Density, Viscosity, Refractive Index, and Speed of Sound for Binary Mixtures of Anisole with 2-Chloroethanol, 1,4-Dioxane, Tetrachloroethylene, Tetrachloroethane, DMF, DMSO, and Diethyl Oxalate at (298.15, 303.15, and 308.15) K

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The density, viscosity, refractive index at (298.15, 303.15, and 308.15) K, and the speed of sound at 298.15 K in binary mixtures of anisole with 2-chloroethanol, 1,4-dioxane, tetrachloroethylene, tetrachloroethane, dimethyl formamide, dimethyl sulfoxide, and diethyl oxalate were measured over the entire mole fraction range of the binary mixtures. Using these data, the excess molar volume, deviations in viscosity, molar refraction, speed of sound, and isentropic compressibility were calculated. The computed quantities were fitted to the Redlich−Kister equation to derive the coefficients and estimate the standard error values.

Introduction

Anisole is a cyclic molecule used in a variety of applications in industrial sectors. Its interactions with different types of liquids such as 2-chloroethanol, 1,4-dioxane, tetrachloroethylene, tetrachloroethane, *N*,*N*-dimethyl formamide, dimethyl sulfoxide, and diethyl oxalate are important from a fundamental viewpoint. In continuation of our ongoing program of research[1−5] on the properties of binary mixtures containing anisole as one component with a variety of other liquids, we present here the experimental data on density, ρ, viscosity, η, and refractive index for the sodium D line, n_D, of binary mixtures of anisole, + 2-chloroethanol, + 1,4-dioxane, + tetrachloroethylene, + tetrachloroethane, + dimethylformamide, + dimethylsulfoxide, or + diethyloxalate at (298.15, 303.15, and 308.15) K, along with those of the speed of sound, u, at T = 298.15 K. From these data, the excess molar volume, V^E, deviation in viscosity, $\Delta\eta$, deviation in molar refraction, ΔR, deviation in sound velocity, Δu, and deviation in isentropic compressibility, Δk_s, have been computed, and the results are discussed in terms of the nature of molecular interactions between the mixing components. A large number of binary mixtures containing the above liquids as one of the components have been studied by different authors.[6−16]

Experimental Section

Materials. High-purity analytical reagent grade samples of DMF, tetrachloroethane, tetrachloroethylene and laboratory reagent grade samples of dimethylsulfoxide and diethyloxalate were procured from s.d. fine chemicals, Mumbai, India. Anisole, 2-chloroethanol, and 1,4-dioxane were extra pure grade samples procured from s.d. fine chemicals, Mumbai, India. The mol % purities of these liquids as determined by GC (HP 6890) using an FID detector were >99% and are reported in Table 1 along with a comparison of density and refractive index data measured at 298.15 K for pure liquids with literature values.

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Binary mixtures were prepared by mass[1,5,17] in specially designed conical flasks. Mass measurements accurate to ±0.01 mg were performed on a digital electronic balance (Mettler, AE 240, Switzerland). A set of nine compositions were prepared for each mixture, and their physical properties were measured at the respective composition on the mole fraction scale from 0.1 to 0.9 in steps of 0.1 units. The possible uncertainty in the mole fraction was less than 0.0002 units.

Methods. Densities of liquids and liquid mixtures were measured within a precision of ±0.0001 g.cm^{-3} using a capillary-type pycnometer of 10 cm^3 volume and a capillary bore with an internal diameter of 1 mm. Doubly distilled, deionized, and degassed water with a specific conductance of 1×10^{-4} Ω^{-1} cm^{-1} was used. Experimental details and calibration procedures of the pycnometer and measurements of the densities are the same as reported earlier.[5,17,18]

Viscosities were measured using a Cannon Fenske viscometer (size 75, ASTM D 445, Industrial Research Glassware Ltd., Roselle, NJ). An electronic digital stopwatch with a readability of ±0.01 s was used for the flow time measurements. The uncertainty in the measured viscosity values is ±0.001 mPa·s.

Refractive indices of the liquids and the binary mixtures for the sodium D line were measured using a thermostatically controlled Abbe refractometer (Atago 3T, Japan). A minimum of three independent readings were taken for each composition, and the average value was considered in all of the calculations. The uncertainty in the refractive index data is ±0.0001 units.

The speed of sound was measured using a variable-path single-crystal interferometer (Mittal Enterprises, model M-84, New Delhi). A crystal-controlled high-frequency generator was used to excite the transducer at a frequency of 1 MHz. Frequency was measured within an accuracy of 1 in 10^4 using a digital frequency meter. The interferometer cell was filled with the test liquid, and water was circulated around the measuring cell from a constant-temperature bath maintained at (298.15 ± 0.01) K. Details of the speed

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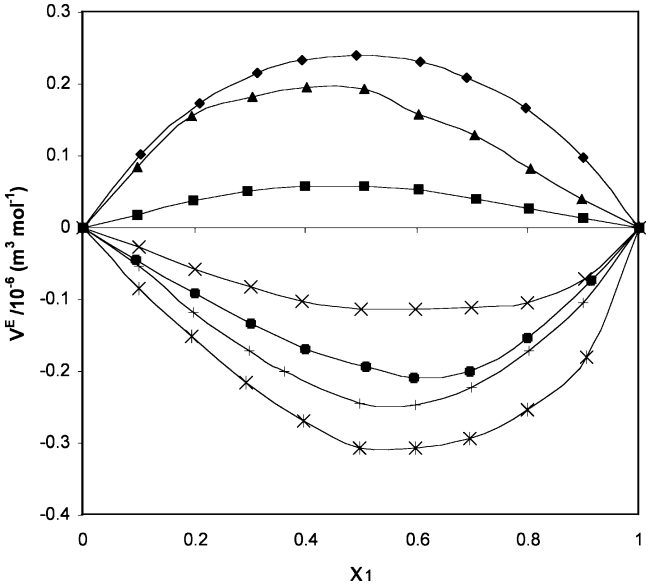

Figure 1. Excess molar volume vs mole fraction of anisole with (♦), 2-chloroethanol; (■), dioxane; (▲), tetrachloroethylene; (×), tetrachloroethane; (*), dimethylformamide; (●), dimethylsulfoxide; and (+), diethyloxalate at 298.15 K.

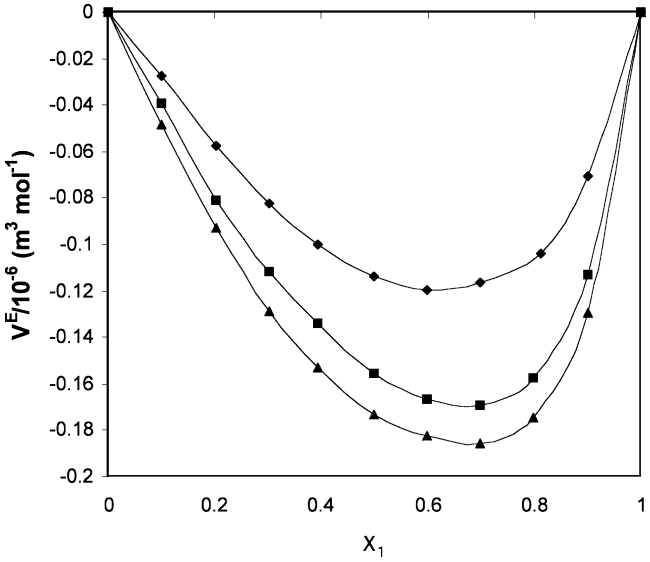

Figure 2. Effect of temperature on V^E for the anisole (1) + tetrachloroethane (2) mixture at (♦), 298.15 K; (■), 303.15 K; and (▲), 308.15 K.

of sound measurements were given earlier,[17] and the uncertainty in these data is ±2 in 1000 m·s^{-1}.

In all of the property measurements, temperature was controlled within an accuracy of ±0.01 K using a constant-temperature bath. A Julabo immersion cooler (FT 200, Julabo Labortechnik, Gmbh, Germany) was used to cool the water bath. This unit was installed at the intake of a heating circulator to draw the heat away from the circulating bath liquid. An immersion probe was connected to the instrument with a flexible and insulated tube, which maintained the constant temperature of the bath. All of the measurements were carried out at ambient pressure.

Results and Discussion

At least three independent readings of all of the physical property measurements on ρ, η, n_D, and u were taken for each composition, and the average of these experimental values is presented in Table 2.

From the density results, the excess molar volume, V^E, has been calculated as

$$V^E = V_m - V_1x_1 - V_2x_2 \quad (1)$$

Here, V_m is the molar volume of the mixture, V_1 and V_2 are the molar volumes of the respective pure components, and x_i represents the mole fraction of the ith component of the mixture. In a similar manner, the results of $\Delta\eta$, ΔR, Δu, and Δk_s have been calculated using the values of η, n_D, and u from a general relationship of the type used earlier.[17,19]

$$\Delta Y = Y_m - Y_1x_1 - Y_2x_2 \quad (2)$$

In the above equation, ΔY represents $\Delta\eta$, ΔR, Δu, and Δk_s, respectively, whereas Y_m represents the respective mixture properties, viz., the viscosity, η, molar refractivity, R (calculated from the Lorentz−Lorenz relation), speed of sound, u, and isentropic compressibility, k_s (= $1/u^2\rho$) of the binary mixture; the symbol Y_i refers to the same properties for pure components of the mixture. To calculate ΔR and Δk_s, the volume fraction, ϕ_i(= $x_iv_i/\sum_{i=1}^{2} x_iv_i$), was used,[1,17] but to calculate $\Delta\eta$ and Δu, the mole fraction, x_i, was used.

All of the quantities (V^E, $\Delta\eta$, ΔR, Δu, and Δk_s) have been fitted to the Redlich−Kister [23] equation by the method of least squares using the Marquardt algorithm[24] to derive the binary coefficients, A_j, and the standard deviation σ as follows.

$$V^E(\Delta Y) = x_1x_2\sum_{j=1}^{k} A_j(x_2 - x_1)^{j-1} \quad (3)$$

In each case, the optimum number of coefficients, A_j, was determined from an examination of the variation of standard deviation σ as calculated by

$$\sigma = \left(\frac{\sum(Y^E_{calcd} - Y^E_{obsd})^2}{n - m}\right)^{1/2} \quad (4)$$

Here, n represents the number of measurements, and m is the number of coefficients used in fitting the data. The

Table 1. Comparison of Experimental Densities (ρ) and Refractive Indices (n_D) of Pure Liquids with Literature Values at 298.15 K

		ρ/kg·m^{-3}		n_D	
liquid	mol % purity	exptl	lit	exptl	lit
anisole	>99.0	988.9	989.3[20]	1.5148	1.5143[21]
2-chloroethanol	>99.0	1200.9	1200.0[21]	1.4411	1.4416[22]
1,4-dioxane	>99.0	1028.3	1027.9[20]	1.4181	1.4203[21]
tetrachloroethylene	>99.9	1614.7	1614.3[20]	1.5036	1.5032[21]
tetrachloroethane	>99.0	1587.8	1586.6[21]	1.4922	1.4924[21]
dimethyl formamide	>99.5	943.9	943.8[21]	1.4288	1.4282[21]
dimethylsulfoxide	>99.0	1095.4	1095.3 [21]	1.4768	1.4765[20]
diethyl oxalate	>99.0	1072.3	1072.9[21]	1.4084	1.4084[21]

Table 2. Experimental Density (ρ), Viscosity (η), Refractive Index (n_D), and Speed of Sound (u) of the Binary Mixtures at Different Temperatures

x_1	ρ/kg·m^{-3}	η/mPa·s	n_D	u/m·s^{-1}	x_1	ρ/kg·m^{-3}	η/mPa·s	n_D	u/m·s^{-1}	x_1	ρ/kg·m^{-3}	η/mPa·s	n_D	u/m·s^{-1}
Anisole (1) + 2-Chloroethanol (2)														
T = 298.15 K														
0	1200.9	3.104	1.4411	1358	0.3950	1088.7	1.583	1.4767	1382	0.7970	1015.9	1.087	1.5034	1402
0.1030	1165.8	2.600	1.4495	1365	0.4900	1068.8	1.418	1.4836	1388	0.8980	1001.9	1.007	1.5094	1406
0.2090	1134.5	2.130	1.4610	1372	0.5900	1049.8	1.269	1.4899	1392	1.0	988.9	0.992	1.5148	1410
0.3130	1107.6	1.778	1.4712	1378	0.6900	1032.5	1.155	1.4978	1397					
T = 303.15 K														
0	1192.5	2.669	1.4380		0.3950	1083.9	1.452	1.4745		0.7970	1010.0	1.004	1.5011	
0.1030	1158.6	2.334	1.4793		0.4900	1064.3	1.289	1.4807		0.8980	996.1	0.936	1.5067	
0.2090	1129.0	1.943	1.4586		0.5900	1044.8	1.158	1.4879		1.0	984.1	0.919	1.5124	
0.3130	1102.5	1.631	1.4684		0.6900	1027.5	1.064	1.4951						
T = 308.15 K														
0	1187.1	2.347	1.4326		0.3950	1078.8	1.320	1.4723		0.7970	1006.6	0.921	1.4999	
0.1030	1153.9	2.068	1.4468		0.4900	1058.9	1.160	1.4778		0.8980	992.5	0.865	1.5041	
0.2090	1123.7	1.755	1.4564		0.5900	1040.1	1.046	1.4859		1.0	979.4	0.853	1.5092	
0.3130	1097.5	1.485	1.4652		0.6900	1023.0	0.972	1.4923						
Anisole (1) + 1,4-Dioxane (2)														
T = 298.15 K														
0.0	1028.3	1.415	1.4181	1345	0.3980	1009.7	1.120	1.4647	1378	0.8028	995.1	1.032	1.5009	1401
0.0982	1023.3	1.342	1.4320	1355	0.5046	1005.5	1.072	1.4750	1385	0.9005	991.9	1.011	1.5084	1405
0.1990	1018.4	1.267	1.4434	1364	0.6044	1001.8	1.048	1.4840	1390	1.0	988.9	0.992	1.5148	1410
0.2960	1014.0	1.190	1.4538	1371	0.7057	998.3	1.042	1.4925	1396					
T = 303.15 K														
0.0	1023.1	1.171	1.4176		0.3980	1004.6	1.028	1.4628		0.8028	990.5	0.957	1.4982	
0.0982	1017.9	1.185	1.4295		0.5046	1000.6	0.994	1.4720		0.9005	987.4	0.941	1.5054	
0.1990	1013.2	1.128	1.4408		0.6044	996.9	0.976	1.4814		1.0	984.1	0.919	1.5124	
0.2960	1008.6	1.074	1.4514		0.7057	993.5	0.969	1.4899						
T = 308.15 K														
0.0	1017.8	1.068	1.4141		0.3980	999.8	0.936	1.4603		0.8028	985.4	0.883	1.4956	
0.0982	1012.9	1.028	1.4270		0.5046	995.7	0.917	1.4700		0.9005	982.4	0.870	1.5025	
0.1990	1008.2	0.990	1.4383		0.6044	992.1	0.904	1.4789		1.0	979.4	0.853	1.5092	
0.2960	1003.9	0.957	1.4496		0.7057	988.6	0.897	1.4872						
Anisole (1) + Tetrachloroethylene (2)														
T = 298.15 K														
0.0	1614.7	0.861	1.5036	1038	0.4024	1350.9	0.861	1.5075	1159	0.8036	1105.0	0.935	1.5124	1314
0.0979	1548.6	0.859	1.5044	1065	0.5044	1286.9	0.874	1.5086	1195	0.8974	1049.2	0.961	1.5135	1359
0.1962	1483.4	0.854	1.5053	1094	0.6045	1225.3	0.892	1.5099	1232	1.0	988.9	0.992	1.5148	1410
0.3035	1413.9	0.854	1.5065	1127	0.7033	1165.1	0.909	1.5111	1271					
T = 303.15 K														
0.0	1606.9	0.817	1.5010		0.4024	1343.5	0.815	1.5044		0.8036	1099.6	0.877	1.5096	
0.0979	1540.9	0.818	1.5015		0.5044	1280.5	0.825	1.5056		0.8974	1044.8	0.898	1.5101	
0.1962	1476.1	0.813	1.5023		0.6045	1219.3	0.839	1.5069		1.0	984.1	0.919	1.5124	
0.3035	1407.0	0.811	1.5034		0.7033	1159.6	0.855	1.5083						
T = 308.15 K														
0.0	1599.0	0.782	1.4980		0.4024	1337.9	0.770	1.5014		0.8036	1094.5	0.817	1.5068	
0.0979	1533.6	0.776	1.4986		0.5044	1274.6	0.776	1.5026		0.8974	1039.2	0.835	1.5080	
0.1962	1469.0	0.770	1.4993		0.6045	1213.5	0.787	1.5040		1.0	979.4	0.853	1.5092	
0.3035	1400.4	0.767	1.5004		0.7033	1154.1	0.799	1.5054						
Anisole (1) + Tetrachloroethane (2)														
T = 298.15 K														
0	1587.8	1.591	1.4922	1153	0.3939	1348.3	1.419	1.5009	1235	0.7983	1107.6	1.149	1.5105	1347
0.1003	1526.3	1.555	1.4943	1172	0.4986	1285.5	1.355	1.5032	1262	0.9012	1047.0	1.074	1.5129	1379
0.2021	1464.3	1.518	1.4966	1193	0.5975	1226.5	1.292	1.5055	1289	1.0	988.9	0.992	1.5148	1410
0.3030	1403.1	1.470	1.4989	1214	0.6972	1167.2	1.224	1.5080	1317					
T = 303.15 K														
0	1580.6	1.471	1.4894		0.3939	1342.2	1.315	1.4980		0.7983	1102.7	1.064	1.5076	
0.1003	1519.4	1.439	1.4915		0.4986	1279.9	1.255	1.5005		0.9012	1042.8	0.994	1.5100	
0.2021	1457.7	1.404	1.4937		0.5975	1221.1	1.196	1.5028		1.0	984.1	0.919	1.5124	
0.3030	1396.9	1.362	1.4960		0.6972	1162.1	1.131	1.5052						
T = 308.15 K														
0	1573.3	1.361	1.4865		0.3939	1336.2	1.210	1.4952		0.7983	1097.7	0.979	1.5050	
0.1003	1512.6	1.323	1.4887		0.4986	1274.0	1.155	1.4977		0.9012	1037.4	0.914	1.5072	
0.2021	1451.2	1.290	1.4909		0.5975	1215.6	1.100	1.5000		1.0	979.4	0.853	1.5092	
0.3030	1390.6	1.253	1.4931		0.6972	1156.9	1.038	1.5023						

Table 2. (Continued)

x_1	ρ/kg·m^{-3}	η/mPa·s	n_D	u/m·s^{-1}	x_1	ρ/kg·m^{-3}	η/mPa·s	n_D	u/m·s^{-1}	x_1	ρ/kg·m^{-3}	η/mPa·s	n_D	u/m·s^{-1}
Anisole (1) + Dimethyl Formamide (2)														
T = 298.15 K														
0.0	943.9	0.801	1.4288	1462	0.3966	968.5	0.912	1.4708	1438	0.7984	984.7	0.994	1.5024	1418
0.1004	951.0	0.833	1.4407	1456	0.4975	973.4	0.937	1.4798	1432	0.9042	987.7	1.006	1.5099	1413
0.1960	957.0	0.859	1.4513	1451	0.5983	977.6	0.957	1.4878	1427	1.0	988.9	0.992	1.5148	1410
0.2939	962.9	0.886	1.4614	1445	0.6953	981.2	0.977	1.4953	1422					
T = 303.15 K														
0.0	939.5	0.754	1.4264		0.3966	964.1	0.856	1.4683		0.7984	980.3	0.928	1.5000	
0.1004	946.6	0.787	1.4381		0.4975	968.8	0.878	1.4771		0.9042	983.3	0.938	1.5071	
0.1960	952.7	0.810	1.4487		0.5983	973.2	0.897	1.4852		1.0	984.1	0.919	1.5124	
0.2939	958.2	0.833	1.4587		0.6953	976.9	0.913	1.4928						
T = 308.15 K														
0.0	935.0	0.711	1.4238		0.3966	959.7	0.799	1.4656		0.7984	975.9	0.863	1.4973	
0.1004	942.3	0.739	1.4356		0.4975	964.4	0.819	1.4744		0.9042	978.5	0.871	1.5043	
0.1960	948.2	0.760	1.4462		0.5983	968.7	0.836	1.4825		1.0	979.4	0.853	1.5092	
0.2939	953.9	0.780	1.4558		0.6953	972.4	0.851	1.4902						
Anisole (1) + Dimethylsulfoxide (2)														
T = 298.15 K														
0.0	1095.4	1.984	1.4768	1493	0.3987	1043.6	1.466	1.4962	1462	0.7988	1005.5	1.157	1.5105	1428
0.0938	1081.5	1.836	1.4817	1487	0.5074	1032.5	1.369	1.4996	1454	0.8933	997.4	1.077	1.5124	1421
0.2016	1066.7	1.691	1.4878	1477	0.5940	1024.1	1.318	1.5031	1445	1.0	988.9	0.992	1.5148	1410
0.3025	1054.4	1.565	1.4929	1468	0.6956	1014.7	1.249	1.5069	1437					
T = 303.15 K														
0.0	1090.8	1.801	1.4594		0.3987	1039.2	1.347	1.4935		0.7988	1001.4	1.073	1.5075	
0.0938	1077.0	1.683	1.4772		0.5074	1027.9	1.268	1.4974		0.8933	992.8	1.004	1.5096	
0.2016	1062.1	1.549	1.4853		0.5940	1019.7	1.219	1.5006		1.0	984.1	0.919	1.5124	
0.3025	1049.9	1.438	1.4901		0.6956	1010.3	1.152	1.5043						
T = 308.15 K														
0.0	1086.2	1.651	1.4547		0.3987	1034.7	1.228	1.4906		0.7988	996.7	0.989	1.5046	
0.0938	1072.3	1.529	1.4727		0.5074	1023.6	1.166	1.4952		0.8933	988.5	0.931	1.5069	
0.2016	1057.6	1.407	1.4828		0.5940	1015.1	1.119	1.4980		1.0	979.4	0.853	1.5092	
0.3025	1045.3	1.310	1.4873		0.6956	1005.7	1.054	1.5017						
Anisole (1) + Diethyl Oxalate (2)														
T = 298.15 K														
0.0	1072.3	1.844	1.4084	1267	0.3621	1047.7	1.495	1.4412	1316	0.8016	1010.1	1.140	1.4896	1377
0.1017	1065.8	1.732	1.4171	1280	0.4971	1037.4	1.380	1.4551	1334	0.9007	999.9	1.061	1.5021	1393
0.1976	1059.5	1.640	1.4257	1293	0.5975	1029.1	1.301	1.4660	1348	1.0	988.9	0.992	1.5148	1410
0.2978	1052.6	1.550	1.4350	1307	0.6977	1020.1	1.223	1.4773	1362					
T = 303.15 K														
0.0	1066.6	1.659	1.4061		0.3621	1042.3	1.367	1.4388		0.8016	1005.3	1.054	1.4868	
0.1017	1060.1	1.578	1.4148		0.4971	1031.9	1.265	1.4525		0.9007	995.4	0.985	1.4991	
0.1976	1053.8	1.497	1.4232		0.5975	1023.8	1.195	1.4634		1.0	984.1	0.918	1.5124	
0.2978	1047.1	1.416	1.4325		0.6977	1014.9	1.126	1.4746						
T = 308.15 K														
0.0	1060.7	1.508	1.4039		0.3621	1036.7	1.239	1.4362		0.8016	1000.0	0.968	1.4840	
0.1017	1054.3	1.424	1.4124		0.4971	1026.5	1.149	1.4499		0.9007	990.2	0.910	1.4962	
0.1976	1048.1	1.354	1.4207		0.5975	1018.5	1.089	1.4607		1.0	979.4	0.853	1.5092	
0.2978	1041.4	1.282	1.4300		0.6977	1009.7	1.030	1.4718						

estimated values of A_j and σ for V^E, $\Delta\eta$, ΔR, Δu, and Δk_s are presented in Table 3. In all cases, the best fit was found by using only three adjustable fitting coefficients in eq 3.

Excess molar volumes, V^E, of the binary mixtures of anisole + 2-chloroethanol, + 1,4-dioxane, + tetrachloroethylene, + tetrachloroethane, + *N*,*N*-dimethylformamide, + dimethylsulfoxide, and + diethyloxalate as a function of mole fraction, x_1, of anisole at 298.15 K are displayed in Figure 1. It is observed that for mixtures of anisole + 1,4-dioxane, + tetrachloroethylene, or + 2-chloroethanol the V^E data are positive. These positive V^E values vary in the order 2-chloroethanol > tetrachloroethylene > 1,4-dioxane because of the repulsive forces operating between the component liquids of the mixtures depending on their dipole moments and dielectric constants. The breaking up of intermolecular H bonding in 2-chloroethanol by anisole molecules combined with repulsive forces between the lone pair of electrons on oxygen atoms of both of the components of the mixture leads to the positive deviation in V^E of the mixture. Similar dispersion forces between the component molecules combined with a low molar volume of dioxane leads to small positive values of the excess molar volume for mixtures of anisole + dioxane. Dispersion forces also exist between electronic charges on the oxygen atom of anisole molecules and the π electrons of the double bond of tetrachloroethylene having a higher molar volume leading to higher positive V^E values. In the case of mixtures of anisole (1) + tetrachloroethane (2), or + dimethylsulfoxide, or + diethyloxalate, or dimethylacetamide, the V^E versus x_1 plots exhibit negative trends. The negative V^E values vary in the order tetrachloroethane > dimethylsulfoxide > diethyloxalate > dimethylformamide.

Table 3. Derived Parameters of Equation 3 for Various Functions of the Binary Mixtures at Different Temperatures

function	T/K	A_1	A_2	A_3	σ
Anisole (1) + 2-Chloroethanol (2)					
$V^E/10^{-6}$/m^3·mol^{-1}	298.15	0.922	0.031	0.312	0.005
	303.15	0.412	−0.678	1.312	0.029
	308.15	0.484	−0.173	−0.091	0.008
$\Delta\eta$/mPa·s	298.15	−2.638	−0.923	−0.075	0.021
	303.15	−2.111	−0.367	0.546	0.026
	308.15	−1.806	−0.158	0.621	0.022
$\Delta R \times 10^6$/m^3·mol^{-1}	298.15	−7.346	−1.589	−0.903	0.043
	303.15	−7.795	−5.080	7.177	0.464
	308.15	−7.228	−2.012	0.549	0.035
Δu/m·s^{-1}	298.15	14.26	0.17	1.60	0.039
Δk_S/Tpa^{-1}	298.15	−0.17	−0.08	0.09	0.001
Anisole (1) + 1,4-Dioxane (2)					
$V^E/10^{-6}$m^3·mol^{-1})	298.15	0.235	0.048	−0.084	0.001
	303.15	0.215	0.343	−0.224	0.011
	308.15	0.146	0.094	−0.007	0.0003
$\Delta\eta$/mPa·s	298.15	−0.507	−0.109	0.409	0.009
	303.15	−0.202	0.105	0.575	0.010
	308.15	−0.169	−0.126	0.059	0.002
$\Delta R \times 10^6$/m^3·mol^{-1}	298.15	−2.121	−0.350	0.516	0.020
	303.15	−2.285	−0.238	−0.132	0.021
	308.15	−2.078	−0.274	0.077	0.022
Δu/m·s^{-1}	298.15	28.67	11.73	0.25	0.138
Δk_S/TPa^{-1}	298.15	−11.60	5.31	1.76	0.074
Anisole (1) + Tetrachloroethylene (2)					
$V^E/10^{-6}$ m^3·mol^{-1}	298.15	0.755	0.363	−0.087	0.005
	303.15	0.854	0.609	−0.595	0.034
	308.15	0.697	0.454	−0.198	0.008
$\Delta\eta$/mPa·s	298.15	−0.216	−0.007	0.038	0.0018
	303.15	−0.176	−0.011	0.090	0.0016
	308.15	−0.168	−0.019	0.051	0.0010
$\Delta R \times 10^6$/m^3·mol^{-1}	298.15	−0.095	−0.049	−0.005	0.0015
	303.15	−0.165	−0.091	−0.279	0.0163
	308.15	−0.200	0.040	0.050	0.0012
Δu/m·s^{-1}	298.15	−124.04	27.70	−1.33	0.494
Δk_S/TPa^{-1}	298.15	16.31	4.30	−3.67	0.2846
Anisole (1) + Tetrachloroethane (2)					
$V^E/10^{-6}$ m^3·mol^{-1}	298.15	−0.436	0.232	−0.172	0.005
	303.15	−0.574	0.494	−0.657	0.043
	308.15	−0.664	0.434	−0.498	0.010
$\Delta\eta$/mPa·s	298.15	0.255	0.047	0.020	0.0037
	303.15	0.241	0.052	0.014	0.0030
	308.15	0.194	0.053	−0.074	0.0037
$\Delta R \times 10^6$/m^3·mol^{-1}	298.15	−0.288	0.024	0.132	0.005
	303.15	−0.360	−0.121	−0.201	0.015
	308.15	−0.340	−0.010	0.015	0.005
Δu/m·s^{-1}	298.15	−76.08	−6.97	5.48	0.442
Δk_S/TPa^{-1}	298.15	−11.96	−18.46	−7.32	0.2469
Anisole (1) + Dimethyl formamide (2)					
$V^E/10^{-6}$ m^3·mol^{-1}	298.15	−1.173	0.613	−0.451	0.034
	303.15	−1.263	0.885	−0.729	0.041
	308.15	−1.370	0.860	−0.730	0.025
$\Delta\eta$/mPa·s	298.15	0.156	−0.098	0.122	0.0028
	303.15	0.161	−0.099	0.165	0.0024
	308.15	0.141	−0.093	0.149	0.0019
$\Delta R \times 10^6$/m^3·mol^{-1}	298.15	−4.490	−0.892	−0.125	0.010
	303.15	−4.559	−0.971	−0.294	0.006
	308.15	−4.555	−0.876	−0.090	0.007
Δu/m·s^{-1}	298.15	−14.89	10.15	5.10	0.360
Δk_S/TPa^{-1}	298.15	−10.72	4.30	−2.26	0.1711
Anisole (1) + Dimethylsulfoxide (2)					
$V^E/10^{-6}$ m^3·mol^{-1}	298.15	−0.761	0.410	0.160	0.018
	303.15	−0.904	0.622	−0.077	0.019
	308.15	−0.970	0.687	−0.179	0.010
$\Delta\eta$/mPa·s	298.15	−0.416	−0.351	0.041	0.010
	303.15	−0.337	−0.301	0.119	0.007
	308.15	−0.333	−0.337	0.008	0.009
$\Delta R \times 10^6$/m^3·mol^{-1}	298.15	−5.529	−1.303	−0.088	0.032
	303.15	−4.509	−2.975	1.188	0.021
	308.15	−4.287	−2.968	1.123	0.019
Δu/m·s^{-1}	298.15	8.07	−1.68	6.54	1.221
Δk_S/TPa^{-1}	298.15	−43.79	−14.93	−10.12	1.0276
Anisole (1) + Diethyl oxalate (2)					
$V^E/10^{-6}$ m^3·mol^{-1}	298.15	−0.920	0.334	0.031	0.0104
	303.15	−0.891	0.477	−0.282	0.0224
	308.15	−0.902	0.346	0.035	0.0123
$\Delta\eta$/mPa·s	298.15	−0.151	−0.072	−0.090	0.0025
	303.15	−0.100	−0.023	0.044	0.0018
	308.15	−0.125	−0.058	−0.010	0.0016
$\Delta R \times 10^6$/m^3·mol^{-1}	298.15	−0.245	0.058	0.085	0.0039
	303.15	−0.290	−0.102	−0.182	0.0104
	308.15	−0.275	0.038	−0.126	0.0041
Δu/m·s^{-1}	298.15	−16.45	12.28	−17.50	0.295
Δk_S/TPa^{-1}	298.15	−27.91	11.55	9.37	0.42

The excess molar volume decreases with increasing temperature for the mixtures of anisole + tetrachloroethane, or + dimethylformamide, or + dimethylsulfoxide. A typical plot showing the effect of temperature on the values of V^E for the mixtures of anisole + tetrachloroethane is shown in Figure 2. For other mixtures, no systematic trend is observed with increasing temperature.

The results of $\Delta\eta$ versus x_1 at 298.15 K are displayed in Figure 3. It is observed that large negative values of $\Delta\eta$ are observed for anisole + 2-chloroethanol. Negative $\Delta\eta$ values are also observed for anisole + diethyloxalate, or + tetrachloroethylene, or + dimethylsulfoxide, or + 1,4-dioxane. For these mixtures, the values vary in the order diethyloxalate > tetrachloroethylene > dimethylsulfoxide > 1,4-dioxane > 2-chloroethanol. The positive $\Delta\eta$ values are observed for mixtures of anisole + tetrachloroethane or + *N*,*N*-dimethylformamide. With increasing temperature, $\Delta\eta$ values decrease for the mixtures of anisole + tetrachloroethane, whereas those for anisole + 2-chloroethanol show an increasing trend with increasing temperature. Typical plots showing the effect of temperature on $\Delta\eta$ for these two mixtures are shown in Figures 4 and 5. For anisole + tetrachloroethylene, the effect of temperature on $\Delta\eta$ is not appreciable, whereas for others no systematic trend is observed with increasing temperature for $\Delta\eta$.

The results of deviations in molar refraction, ΔR plotted as a function of ϕ_1 of anisole at 298.15 K, displayed in Figure 6, indicate negative values for all of the mixtures. The negative ΔR values vary in the order 2-chloroethanol > DMSO > DMF > 1,4-dioxane > tetrachloroethane > diethyloxalate > tetrachloroethylene. The effect of tem-

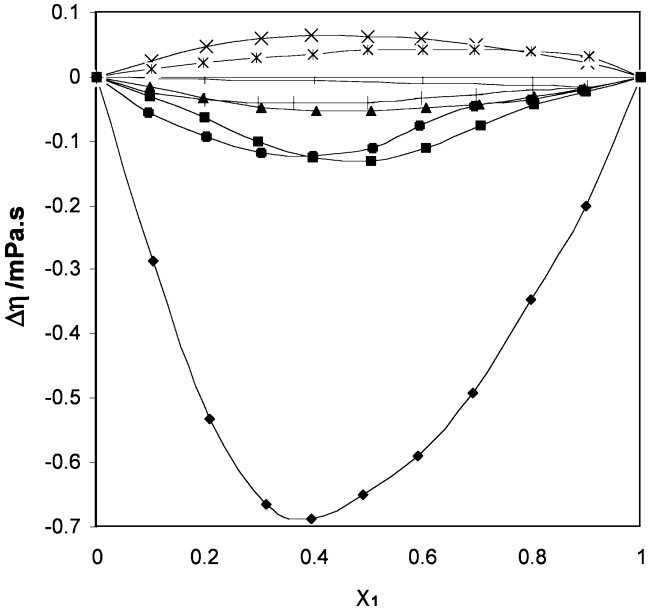

Figure 3. Deviations in viscosity vs mole fraction at 298.15 K for the same mixtures presented in Figure 1.

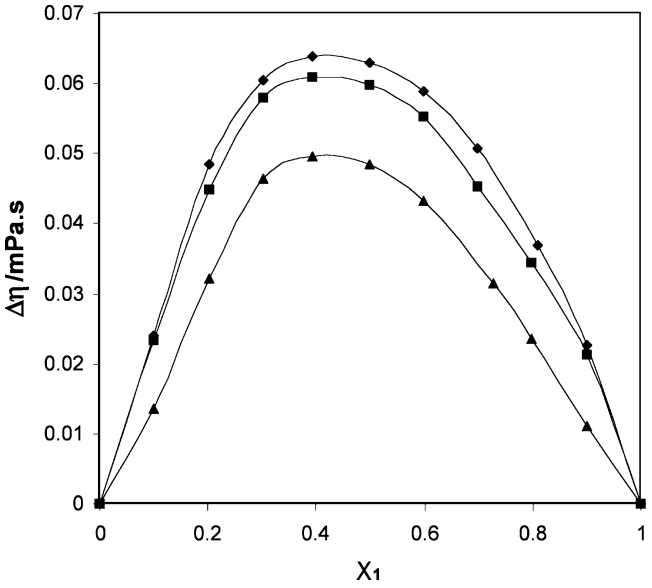

Figure 4. Effect of temperature on $\Delta\eta$ for the anisole (1) + tetrachloroethane (2) mixture at (♦) 298.15 K, (■) 303.15 K, and (▲) 308.15 K.

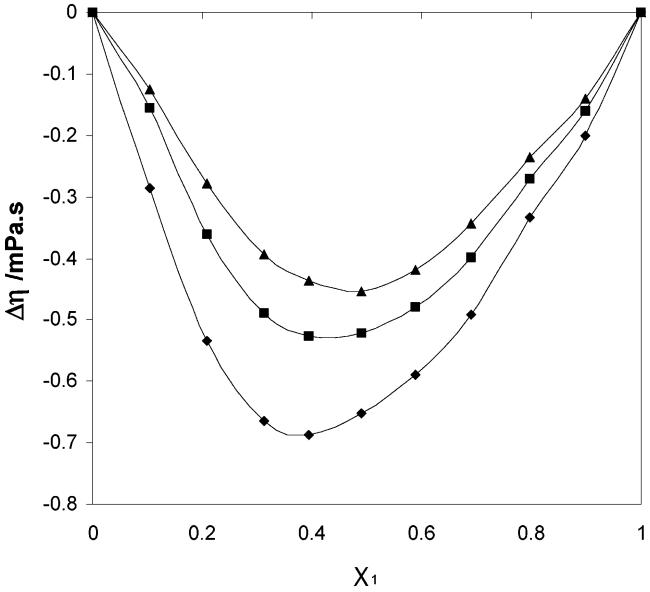

Figure 5. Effect of temperature on $\Delta\eta$ for anisole (1) + 2-chloroethanol (2) Mixture at (♦), 298.15 K; (■), 303.15 K; and (▲), 308.15 K.

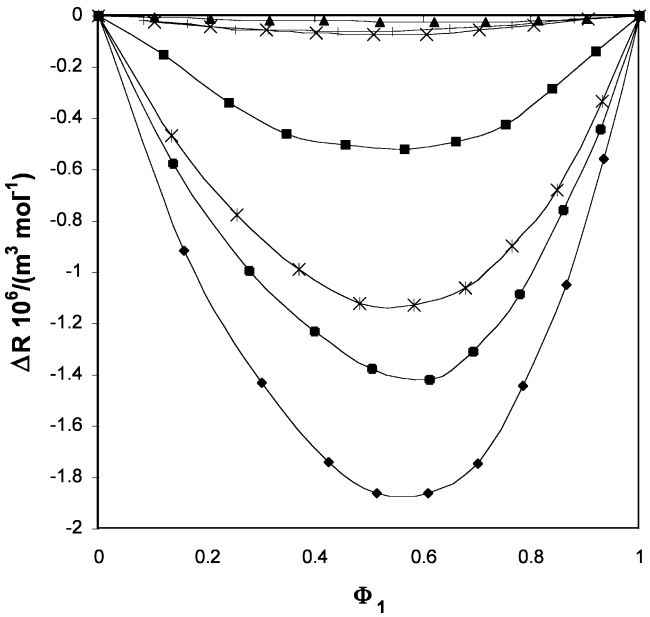

Figure 6. Deviations in molar refraction (ΔR) vs volume fraction at 298.15 K for the same mixtures presented in Figure 1.

perature on ΔR for anisole + 2-chloroethanol or + DMF is not observed, whereas for other systems the effect of temperature exhibits no systematic trend in ΔR values.

The results of Δu versus x_1 and Δk_s versus ϕ_1 of the binary mixtures at 298.15 K are presented in Figures 7 and 8 . A negative Δu is observed in the case of anisole + tetrachloroethylene, or + tetrachloroethane, or + diethyloxalate, or + DMF. However, for mixtures of anisole with 2-chloroethanol, or DMSO, or 1,4-dioxane, Δu values are positive. The Δk_s values for all of the mixtures are negative except for the mixtures of anisole + tetrachloroethylene, which are positive. For anisole + tetrachloroethane mixtures, at lower volume fractions the negative deviations are small, whereas at higher volume fractions the negative values are greater. For mixtures with 1,4-dioxane and *N*,*N*-dimethylformamide, the two curves overlap one another, whereas for mixtures with DMSO and diethyloxalate larger negative values are observed.

It may be noted that in all of the plots, points represent the quantities calculated from eqs 1 and 2, whereas the smooth curves are drawn from the best-fit values calculated from eq 3.

Conclusions

Experimental data of the density, viscosity, refractive index, and speed of sound have been measured for binary mixtures of anisole with 2-chloroethanol, 1,4-dioxane, tetrachloroethylene, tetrachloroethane, DMF, DMSO, and diethyloxalate. These data have been further used to compute excess quantities such as the excess molar volume, deviations in viscosity, molar refractivity, and speed of sound. The sign and magnitude of these quantities have been discussed in terms of the molecular interactions between the mixing components. Both negative and positive deviations are observed for V^E, $\Delta\eta$, Δu, and Δk_s,

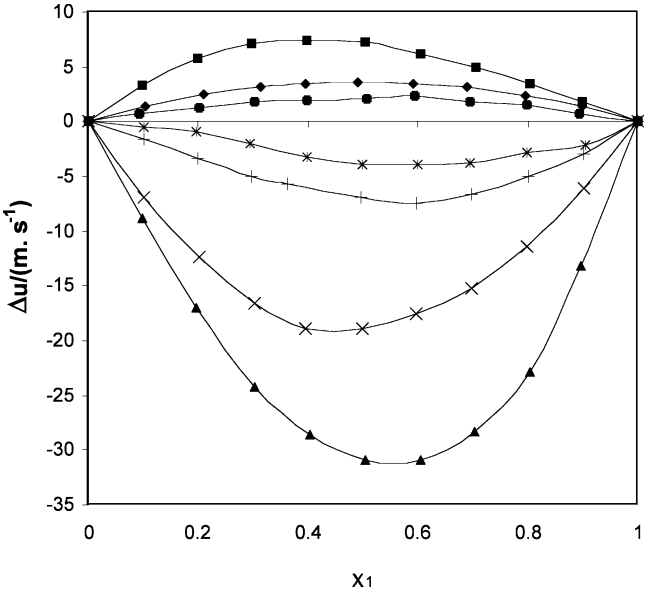

Figure 7. Deviations in speed of sound (Δu) vs mole fraction at 298.15 K for the same mixtures presented in Figure 1.

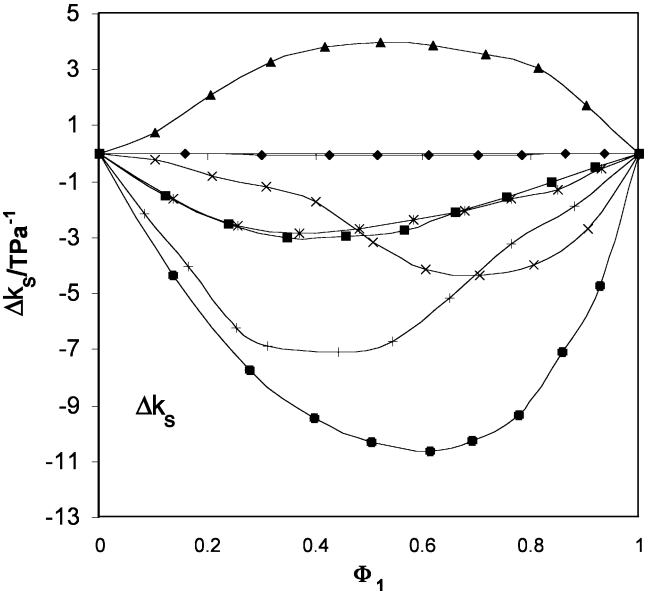

Figure 8. Deviations in isentropic compressibility (Δk_s) vs volume fraction at 298.15 K for the same mixtures presented in Figure 1.

whereas negative deviations in ΔR are observed for all of the binary mixtures.

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