.2	1264.5	306.8	1276.0	304.35	1295.8	307.7	1307.2	311.0	1308.1	307.45	1327.9	305.2	1329.4
306.5	1266.4	308.95	1265.8	302.25	1278.7	302.1	1297.2	305.55	1308.4	308.75	1309.6	305.25	1329.3	300.85	1332.2
304.25	1267.7	306.7	1267.2	300.1	1280.0	299.8	1298.5	303.3	1309.8	306.7	1310.9	302.95	1330.8	298.5	1333.6
302.1	1269.1	304.55	1268.5	297.9	1281.3	297.5	1299.9	301.05	1311.3	304.35	1312.3	300.75	1332.1		
4.285 mol·kg^{-1}		4.403 mol·kg^{-1}		4.728 mol·kg^{-1}		4.883 mol·kg^{-1}		4.970 mol·kg^{-1}		5.134 mol·kg^{-1}		5.282 mol·kg^{-1}			
321.8	1335.1	323.05	1341.3	321.9	1363.5	322.2	1370.0	322.8	1375.7	324.45	1385.4	325.25	1393.7		
317.55	1337.9	318.8	1344.0	319.9	1364.8	317.95	1372.7	318.5	1378.6	320.2	1388.4	323.15	1395.1		
313.25	1340.7	314.5	1346.8	315.6	1367.6	313.7	1375.5	316.35	1380.1	315.8	1391.1	320.9	1396.6		
308.85	1343.6	312.4	1348.2	311.25	1370.6	311.45	1377.1	312.0	1382.9	311.35	1394.0	318.8	1398.1		
304.55	1346.2	310.15	1349.7	309.05	1371.9	309.35	1378.4	309.75	1384.3	306.7	1397.0	316.45	1399.6		
302.4	1347.6	308.1	1351.0	306.75	1373.4	307.05	1379.9	307.65	1385.7	302.95	1399.9	314.15	1401.1		
300.3	1349.0	303.5	1353.9	304.55	1374.9	304.8	1381.4	303.15	1388.7	300.5	1401.4	311.95	1402.5		
297.85	1350.5	301.25	1355.4	302.3	1376.3	302.6	1382.9	301.0	1390.1	298.2	1402.9	308.7	1404.1		
				299.95	1377.8	300.15	1384.4			296.0	1404.4				

Table 2. Ultrasonic Velocities of Aqueous Solutions of Magnesium Acetate and Magnesium Nitrate as Functions of Concentration and Temperature

T/K	u/m·s^{-1}							
	$Mg(OAc)_2$(aq)							
	0.0414 mol·kg^{-1}	0.0831 mol·kg^{-1}	0.1671 mol·kg^{-1}	0.4247 mol·kg^{-1}	0.6460 mol·kg^{-1}	0.8751 mol·kg^{-1}	1.106 mol·kg^{-1}	1.354 mol·kg^{-1}
273.15	1411.1	1421.7	1435.8	1486.1	1523.6	1563.5	1599.6	1633.9
278.15	1433.9	1443.6	1458.6	1504.5	1539.4	1571.6	1611.8	1644.1
283.15	1453.9	1464.2	1477.0	1522.7	1553.8	1584.2	1622.1	1651.4
288.15	1471.7	1481.5	1494.1	1535.1	1566.5	1601.1	1631.4	1659.4
293.15	1487.6	1497.5	1508.3	1545.4	1577.8	1609.8	1639.8	1665.7
298.15	1501.7	1510.4	1520.6	1556.9	1587.3	1616.2	1645.9	1671.1
303.15	1513.4	1521.5	1532.2	1567.4	1595.7	1625.4	1651.6	1676.1
308.15	1523.3	1530.3	1541.4	1575.1	1601.9	1631.2	1655.9	1677.9
313.15	1532.2	1539.0	1547.7	1582.3	1607.4	1635.6	1659.1	1679.3
318.15	1539.3	1546.0	1552.2	1587.9	1613.4	1638.1	1661.5	1683.6
323.15	1544.5	1549.2	1557.7	1591.1	1615.2	1637.7	1662.2	1683.9
	1.608 mol·kg^{-1}	1.866 mol·kg^{-1}	2.134 mol·kg^{-1}	2.411 mol·kg^{-1}	2.622 mol·kg^{-1}	3.043 mol·kg^{-1}	3.437 mol·kg^{-1}	3.819 mol·kg^{-1}
273.15	1670.3	1705.9	1742.2	1777.1	1797.1	1840.9	1885.2	1910.1
278.15	1679.6	1713.0	1746.8	1780.1	1799.2	1839.8	1881.6	1903.6
283.15	1685.9	1718.2	1750.4	1781.4	1799.1	1838.2	1877.4	1897.9
288.15	1692.8	1722.3	1752.7	1782.9	1799.1	1835.6	1872.2	1891.9
293.15	1697.3	1725.6	1754.5	1782.6	1798.8	1832.8	1866.8	1884.3
298.15	1700.3	1727.7	1754.6	1781.9	1797.3	1829.5	1861.2	1878.0
303.15	1703.0	1728.9	1755.5	1781.3	1795.2	1824.8	1855.5	1870.5
308.15	1705.0	1728.9	1754.2	1782.5	1791.3	1819.5	1847.8	1862.6
313.15	1704.6	1728.4	1752.5	1778.6	1787.1	1815.0	1840.3	1854.1
318.15	1705.8	1727.8	1749.8	1773.8	1782.8	1808.1	1832.0	1846.6
323.15	1703.7	1725.0	1746.5	1767.3	1778.6	1800.3	1825.0	1837.4
	4.547 mol·kg^{-1}	5.165 mol·kg^{-1}	5.732 mol·kg^{-1}					
273.15	1953.7							
278.15	1945.3							
283.15	1936.1	1964.1						
288.15	1927.4	1953.3						
293.15	1917.4	1940.8	1954.7					
298.15	1908.0	1929.7	1940.2					
303.15	1899.1	1919.0	1926.8					
308.15	1888.8	1908.0	1914.4					
313.15	1878.9	1896.0	1920.2					
318.15	1868.1	1882.7	1888.5					
323.15	1857.2	1871.0	1874.6					
	$Mg(NO_3)_2$(aq)							
	0.0145 mol·kg^{-1}	0.0528 mol·kg^{-1}	0.2491 mol·kg^{-1}	0.3405 mol·kg^{-1}	0.6173 mol·kg^{-1}	0.8960 mol·kg^{-1}	0.9898 mol·kg^{-1}	1.262 mol·kg^{-1}
273.15	1410.5	1415.6	1430.4	1443.0	1469.3	1498.6	1510.3	1538.0
278.15	1434.8	1438.7	1451.6	1456.8	1486.9	1514.8	1524.8	1551.3
283.15	1449.2	1458.5	1470.7	1475.6	1503.7	1529.0	1538.8	1563.1
288.15	1471.7	1477.1	1487.6	1491.5	1517.8	1541.2	1550.4	1573.8
293.15	1484.3	1486.7	1501.9	1507.0	1530.1	1553.1	1561.5	1582.5
298.15	1498.3	1500.5	1514.9	1519.0	1540.9	1563.0	1570.8	1590.0
303.15	1509.5	1511.9	1526.5	1529.9	1550.7	1571.2	1578.7	1596.4
308.15	1520.8	1522.6	1536.2	1539.2	1559.2	1578.7	1585.6	1602.4
313.15	1532.2	1531.9	1544.5	1546.0	1566.4	1584.7	1591.3	1607.1
318.15	1540.2	1541.4	1554.4	1552.3	1572.0	1590.0	1596.3	1612.6
323.15	1545.7	1548.0	1559.2	1563.6	1576.6	1593.9	1600.3	1614.9
	1.525 mol·kg^{-1}	1.827 mol·kg^{-1}	2.131 mol·kg^{-1}	2.493 mol·kg^{-1}	2.793 mol·kg^{-1}	3.118 mol·kg^{-1}	3.170 mol·kg^{-1}	3.501 mol·kg^{-1}
273.15	1566.3	1600.5	1632.0	1664.6	1693.2	1721.2	1730.6	1752.4
278.15	1577.1	1610.1	1639.7	1670.1	1696.9	1723.7	1733.0	1753.7
283.15	1587.6	1617.9	1645.2	1675.2	1700.3	1725.7	1734.2	1754.9
288.15	1596.3	1625.4	1650.6	1677.8	1703.5	1727.3	1735.3	1755.4
293.15	1604.4	1631.9	1656.3	1682.1	1705.3	1728.1	1736.5	1755.4
298.15	1611.1	1637.3	1660.5	1685.3	1706.5	1728.8	1736.6	1754.6
303.15	1617.0	1641.0	1663.8	1686.8	1708.1	1729.1	1736.9	1753.9
308.15	1621.7	1644.8	1666.7	1688.0	1708.9	1728.7	1735.9	1752.2
313.15	1625.9	1647.8	1667.8	1688.9	1709.0	1728.1	1734.7	1751.2
318.15	1629.5	1650.5	1668.7	1689.3	1708.7	1727.2	1733.9	1748.8
323.15	1631.4	1651.2	1667.3	1689.2	1707.5	1725.2	1731.8	1744.0
	3.757 mol·kg^{-1}	4.051 mol·kg^{-1}	4.285 mol·kg^{-1}	4.403 mol·kg^{-1}	4.883 mol·kg^{-1}	5.134 mol·kg^{-1}		
273.15	1771.9	1791.3	1808.5	1820.2				
278.15	1772.4	1791.4	1807.3	1815.4				
283.15	1771.9	1790.4	1806.3	1813.5	1847.2			
288.15	1771.3	1789.6	1804.5	1810.8	1842.3			
293.15	1771.3	1787.5	1802.4	1809.3	1838.8			
298.15	1774.2	1786.2	1800.3	1806.6	1831.8	1855.2		
303.15	1772.5	1783.6	1797.4	1804.5	1830.6	1842.9		
308.15	1770.5	1781.1	1794.4	1800.6	1826.2	1838.4		
313.15	1767.8	1778.4	1791.3	1797.9	1823.1	1834.3		
318.15	1761.7	1776.0	1787.8	1794.4	1818.4	1832.8		
323.15	1758.7	1770.9	1783.2	1789.3	1811.5	1828.2		

Table 3. Viscosities of Aqueous Solutions of Magnesium Acetate and Magnesium Nitrate as Functions of Concentration and Temperature

T/K	η/mPa·s						
				$Mg(OAc)_2(aq)$			
	0.0414 mol·kg^{-1}	0.0831 mol·kg^{-1}	0.1671 mol·kg^{-1}	0.4247 mol·kg^{-1}	0.6460 mol·kg^{-1}	0.8751 mol·kg^{-1}	1.106 mol·kg^{-1}
273.15	1.895	1.974	2.142	2.763	3.520	4.302	5.537
278.15	1.603	1.663	1.805	2.301	2.887	3.533	4.511
283.15	1.374	1.423	1.540	1.954	2.444	2.956	3.725
288.15	1.196	1.238	1.335	1.677	2.072	2.499	3.138
293.15	1.052	1.089	1.170	1.461	1.788	2.150	2.678
298.15	0.9322	0.9640	1.034	1.286	1.566	1.873	2.310
303.15	0.8350	0.8624	0.9234	1.141	1.383	1.640	2.014
308.15	0.7529	0.7775	0.8306	1.021	1.231	1.450	1.774
313.15	0.6835	0.7037	0.7523	0.9195	1.105	1.294	1.573
318.15	0.6244	0.6418	0.6857	0.8341	0.9967	1.163	1.405
323.15	0.5741	0.5893	0.6282	0.7596	0.9059	1.052	1.271
	1.354 mol·kg^{-1}	1.608 mol·kg^{-1}	1.866 mol·kg^{-1}	2.134 mol·kg^{-1}	2.411 mol·kg^{-1}	2.622 mol·kg^{-1}	3.043 mol·kg^{-1}
273.15	7.125	9.270	12.12	16.35	23.36	28.17	45.46
278.15	5.709	7.376	9.522	12.57	17.59	21.20	33.22
283.15	4.687	5.959	7.615	9.905	13.67	16.25	24.92
288.15	3.895	4.919	6.192	8.005	10.80	12.79	19.07
293.15	3.294	4.125	5.143	6.573	8.745	10.25	14.98
298.15	2.821	3.504	4.320	5.472	7.183	8.354	12.02
303.15	2.446	3.011	3.688	4.619	6.056	6.928	9.798
308.15	2.139	2.631	3.181	3.943	5.121	5.819	8.110
313.15	1.887	2.304	2.771	3.404	4.373	4.948	6.797
318.15	1.679	2.027	2.437	2.967	3.777	4.254	5.774
323.15	1.503	1.804	2.166	2.610	3.295	3.695	4.961
	3.437 mol·kg^{-1}	4.001 mol·kg^{-1}	4.563 mol·kg^{-1}	4.929 mol·kg^{-1}	5.410 mol·kg^{-1}	5.732 mol·kg^{-1}	6.187 mol·kg^{-1}
273.15	85.35	167.7	374.7				
278.15	59.47	110.6	234.4				
283.15	43.12	77.03	153.7	208.4			
288.15	31.95	55.77	105.5	140.3			
293.15	24.40	41.34	75.04	97.76			
298.15	19.05	31.38	55.00	70.36	141.2		
303.15	15.20	24.27	41.02	51.77	99.40	135.8	
308.15	12.30	19.17	31.43	39.25	72.56	96.97	175.6
313.15	10.13	15.43	24.53	30.41	54.06	71.46	120.0
318.15	8.453	12.63	19.60	24.03	41.38	53.77	87.61
323.15	7.136	10.52	15.97	19.29	32.16	41.44	65.72
				$Mg(NO_3)_2(aq)$			
	0.0145 mol·kg^{-1}	0.0528 mol·kg^{-1}	0.2491 mol·kg^{-1}	0.5931 mol·kg^{-1}	0.9898 mol·kg^{-1}	1.262 mol·kg^{-1}	1.827 mol·kg^{-1}
273.15	1.852	1.874	1.958	2.122	2.391	2.659	3.232
278.15	1.556	1.580	1.654	1.805	2.047	2.268	2.765
283.15	1.339	1.357	1.429	1.564	1.775	1.971	2.400
288.15	1.164	1.180	1.244	1.367	1.554	1.727	2.098
293.15	1.021	1.038	1.092	1.209	1.378	1.530	1.859
298.15	0.9075	0.9227	0.9713	1.079	1.232	1.366	1.662
303.15	0.8115	0.8250	0.8716	0.9679	1.112	1.228	1.493
308.15	0.7364	0.7450	0.7877	0.8757	1.005	1.110	1.342
313.15	0.6666	0.6778	0.7155	0.7972	0.9130	1.008	1.305
318.15	0.6082	0.6200	0.6550	0.7284	0.8367	0.9225	1.117
323.15	0.5591	0.5708	0.6023	0.6703	0.7676	0.8482	1.028
	2.131 mol·kg^{-1}	2.584 mol·kg^{-1}	3.096 mol·kg^{-1}	3.329 mol·kg^{-1}	3.704 mol·kg^{-1}	4.039 mol·kg^{-1}	4.403 mol·kg^{-1}
273.15	3.587	4.348	5.355	5.964	6.966	8.210	9.677
278.15	3.062	3.696	4.538	5.056	5.857	6.897	8.051
283.15	2.663	3.207	3.946	4.336	5.020	5.864	6.845
288.15	2.330	2.821	3.408	3.754	4.345	5.051	6.038
293.15	2.064	2.471	3.002	3.308	3.807	4.432	5.111
298.15	1.842	2.206	2.665	2.921	3.367	3.889	4.493
303.15	1.654	1.969	2.380	2.611	2.998	3.462	3.977
308.15	1.498	1.777	2.146	2.343	2.692	3.089	3.555
313.15	1.364	1.616	1.947	2.128	2.435	2.798	3.199
318.15	1.245	1.473	1.772	1.935	2.216	2.545	2.895
323.15	1.145	1.353	1.629	1.772	2.028	2.319	2.641
	4.728 mol·kg^{-1}	4.970 mol·kg^{-1}	5.282 mol·kg^{-1}				
273.15	11.85						
278.15	9.740						
283.15	8.233						
288.15	7.067	7.798					
293.15	6.098	6.799					
298.15	5.349	5.933	7.034				
303.15	4.730	5.225	6.141				
308.15	4.262	4.654	5.506				
313.15	3.817	4.176	4.924				
318.15	3.456	3.760	4.426				
323.15	3.107	3.418	3.975				

Table 4. Least-Squares Fitted Values of the Parameters of Equation 2 for $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq) Systems

T/K	$\ln a_0$ mPa·s	b_0 mPa·s·kg·mol^{-1}	c_0 mPa·s·kg^2·mol^{-2}	SD in ln η
		$Mg(OAc)_2$(aq)		
273.15	0.6167 ± 0.0189	0.9121 ± 0.0283	0.0534 ± 0.0084	0.0333
298.15	−0.1013 ± 0.0151	0.8178 ± 0.0160	0.0157 ± 0.0033	0.0296
323.15	−0.5541 ± 0.0206	0.6747 ± 0.0169	0.0133 ± 0.0026	0.0436
		$Mg(NO_3)_2$(aq)		
273.15	0.6060 ± 0.0063	0.2553 ± 0.0069	0.0289 ± 0.0015	0.0113
298.15	−0.0984 ± 0.0063	0.2962 ± 0.0061	0.0166 ± 0.0011	0.0116
323.15	−0.5810 ± 0.0056	0.3099 ± 0.0054	0.0109 ± 0.0010	0.0103

Schott-Geräte CT 1450 or Julabo F32 HP thermostats were used to control solution temperatures to ± 0.02 K.

Results and Discussion

Densities. The measured densities (ρ) of the aqueous solutions of $Mg(OAc)_2$ and $Mg(NO_3)_2$ (Table 1) were found to vary linearly with temperature at a fixed concentration. The density isotherms for both salts at 298.15 K are depicted in Figure 1 and agree to within ± 0.4 % with literature data[8−10] for both systems.

Ultrasonic Velocities. The experimental ultrasonic velocities (u) in $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq) are given as functions of temperature and concentration in Table 2. Where comparison was possible, at 298.15 K, the data were comparable to within ± 0.2 % with literature values.[8,14] Plots of $(u - u_0)/m$ versus $m^{1/2}$ at 298.15 K (not shown), where u_0 is the ultrasonic velocity in pure water, exhibit a maximum at ~0.3 and ~2.0 mol kg^{-1} for $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq), respectively, similar to those observed for other inorganic salt solutions.[18,19] Such maxima are due to the transition from free hydrated ions to solvent-shared ion pairs or the formation of ion clusters.[15,18]

Isentropic compressibilities, κ_s $(= (u^2\rho)^{-1})$ of $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq) derived from the sound velocities and solution densities are plotted against concentration at 298.15 K in Figure 2. An empirical equation[19,20]

$$\kappa_s = a_1 + b_1 m + c_1 m^{1.5} + d_1 m^2 + e_1 m^{2.5} + f_1 m^3 \qquad (1)$$

was used to describe the κ_s isotherms, where a_1, b_1, c_1, d_1, e_1, and f_1 are temperature-dependent parameters, and m is the concentration in mol·kg^{-1}. The numerical values of these parameters are reported elsewhere.[15]

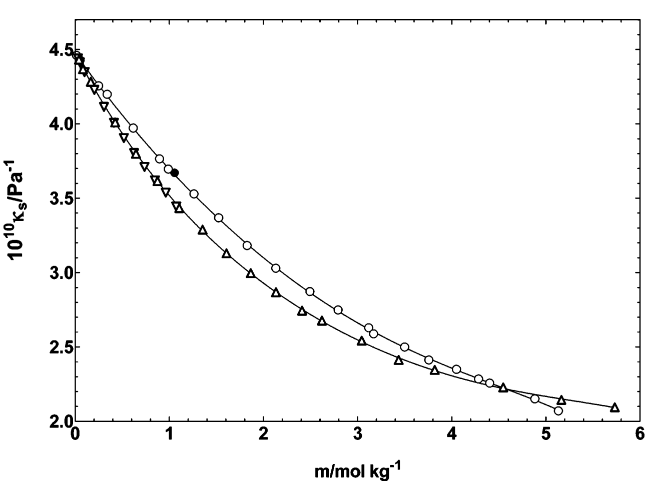

Figure 2. Present results for the isentropic compressibilities of aqueous solutions of $Mg(OAc)_2$ (open triangles) and $Mg(NO_3)_2$ (open circles) as a function of concentration at 298.15 K. Solid curves are calculated from eq 1. Literature data: ▽, ref 8; ●, ref 14.

The isentropic compressibility of $Mg(OAc)_2$(aq) at any given concentration up to ~4.6 mol·kg^{-1} is lower than that of $Mg(NO_3)_2$(aq) (Figure 2). As discussed elsewhere,[15] this implies that OAc^- is more efficient in influencing the water molecules in its immediate vicinity than NO_3^-. At higher concentrations, > 4.5 mol·kg^{-1}, the κ_s isotherm of $Mg(NO_3)_2$(aq) crosses over that of $Mg(OAc)_2$(aq), suggesting a strong ion pair formation resulting in more rigid structure with lesser compressibility in the former.

Viscosity. The measured viscosities (η) of aqueous solutions of $Mg(OAc)_2$ and $Mg(NO_3)_2$ at different concentrations and temperatures are given in Table 3; isotherms are depicted in Figure 3. The present viscosities for $Mg(NO_3)_2$(aq) at 298.15 K are comparable to within ± 5 % with literature values.[9,10] For $Mg(OAc)_2$(aq), no previous viscosity data to the best of

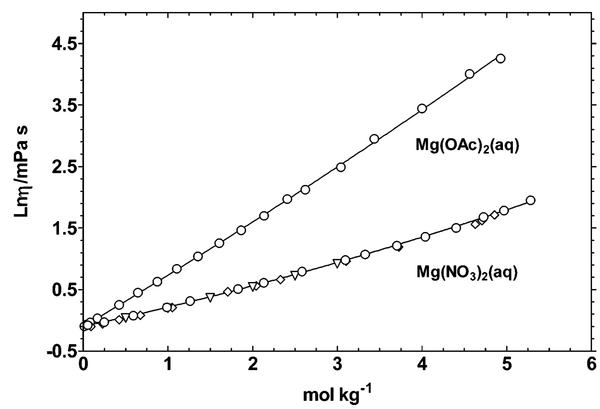

Figure 3. Variation of viscosity with concentration for aqueous solutions of $Mg(OAc)_2$ (open symbols) and $Mg(NO_3)_2$ (solid symbols) at 298.15 K; ▽, ref 9; ◇, ref 10.

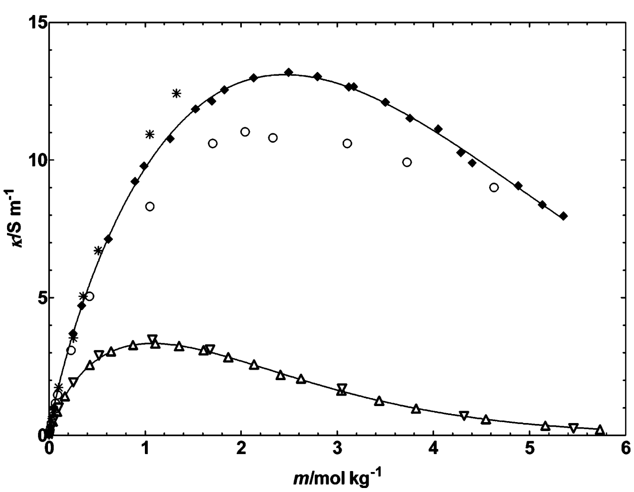

Figure 4. Variation of the present electrical conductivities with concentration for aqueous solutions of $Mg(OAc)_2$ (open triangles) and $Mg(NO_3)_2$ (solid diamonds) at 298.15 K. Literature data: ▽, ref 11; ×, ref 12; ○, ref 13.

Table 5. Electrical Conductivities of Aqueous Solutions of Magnesium Acetate and Magnesium Nitrate as Functions of Concentration and Temperature

T/K	κ/S·m^{-1}							
	$Mg(OAc)_2$(aq)							
	0.0414 mol·kg^{-1}	0.0831 mol·kg^{-1}	0.1671 mol·kg^{-1}	0.4247 mol·kg^{-1}	0.6460 mol·kg^{-1}	0.8751 mol·kg^{-1}	1.106 mol·kg^{-1}	1.354 mol·kg^{-1}
273.15	0.2574	0.4452	0.7388	1.306	1.531	1.615	1.590	1.496
278.15	0.3011	0.5225	0.8632	1.532	1.810	1.914	1.899	1.801
283.15	0.3482	0.6030	0.9947	1.776	2.100	2.233	2.237	2.135
288.15	0.3968	0.6870	1.134	2.028	2.411	2.573	2.584	2.493
293.15	0.4473	0.7717	1.276	2.288	2.727	2.922	2.951	2.862
298.15	0.5001	0.8612	1.422	2.556	3.054	3.281	3.331	3.248
303.15	0.5540	0.9531	1.574	2.828	3.384	3.648	3.722	3.644
308.15	0.6094	1.047	1.727	3.103	3.724	4.025	4.114	4.050
313.15	0.6656	1.142	1.881	3.378	4.064	4.405	4.516	4.463
318.15	0.7221	1.235	2.036	3.652	4.406	4.779	4.919	4.887
323.15	0.7785	1.332	2.192	3.924	4.748	5.155	5.318	5.305
	1.608 mol·kg^{-1}	1.866 mol·kg^{-1}	2.134 mol·kg^{-1}	2.411 mol·kg^{-1}	2.622 mol·kg^{-1}	3.043 mol·kg^{-1}	3.437 mol·kg^{-1}	3.819 mol·kg^{-1}
273.15	1.370	1.206	1.039	0.8363	0.7557	0.5375	0.3812	0.2662
278.15	1.666	1.485	1.293	1.053	0.9618	0.7035	0.5088	0.3637
283.15	1.997	1.787	1.582	1.306	1.200	0.8967	0.6629	0.4832
288.15	2.343	2.122	1.893	1.576	1.523	1.115	0.8466	0.6244
293.15	2.710	2.470	2.224	1.876	1.826	1.360	1.049	0.7878
298.15	3.093	2.836	2.579	2.199	2.061	1.630	1.262	0.9737
303.15	3.493	3.214	2.948	2.540	2.388	1.922	1.504	1.180
308.15	3.900	3.615	3.328	2.899	2.734	2.233	1.770	1.407
313.15	4.315	4.026	3.723	3.272	3.092	2.559	2.052	1.653
318.15	4.732	4.444	4.120	3.653	3.460	2.896	2.347	1.911
323.15	5.153	4.827	4.528	4.053	3.834	3.234	2.651	2.182
	4.547 mol·kg^{-1}	5.165 mol·kg^{-1}	5.732 mol·kg^{-1}	6.187 mol·kg^{-1}	6.545 mol·kg^{-1}			
273.15	0.1317	0.0601						
278.15	0.1881	0.0925						
283.15	0.2639	0.1364						
288.15	0.3547	0.1930	0.1089					
293.15	0.4634	0.2648	0.1547					
298.15	0.5891	0.3528	0.2126					
303.15	0.7353	0.4571	0.2822	0.1846				
308.15	0.9039	0.5801	0.3672	0.2472				
313.15	1.089	0.7180	0.4677	0.3223				
318.15	1.290	0.8715	0.5803	0.4094				
323.15	1.503	1.036	0.7088	0.5105	0.4031			
	$Mg(NO_3)_2$(aq)							
	0.0145 mol·kg^{-1}	0.0528 mol·kg^{-1}	0.2491 mol·kg^{-1}	0.3405 mol·kg^{-1}	0.6173 mol·kg^{-1}	0.8960 mol·kg^{-1}	0.9898 mol·kg^{-1}	1.262 mol·kg^{-1}
273.15	0.1698	0.5571	2.109	2.731	4.159	5.437	5.788	6.413
278.15	0.1954	0.6397	2.405	3.109	4.721	6.150	6.542	7.238
283.15	0.2216	0.7260	2.713	3.498	5.298	6.884	7.321	8.096
288.15	0.2491	0.8146	3.028	3.897	5.907	7.641	8.115	8.964
293.15	0.2779	0.9062	3.358	4.285	6.500	8.421	8.942	9.864
298.15	0.3078	1.001	3.700	4.710	7.134	9.221	9.783	10.78
303.15	0.3386	1.098	4.045	5.140	7.765	10.02	10.63	11.70
308.15	0.3699	1.197	4.391	5.576	8.409	10.82	11.49	12.63
313.15	0.4019	1.297	4.748	6.017	9.056	11.66	12.36	14.55
318.15	0.4343	1.398	5.102	6.463	9.702	12.46	13.21	14.47
323.15	0.4666	1.496	5.448	6.915	10.33	13.25	14.04	15.45
	1.525 mol·kg^{-1}	1.694mol·kg^{-1}	1.827 mol·kg^{-1}	2.131 mol·kg^{-1}	2.493 mol·kg^{-1}	2.793 mol·kg^{-1}	3.118 mol·kg^{-1}	3.170 mol·kg^{-1}
273.15	7.008	7.195	7.549	7.734	7.767	7.599	7.280	7.242
278.15	7.926	8.126	8.434	8.733	8.794	8.625	8.293	8.257
283.15	8.881	9.085	9.438	9.762	9.852	9.681	9.339	9.301
288.15	9.845	10.07	10.46	10.81	10.95	10.78	10.41	10.40
293.15	10.85	11.07	11.49	11.89	12.06	11.90	11.51	11.53
298.15	11.86	12.14	12.55	12.99	13.19	13.04	12.66	12.67
303.15	12.91	13.13	13.64	14.10	14.34	14.34	13.80	13.84
308.15	13.94	14.17	14.69	15.22	15.49	15.34	14.94	14.99
313.15	14.99	15.21	15.76	16.33	16.62	16.49	16.09	16.17
318.15	16.05	16.29	16.83	17.44	17.78	17.64	17.24	17.33
323.15	17.12	17.61	17.89	18.58	18.88	18.79	18.36	18.44
	3.501 mol·kg^{-1}	3.757 mol·kg^{-1}	4.051 mol·kg^{-1}	4.285 mol·kg^{-1}	4.403 mol·kg^{-1}	4.883 mol·kg^{-1}	5.134 mol·kg^{-1}	5.352 mol·kg^{-1}
273.15	6.857	6.435	6.131	5.576	5.399	4.737		
278.15	7.835	7.386	7.054	6.443	6.222	5.524		
283.15	8.850	8.372	8.026	7.347	7.093	6.358		
288.15	9.893	9.382	9.028	8.290	8.001	7.225	6.621	
293.15	10.98	10.44	10.06	9.277	8.933	8.133	7.482	
298.15	12.10	11.52	11.13	10.28	9.898	9.066	8.376	7.970
303.15	13.21	12.61	12.20	11.30	10.87	10.02	9.283	8.848
308.15	14.35	13.70	13.27	12.33	11.87	10.99	10.20	9.740
313.15	15.49	14.81	14.37	13.37	12.87	11.98	11.13	10.65
318.15	16.59	15.90	15.45	14.43	13.87	12.99	12.07	11.57
323.15	17.63	16.97	16.50	15.47	15.07	13.91	12.99	12.47

Table 6. Least-Squares Fitted Values of the Parameters of Equation 3 for $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq) at Different Temperatures

T/K	κ_{max}/S·m^{-1}	μ/mol·kg^{-1}	a	$10^{-3}b$/kg^2·mol^{-2}	SD in κ
		$Mg(OAc)_2$(aq)			
273.15	1.616 ± 0.004	0.935 ± 0.005	0.832 ± 0.010	−0.048 ± 0.004	0.009
298.15	3.344 ± 0.009	1.078 ± 0.006	0.811 ± 0.011	−0.025 ± 0.003	0.021
323.15	5.351 ± 0.012	1.199 ± 0.006	0.786 ± 0.009	−0.012 ± 0.002	0.029
		$Mg(NO_3)_2$(aq)			
273.15	7.730 ± 0.025	2.347 ± 0.015	0.857 ± 0.025	−0.032 ± 0.025	0.066
298.15	13.10 ± 0.040	2.454 ± 0.017	0.840 ± 0.022	−0.021 ± 0.002	0.112
323.15	18.84 ± 0.05	2.513 ± 0.015	0.835 ± 0.017	−0.014 ± 0.002	0.130

our knowledge have been reported in wide concentration and temperature ranges.

Horvath[21] has reviewed the available theoretical and empirical equations for describing viscosity isotherms of electrolyte solutions. A semiempirical equation

$$\eta = a_0 \exp(b_0 m + c_0 m^2) \tag{2}$$

where a_0, b_0, and c_0 are adjustable temperature-dependent parameters has been shown to be useful over wide concentration ranges.[10,21−23]

It is apparent from Table 4 and Figure 3 that eq 2 adequately fits the viscosity data of $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq). The value of a_0 corresponds to the viscosity at infinite dilution but is ∼1.0 to 5.0 % higher than that of pure water at the corresponding temperature due to the extrapolation from higher concentrations. The noteworthy point is the higher value (∼2 to 4 times) of b_0 for $Mg(OAc)_2$(aq) compared with $Mg(NO_3)_2$(aq) over the temperature range studied. This probably reflects the higher ion−solvent interactions in the former. It has been shown[22] that the product of a_0 and b_0 yields the Jones−Dole viscosity B-coefficient. For $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq), the present results give 0.74 and 0.28, respectively, at 298.15 K, which are roughly comparable (∼18 % deviation) with the reported values.[24] In $Mg(OAc)_2$(aq), b_0 decreases with increasing temperature. This trend is the reverse in $Mg(NO_3)_2$(aq), again reflecting, most probably, the difference in ion associations or ion clusters formation in the two aqueous systems.[15]

Electrical Conductivity. The measured values of the electrical conductivity (κ) of $Mg(OAc)_2$(aq) and $Mg(NO_3)_2$(aq) are tabulated in Table 5. The present values are ∼3 to 6 %[11] and ∼16 %,[12,13] respectively, lower or higher than the literature values at 298.15 K. The sources of these discrepancies are not known. The present results employing four-terminal connections and a higher quality bridge should be more reliable.

Theoretical and empirical expressions for describing electrical conductivities over wide concentration ranges are limited.[7,13,25] The Casteel−Amis equation[26,27]

$$\kappa = \kappa_{max}(m/\mu)^a \exp[b(m-\mu)^2 - a(m-\mu)/\mu] \tag{3}$$

where μ is the concentration corresponding to the maximum conductivity κ_{max} at a given temperature, a and b are empirical parameters, and m is concentration in mol·kg^{-1} has been widely used. The least-squares fitted values of the parameters of eq 3 are summarized in Table 6.

From Figure 4, it is apparent that the variations of the conductivity isotherms with concentration for the two systems are quite different. The lower κ for $Mg(OAc)_2$(aq) reflects the greater association of Mg^{2+} with OAc^- than with NO_3^- as discussed elsewhere.[15]

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