J. Chem. Eng. Data **2010,** *55,* 5471–5477

Thermodynamic and Acoustic Properties of Mixtures of 1,6-Dichlorohexane with Heptane from (293 to 313) K[†]

Mirosław Chorążewski,*,[‡] Paweł Góralski,[§] Małgorzata Hrynko,[‡] Jean-Pierre Grolier,[||] and Emmerich Wilhelm[⊥]

Institute of Chemistry, University of Silesia, Szkolna 9, 40-006 Katowice, Poland, Department of Physical Chemistry, University of Łódź, Pomorska 165, 90-236 Łódź, Poland, Laboratory of Thermodynamics of Solutions and Polymers, Blaise Pascal University of Clermont-Ferrand, F-63177, Aubière, France, and Institute of Physical Chemistry, University of Wien, Währinger Strasse 42, A-1090 Wien, Austria

For $\{x\mathrm{Cl(CH_2)_6Cl} + (1 - x)\, n\text{-}\mathrm{C_7H_{16}}\}$, densities ρ were measured with a vibrating-tube densimeter at (293.15, 298.15, 303.15, 308.15, and 313.15) K, covering the whole composition range. From the densities the corresponding isobaric expansivities α_p and the excess molar volumes V^{E} were calculated. At the same temperatures, the molar heat capacities at constant pressure C_p were also measured over the whole composition range using a differential scanning calorimeter (DSC III from Setaram), and excess molar heat capacities at constant pressure C_p^{E} were calculated therefrom. In addition, ultrasound speeds u were determined with a pulse-echo-overlap apparatus. From these results, isentropic compressibilities κ_S, isothermal compressibilities κ_T, molar heat capacities at constant volume C_V, and internal pressures Π were obtained for this system at all five temperatures. The V^{E} are negative throughout; they are somewhat skewed with minima around $x = 0.6$, and they become less negative with decreasing temperature. The C_p^{E} are all negative and strongly asymmetric with minima around $x = 0.3$ and rather broad shoulders at larger mole fractions of 1,6-dichlorohexane. With decreasing temperature, the $C_p^{\mathrm{E}}(x)$ curves become less negative with more pronounced shoulders, which behavior is reminiscent of the onset of a W-shaped composition dependence.

Introduction

Directional intermolecular forces contribute significantly to the thermodynamic properties of pure liquids and liquid mixtures. A versatile approximate statistical−mechanical method for estimating and discussing dipolar and quadrupolar contributions was presented some time ago by Pople,[1] with later contributions being due to Kalali et al.[2] and to Patterson.[3] In pure liquids, at high densities and low temperatures, these orientational contributions lead to local structure, that is, to ordering. The presence of order lowers the Helmholtz energy as well as the internal energy and the entropy, and increasingly so at low temperatures, while the contribution to the heat capacity at constant volume of the pure liquid is positive. Extension to mixtures is fairly straightforward. The net destruction of order resulting from mixing, say, a polar liquid with a nonpolar alkane or cycloalkane,[2] results in *positive* contributions to the excess molar Gibbs energy G^{E}, to the excess molar enthalpy H^{E}, and to the excess molar entropy S^{E}, and to a *positive* contribution to the excess molar heat capacity C_p^{E} at constant pressure p, which may be expressed as

$$C_p^{\mathrm{E}} = -\frac{2(H^{\mathrm{E}} - G^{\mathrm{E}})}{T} \qquad (1)$$

where T is the thermodynamic temperature. This simple relation appears to hold well for mixtures containing a weakly polar substance. However, for mixtures involving a strongly polar substance as the second component, the experimental C_p^{E} is usually less negative than demanded by eq 1, which indicates that some orientations have considerably greater stability than accounted for by the angle-averaging procedure involved. One possible way of treating these nonrandom effects is based on Guggenheim's quasi-chemical theory,[4] as first suggested by Saint-Victor and Patterson.[5] To an excellent approximation, C_p^{E} may be separated into a random and a nonrandom contribution.[5−10] While the random contribution is always negative with a parabolic composition dependence, the nonrandom contribution is always positive and has zero slope against the mole fraction axis at both ends of the composition range.[11] Thus, the superposition of these two contributions accounts qualitatively for the appearance of W-shaped $C_p^{\mathrm{E}}(x)$ curves, as first reported by Grolier et al.[12] With decreasing temperature, the W-shape becomes more pronounced and is, in fact, indicative for approaching an upper critical solution temperature.

Initially, studies of mixtures of α,ω-dihaloethanes with hydrocarbons have primarily been motivated by interest in the influence of rotational isomerism (involving carbon−carbon single bonds) upon various thermophysical properties of such systems. For instance, the experimental results for mixtures of 1,2-dichloroethane with benzene or cyclohexane,[13,14] respectively, were discussed in terms of stabilization of either the strongly dipolar *gauche* rotamers or the nonpolar *trans* rotamer through interaction with the hydrocarbon component. Thus in view of the above, in systems of type (α,ω-dihaloethanes + alkane or cycloalkane) either W-shaped C_p^{E} or a composition dependence of C_p^{E} indicating incipient W-shape is expected and indeed observed.[15−18] To complement these studies and, in particular, to investigate in detail the temperature dependence of C_p^{E} in such systems, we report here first results obtained for the mixture of 1,6-dichlorohexane with heptane, at atmospheric pressure, from (293 to 313) K. It is, in fact, a continuation of

---

[†] Part of the "Workshop in Memory of Henry V. Kehiaian".

* Corresponding author. E-mail: miroslaw.chorazewski@us.edu.pl.

[‡] University of Silesia.

[§] University of Łódź.

[||] Blaise Pascal University of Clermont-Ferrand.

[⊥] University of Wien.

10.1021/je100610v

recent studies of thermodynamic and acoustic properties of liquid mixtures of dihaloalkanes with heptane.[19,20] We also note that systematic investigations on mixtures of type $\{x\mathrm{Cl(CH_2)}_k\mathrm{Cl} + (1 - x)\ n\text{-}\mathrm{C}_l\mathrm{H}_{2l+2}\}$ will contribute to a better, molecular-based understanding of the so-called intramolecular *proximity effect*, which was first quantified by Kehiaian et al.[21−23] via a group-contributional analysis of excess molar quantities (within the frame of the TOM project).

Specifically, for the system $\{x\ \mathrm{Cl(CH_2)_6Cl} + (1 - x)\ n\text{-}\mathrm{C_7H_{16}}\}$ we report here densities ρ, derived excess molar volumes V^{E}, isobaric expansivities α_p, molar heat capacities C_p, excess molar heat capacities C_p^{E}, speeds of ultrasound u, isentropic compressibilities κ_S, isothermal compressibilities κ_T, molar heat capacities at constant volume C_V, ratios of heat capacities $\gamma \equiv C_p/C_V = \kappa_T/\kappa_S$, and internal pressures Π over the whole composition range in the temperature range (293 to 313) K.

Experimental Section

Materials. Heptane was from Polish Chemicals with a stated purity of more than 99.8 % (molar basis). The 1,6-dichlorohexane was specified by the supplier (Avocado) as having a purity of 97 % and was further purified by fractional distillation. Only the middle fractions were collected, resulting in a liquid sample with a purity of more than 98 % (by gas−liquid chromatography). The mass fraction of water as determined by the Karl Fischer method was less than $3 \cdot 10^{-5}$ for heptane and less than $4 \cdot 10^{-5}$ for 1,6-dichlorohexane. Both liquids were dried with a molecular sieve (Lancaster, type 3A, beads) and stored in the dark. Prior to the experiments, they were degassed ultrasonically. Mixtures were prepared by mass using a Sartorius RC 210D balance (for heat capacity measurements) or an Ohaus AS-2000 balance and used immediately. All molar quantities are based on the relative atomic mass table of IUPAC 2005.[24] The possible error in the mole fraction is about 10^{-4}.

Measurements. Densities ρ were measured with a vibrating-tube densimeter (Anton Paar, model DMA 5000) operated in the static mode with an uncertainty of $5 \cdot 10^{-2}\ \mathrm{kg \cdot m^{-3}}$, as estimated from results of measurements on standard materials for density determinations, such as highly purified and degassed water, aqueous solutions of sodium chloride, and selected organic liquids.

The density of any liquid relative to the density of pure water, ρ_{w}, is given by

$$\rho = \rho_{\mathrm{w}} + b(\tau^2 - \tau_{\mathrm{w}}^{\ 2}) \tag{2}$$

where b is characteristic for a particular oscillator depending somewhat on temperature, and τ and τ_{w} are the periods of vibration of the tube filled with the liquid and with water, respectively. From the measured density ρ of a mixture, the excess molar volume of that mixture with mole fraction x of 1,6-dichlorohexane is obtained from

$$V^{\mathrm{E}} = xM_1\left\{\left(\frac{1}{\rho}\right) - \left(\frac{1}{\rho_1}\right)\right\} + (1 - x)M_2\left\{\left(\frac{1}{\rho}\right) - \left(\frac{1}{\rho_2}\right)\right\} \tag{3}$$

where M_i and ρ_i denote, respectively, the molar mass and the density of pure component $i = 1$ (1,6-$\mathrm{C_6H_{12}Cl_2}$) or $i = 2$ (n-$\mathrm{C_7H_{16}}$).

From the temperature dependence of the densities the isobaric expansivity α_p is obtained via

$$\alpha_p = -\rho^{-1}\left(\frac{\partial \rho}{\partial T}\right)_p \tag{4}$$

Isobaric heat capacities were measured with a differential scanning calorimeter (Micro DSC III, from Setaram) using the "continuous with reference" method as described in detail by Góralski et al.[25] The uncertainty of the measurements is estimated to be about ± 0.15 %. Excess molar heat capacities were then calculated from

$$C_p^{\mathrm{E}} = C_p - \{xC_{p,1} + (1 - x)C_{p,2}\} \tag{5}$$

where $C_{p,i}$ is the molar heat capacity of pure component $i = 1$ or 2.

The speeds of ultrasound at 4 MHz were measured with a pulse-echo-overlap apparatus designed and constructed in the Department of Physical Chemistry of the University of Silesia. The measuring cell was thermostatted to ± 0.005 K using a Techne TU16D temperature controller. The instrument was calibrated with doubly distilled water using Marczak's[26] recent speed-of-ultrasound data for water. The measurement uncertainty was estimated at $0.5\ \mathrm{m \cdot s^{-1}}$, while the precision was an order of magnitude better.[38]

Isentropic compressibilities were then calculated from

$$\kappa_S = \frac{1}{\rho u^2} \tag{6}$$

and isothermal compressibilities from

$$\kappa_T = \gamma \kappa_S \tag{7}$$

where

Table 1. Comparison with Selected Literature Data at T = 298.15 K: Densities ρ, Molar Heat Capacities at Constant Pressure C_p, Speeds of Ultrasound u, Isobaric Expansivities α_p, Isentropic Compressibilities κ_S, Isothermal Compressibilities κ_T, Molar Heat Capacities at Constant Volume C_V, Ratio of Heat Capacities $\gamma = C_p/C_V$, and Internal Pressures Π of the Pure Liquid Components

	this work	literature
	Heptane	
$\rho/(\mathrm{kg \cdot m^{-3}})$	679.56	679.43,[27] 679.50,[28] 679.54,[29] 679.60[30,31]
$C_p/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$	224.72[a]	224.7,[32,33] 224.71,[12] 224.72,[31] 224.78[27]
$u/(\mathrm{m \cdot s^{-1}})$	1130.38	1129.81,[34] 1129.85,[35] 1130.14,[31] 1130.18,[30] 1130.2,[36] 1130.44,[37] 1130.6[38]
$10^3\ \alpha_p/\mathrm{K^{-1}}$	1.257	1.245,[31] 1.246,[29] 1.256[39]
$10^{12}\ \kappa_S/\mathrm{Pa^{-1}}$	1151.66	1152.08,[b] 1152.32,[35] 1152.84[34]
$10^{12}\ \kappa_T/\mathrm{Pa^{-1}}$	1460.6	1438,[40] 1440,[41] 1455,[29,31] 1485[39]
$C_V/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$	177.19	177.92,[b] 178.0[29]
γ	1.2682	
Π/MPa	256.5	
	1,6-Dichlorohexane	
$\rho/(\mathrm{kg \cdot m^{-3}})$	1063.61	1063.0,[c] 1063.74,[43] 1064.39,[17] 1064.65[44]
$C_p/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$	240.64	239.57,[17] 240.39,[25] 240.60[43]
$u/(\mathrm{m \cdot s^{-1}})$	1319.81	1317.28[43]
$10^3\ \alpha_p/\mathrm{K^{-1}}$	0.891	0.890[d]
$10^{12}\ \kappa_S/\mathrm{Pa^{-1}}$	539.75	541.76[d]
$10^{12}\ \kappa_T/\mathrm{Pa^{-1}}$	683.1	684.9[d]
$C_V/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$	190.15	190.31[d]
γ	1.2655	
Π/MPa	388.8	

[a] Value from ref 19. [b] Value calculated from ref 31. [c] Value calculated from ref 42. [d] Value calculated from ref 43.

Table 2. Experimental Molar Heat Capacities at Constant Pressure $C_p(T,x)$ as a Function of Mole Fraction x for {x 1,6-Dichlorohexane + $(1 - x)$ Heptane} at Temperatures $293.15 \leq T/\mathrm{K} \leq 313.15$

	$C_p/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$										
T/K	$x = 0.0000^{a}$	$x = 0.1033$	$x = 0.2005$	$x = 0.3004$	$x = 0.3970$	$x = 0.5025$	$x = 0.5978$	$x = 0.7012$	$x = 0.7975$	$x = 0.8993$	$x = 1.0000$
293.15	222.87	224.18	225.58	226.93	228.73	230.53	232.22	233.79	235.58	237.46	239.21
294.15	223.23	224.47	225.71	227.22	229.08	230.89	232.55	234.00	235.86	237.73	239.50
295.15	223.60	224.85	226.27	227.61	229.51	231.34	232.94	234.33	236.23	238.10	239.69
296.15	223.97	225.28	226.73	227.98	229.89	231.84	233.25	234.73	236.51	238.39	240.02
297.15	224.35	225.70	227.04	228.31	230.27	231.98	233.48	235.05	236.81	238.57	240.35
298.15	224.72	226.02	227.35	228.65	230.41	232.13	233.77	235.36	237.10	238.92	240.64
299.15	225.10	226.42	227.84	228.96	230.75	232.24	234.00	235.65	237.33	239.06	240.85
300.15	225.47	226.82	228.08	229.21	231.06	232.49	234.22	236.05	237.68	239.39	241.15
301.15	225.87	227.16	228.49	229.61	231.57	232.94	234.60	236.34	238.04	239.79	241.46
302.15	226.22	227.48	228.83	230.00	231.80	233.35	234.96	236.63	238.29	240.08	241.80
303.15	226.61	227.86	229.13	230.36	232.08	233.73	235.31	236.93	238.61	240.37	242.06
304.15	227.00	228.19	229.46	230.70	232.56	234.04	235.48	237.20	238.86	240.64	242.34
305.15	227.40	228.57	229.83	230.91	232.74	234.33	235.88	237.53	239.21	240.92	242.62
306.15	227.75	228.88	230.10	231.36	233.13	234.40	236.03	237.84	239.44	241.20	242.83
307.15	228.14	229.30	230.51	231.65	233.51	235.07	236.50	238.18	239.76	241.48	243.21
308.15	228.54	229.71	230.91	232.08	233.76	235.33	236.85	238.49	240.12	241.83	243.49
309.15	228.95	230.05	231.19	232.35	234.03	235.45	237.17	238.74	240.37	242.06	243.73
310.15	229.30	230.40	231.55	232.73	234.35	235.77	237.52	239.07	240.64	242.36	244.00
311.15	229.71	230.86	231.97	233.11	234.88	236.41	237.89	239.43	241.08	242.73	244.35
312.15	230.11	231.16	232.33	233.45	235.01	236.75	238.16	239.72	241.32	243.02	244.68
313.15	230.51	231.55	232.68	233.79	235.43	236.93	238.39	240.06	241.64	243.28	244.91

[a] C_p values for pure liquid heptane were taken from Chorążewski et al.[19]

Table 3. Experimental Densities $\rho(T,x)$ as a Function of Mole Fraction x for {x 1,6-Dichlorohexane + $(1 - x)$ Heptane} at Temperatures $T/\mathrm{K} = 293.15$, 298.15, 303.15, 308.15, and 313.15

	$\rho/(\mathrm{kg \cdot m^{-3}})$				
x	$T =$ 293.15 K	$T =$ 298.15 K	$T =$ 303.15 K	$T =$ 308.15 K	$T =$ 313.15 K
0.0000	683.79	679.56	675.30	671.02	666.71
0.0998	722.22	717.96	713.61	709.34	704.96
0.1999	760.97	756.72	752.30	748.07	743.68
0.2998	799.74	795.42	791.00	786.58	782.17
0.4001	838.66	834.33	830.00	825.61	821.26
0.5001	877.38	873.04	868.59	864.37	859.93
0.6002	916.12	911.75	907.23	902.95	898.61
0.7000	954.46	950.12	945.63	941.10	936.70
0.8002	992.78	988.40	983.71	979.09	974.58
0.9001	1030.70	1026.11	1021.49	1016.82	1012.12
1.0000	1068.33	1063.61	1058.87	1054.14	1049.39

$$\gamma = 1 + \frac{TM{\alpha_p}^2u^2}{C_p} \tag{8}$$

and

$$M = xM_1 + (1 - x)M_2 \tag{9}$$

Finally, the molar heat capacities C_V at constant volume $V = (M/\rho)$ were obtained from

$$C_V = \frac{C_p}{\gamma} \tag{10}$$

and internal pressures Π from

$$\Pi \cong \frac{T\alpha_p}{\kappa_T} \tag{11}$$

thereby neglecting the term $-P_\sigma$, since the vapor pressure is *very much* smaller than $T\alpha_p/\kappa_T$.

Results and Discussion

Densities, molar heat capacities at constant pressure, and speeds of ultrasound obtained in this work at 298.15 K, as well as the derived isobaric expansivities, isentropic compressibilities, isothermal compressibilities, molar heat capacities at constant volume, ratios of the heat capacities, and internal pressures of the pure liquids at 298.15 K are given in Table 1. In general, agreement with reliable values from the literature is satisfactory.

Heat capacity measurements on the pure liquids and the mixtures were carried out from somewhat below 293 K to somewhat above 313 K at a scanning rate of 0.1 K·min^{-1}. The

Table 4. Experimental Speeds of Ultrasound $u(T,x)$ at 4 MHz as a Function of Mole Fraction x for {x 1,6-Dichlorohexane + $(1 - x)$ Heptane} at Various Temperatures in the Range $292.49 \leq T/\mathrm{K} \leq 313.45$

x	$\frac{T}{\mathrm{K}}$	$\frac{u}{\mathrm{m \cdot s^{-1}}}$	$\frac{T}{\mathrm{K}}$	$\frac{u}{\mathrm{m \cdot s^{-1}}}$	$\frac{T}{\mathrm{K}}$	$\frac{u}{\mathrm{m \cdot s^{-1}}}$	$\frac{T}{\mathrm{K}}$	$\frac{u}{\mathrm{m \cdot s^{-1}}}$	$\frac{T}{\mathrm{K}}$	$\frac{u}{\mathrm{m \cdot s^{-1}}}$
0.0000	292.70	1154.11	298.00	1131.06	302.98	1109.45	308.06	1087.42	313.45	1064.29
0.1014	292.92	1167.57	298.21	1145.47	303.20	1124.68	308.18	1103.97	313.25	1082.87
0.1999	292.81	1181.63	298.21	1159.37	303.20	1138.92	308.19	1118.59	313.28	1098.01
0.3004	292.49	1199.10	298.17	1176.14	303.15	1156.10	308.13	1136.24	313.21	1116.15
0.4000	292.91	1215.33	298.20	1194.95	303.19	1175.46	308.17	1156.12	313.26	1136.54
0.4999	292.79	1234.95	298.17	1214.49	303.14	1195.51	308.13	1176.55	313.22	1157.34
0.6004	292.81	1254.97	298.21	1235.23	303.20	1216.82	308.18	1198.30	313.28	1179.51
0.6998	292.56	1276.92	298.16	1256.20	303.14	1237.89	308.12	1219.79	313.21	1201.40
0.8001	292.80	1297.03	298.20	1277.52	303.19	1259.56	308.18	1241.65	313.26	1223.62
0.8957	292.80	1316.31	298.16	1297.10	303.14	1279.45	308.12	1261.91	313.21	1244.05
1.0000	293.01	1337.76	298.18	1319.69	303.15	1302.36	308.14	1284.96	313.23	1267.39

Table 5. Temperature Dependence of Densities, Molar Heat Capacities at Constant Pressure, and Speeds of Ultrasound (at 4 MHz), Respectively, of Mixtures {x 1,6-Dichlorohexane + (1 − x) Heptane} at Experimental Mole Fractions x: Coefficients a_i of Equation 12 with their Standard Deviations and Mean Deviations δ_Q from the Regression Curve

x	a_0	a_1	a_2	δ_Q
		$Q(T,x) = \rho/(\mathrm{kg \cdot mol^{-1}})$		
0.0000	683.816 ± 0.022	−0.8540 ± 0.0018		0.03
0.0998	722.247 ± 0.024	−0.8629 ± 0.0019		0.03
0.1999	760.997 ± 0.039	−0.8649 ± 0.0032		0.05
0.2998	799.775 ± 0.026	−0.8793 ± 0.0021		0.03
0.4001	838.671 ± 0.017	−0.8703 ± 0.0014		0.02
0.5001	877.376 ± 0.045	−0.8714 ± 0.0037		0.06
0.6002	916.095 ± 0.051	−0.8764 ± 0.0042		0.07
0.7000	954.507 ± 0.044	−0.8909 ± 0.0036		0.06
0.8002	992.854 ± 0.064	−0.9144 ± 0.0052		0.08
0.9001	1030.698 ± 0.003	−0.9132 ± 0.0008	−0.000794 ± 0.000041	0.00
1.0000	1068.342 ± 0.007	−0.9474 ± 0.0005		0.01
		$Q(T,x) = C_p/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$		
0.0000[a]	222.867 ± 0.006	0.3673 ± 0.0013	0.000744 ± 0.000056	0.18
0.1033	224.175 ± 0.002	0.3689 ± 0.0002		0.05
0.2005	225.578 ± 0.003	0.3552 ± 0.0002		0.06
0.3004	226.931 ± 0.006	0.3430 ± 0.0004		0.13
0.3970	228.731 ± 0.008	0.3352 ± 0.0006		0.19
0.5025	230.528 ± 0.008	0.3199 ± 0.0006		0.17
0.5978	232.224 ± 0.007	0.3084 ± 0.0005		0.16
0.7012	233.789 ± 0.003	0.3137 ± 0.0002		0.05
0.7975	235.583 ± 0.002	0.3027 ± 0.0002		0.05
0.8993	237.464 ± 0.004	0.2909 ± 0.0003		0.09
1.0000	239.212 ± 0.0	0.2851 ± 0.0002		0.05
		$Q(T,x) = u/(\mathrm{m \cdot s^{-1}})$		
0.0000	1152.168 ± 0.026	−4.3669 ± 0.0060	0.001811 ± 0.000289	0.03
0.1014	1166.594 ± 0.009	−4.1763 ± 0.0022	0.000578 ± 0.000107	0.01
0.1999	1180.220 ± 0.008	−4.1319 ± 0.0019	0.002319 ± 0.000094	0.01
0.3004	1196.419 ± 0.022	−4.0573 ± 0.0051	0.002800 ± 0.000251	0.02
0.4000	1214.408 ± 0.062	−3.8749 ± 0.0051		0.08
0.4999	1233.534 ± 0.050	−3.7998 ± 0.0041		0.06
0.6004	1253.749 ± 0.059	−3.6646 ± 0.0138	−0.001280 ± 0.000665	0.06
0.6998	1274.729 ± 0.017	−3.7124 ± 0.0041	0.002826 ± 0.000200	0.02
0.8001	1295.776 ± 0.027	−3.6289 ± 0.0062	0.001999 ± 0.000301	0.03
0.8957	1315.049 ± 0.024	−3.5897 ± 0.0055	0.002545 ± 0.000692	0.03
1.0000	1337.219 ± 0.050	−3.4814 ± 0.0041		0.06

[a] C_p values for pure liquid heptane were taken from Chorążewski et al.[19]

measured heat capacity was recorded for each successive temperature 0.01 K apart, resulting in about 2600 data points for the temperature range studied. For the sake of clarity, Table 2 contains only values of C_p from (293.15 to 313.15) K at intervals of 1 K. The remaining experimentally determined data, that is, densities and speeds of ultrasound at, roughly, (293.15, 298.15, 303.15, 308.15, and 313.15) K, are shown in Tables 3 and 4, respectively. For the mixtures, no literature results could be found for comparison.

For the pure liquids as well as the mixtures (with mole fraction x of 1,6-dichlorohexane), the temperature dependences of the measured densities, molar heat capacities at constant pressure (considering *all* experimental data points) and speeds of ultrasound at each experimental mole fraction were represented satisfactorily by fitting the data with smoothing functions of the form

$$Q(T,x) = \sum_{i=0}^{2} a_i \tau^i \qquad (12)$$

by the method of unweighted least-squares. Here, $\tau = T/\mathrm{K} - 293.15$, Q denotes either $\rho/(\mathrm{kg \cdot m^{-3}})$, $C_p/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$, or $u/(\mathrm{m \cdot s^{-1}})$, and the a_i are the corresponding polynomial coefficients. The backward stepwise rejection procedure was used to reduce the number of nonzero coefficients. These coefficients and the mean deviations δ_Q from the respective regression curve are given in Table 5.

To obtain consistent results through the use of eqs 6 to 11, for the derived isobaric expansivities $\alpha_p(T,x)/\mathrm{K^{-1}}$, isentropic compressibilities $\kappa_S(T,x)/\mathrm{Pa^{-1}}$, isothermal compressibilities $\kappa_T(T,x)/\mathrm{Pa^{-1}}$, molar heat capacities at constant volume $C_V(T,x)/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$, ratios of heat capacities $\gamma(T,x)$, and internal pressures $\Pi(T,x)/\mathrm{MPa}$, for each of the temperatures (293.15, 298.15, 303.15, 308.15, and 313.15) K, the densities and speeds of ultrasound (as obtained from the results given in Table 5) were smoothed with respect to composition. Using the best fitting polynomials in x, "interpolated" values of these two properties at the mole fractions for which the heat capacities were measured have been thus obtained at each temperature. The interpolated quantities at mole fractions for which the heat capacities were measured have been then used to obtain all properties contained in Table 6. The derived quantities are given in Table 7.

Excess molar volumes $V^E(T,x)$ were calculated from eq 3 and excess molar heat capacities at constant pressure $C_p^E(T,x)$ from eq 5. Numerical values of calculated excess quantities are collected in Table 8. The excess molar volumes obtained for $T/\mathrm{K} = 293.15$, 298.15, 303.15, 308.15, and 313.15 were fitted for each temperature to Redlich−Kister type smoothing functions

$$V^E(T,x) = x(1-x)\sum_{i=0}^{n} A_i(1-2x)^i \qquad (13)$$

The corresponding coefficients A_i and the mean deviations δV^E from the regression curves are collected in Table 9, while graphical representations are provided by Figure 1. Additionally,

Table 6. Interpolated Densities $\rho(T,x)$ and Speeds of Sound $u(T,x)$ as a Function of Mole Fraction x at Which the Heat Capacities Were Measured for {x 1,6-Dichlorohexane + (1 − x) Heptane} at Temperatures T/K = 293.15, 298.15, 303.15, 308.15, and 313.15

	$\rho/(\mathrm{kg \cdot m^{-3}})$					$u/(\mathrm{m \cdot s^{-1}})$				
x	T = 293.15 K	T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K	T = 293.15 K	T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K
0.0000	683.79	679.56	675.3	671.02	666.71	1152.17	1130.38	1108.68	1087.07	1065.55
0.1033	723.58	719.33	714.97	710.65	706.34	1166.64	1145.64	1124.73	1103.88	1083.12
0.2005	761.20	756.92	752.53	748.21	743.82	1180.59	1160.06	1139.63	1119.28	1099.04
0.3004	799.95	795.64	791.24	786.94	782.50	1196.45	1176.40	1156.43	1136.54	1116.73
0.3970	837.45	833.13	828.73	824.43	820.00	1213.58	1194.04	1174.55	1155.10	1135.70
0.5025	878.34	874.00	869.58	865.26	860.90	1234.02	1215.05	1196.09	1177.13	1158.17
0.5978	915.16	910.82	906.35	901.97	897.64	1253.49	1234.95	1216.41	1197.87	1179.32
0.7012	954.93	950.57	946.02	941.55	937.17	1275.02	1256.77	1238.57	1220.41	1202.30
0.7975	991.75	987.34	982.72	978.14	973.61	1294.99	1276.87	1258.87	1240.99	1223.22
0.8993	1030.41	1025.87	1021.18	1016.50	1011.78	1315.96	1298.00	1280.19	1262.53	1245.03
1.0000	1068.33	1063.61	1058.87	1054.14	1049.39	1337.22	1319.81	1302.40	1285.00	1267.59

Table 7. Calculated Isobaric Expansivities α_p, Isentropic Compressibilities κ_S, Isothermal Compressibilities κ_T, Molar Heat Capacities at Constant Volume C_V, Ratio of Heat Capacities $\gamma = C_p/C_V$, and Internal Pressures Π for {x 1,6-Dichlorohexane + (1 − x) Heptane} at Temperatures T/K = 293.15, 298.15, 303.15, 308.15, and 313.15

			$10^3\ \alpha_p/\mathrm{K}^{-1}$		
x	T = 293.15 K	T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K
0.0000	1.249	1.257	1.265	1.273	1.281
0.1033	1.193	1.200	1.207	1.214	1.222
0.2005	1.142	1.149	1.156	1.162	1.169
0.3004	1.090	1.096	1.102	1.108	1.115
0.3970	1.041	1.047	1.052	1.058	1.063
0.5025	0.994	0.999	1.004	1.009	1.014
0.5978	0.959	0.964	0.969	0.973	0.978
0.7012	0.933	0.937	0.942	0.946	0.951
0.7975	0.917	0.921	0.926	0.930	0.934
0.8993	0.905	0.909	0.913	0.917	0.922
1.0000	0.887	0.891	0.895	0.899	0.903
			$10^{12}\ \kappa_S/\mathrm{Pa}^{-1}$		
0.0000	1101.66	1151.66	1204.74	1261.10	1321.03
0.1033	1015.41	1059.19	1105.66	1154.77	1206.79
0.2005	942.55	981.72	1023.18	1066.83	1113.04
0.3004	873.27	908.18	945.05	983.76	1024.76
0.3970	810.78	841.88	874.67	909.09	945.49
0.5025	747.64	774.99	803.83	834.08	865.97
0.5978	695.44	719.90	745.67	772.66	801.00
0.7012	644.16	666.05	689.06	713.09	738.17
0.7975	601.26	621.21	642.11	663.84	686.45
0.8993	560.41	578.57	597.52	617.17	637.61
1.0000	523.47	539.75	556.76	574.51	593.07
			$10^{12}\ \kappa_T/\mathrm{Pa}^{-1}$		
0.0000	1402.3	1460.6	1522.2	1587.2	1656.0
0.1033	1287.6	1338.7	1392.7	1449.5	1509.4
0.2005	1190.3	1236.0	1284.3	1334.8	1388.1
0.3004	1097.2	1138.0	1180.8	1225.6	1272.9
0.3970	1013.2	1049.4	1087.5	1127.3	1169.2
0.5025	930.3	962.2	995.8	1030.8	1067.6
0.5978	864.2	892.9	923.0	954.4	987.1
0.7012	802.6	828.4	855.4	883.4	912.6
0.7975	753.3	776.9	801.6	827.2	853.8
0.8993	707.1	728.8	751.5	774.9	799.2
1.0000	663.4	683.1	703.6	724.9	747.1
			$C_V/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$		
0.0000	175.09	177.19	179.36	181.59	183.88
0.1033	176.78	178.83	180.90	183.00	185.13
0.2005	178.62	180.58	182.55	184.55	186.58
0.3004	180.61	182.48	184.36	186.29	188.22
0.3970	183.04	184.84	186.66	188.51	190.38
0.5025	185.27	186.96	188.67	190.42	192.19
0.5978	186.87	188.48	190.10	191.76	193.44
0.7012	187.63	189.24	190.86	192.50	194.18
0.7975	188.04	189.58	191.13	192.69	194.28
0.8993	188.20	189.66	191.12	192.61	194.10
1.0000	188.76	190.15	191.55	192.97	194.43
			γ		
0.0000	1.2729	1.2682	1.2635	1.2586	1.2536
0.1033	1.2681	1.2639	1.2596	1.2553	1.2508
0.2005	1.2629	1.2591	1.2552	1.2512	1.2471
0.3004	1.2565	1.2530	1.2495	1.2458	1.2421
0.3970	1.2496	1.2465	1.2434	1.2400	1.2367
0.5025	1.2443	1.2416	1.2388	1.2358	1.2328
0.5978	1.2427	1.2403	1.2378	1.2352	1.2324
0.7012	1.2460	1.2437	1.2414	1.2389	1.2363
0.7975	1.2528	1.2506	1.2484	1.2462	1.2438
0.8993	1.2618	1.2597	1.2577	1.2556	1.2534
1.0000	1.2672	1.2655	1.2637	1.2618	1.2597
			Π/MPa		
0.0000	261.1	256.5	251.8	247.1	242.2
0.1033	271.6	267.2	262.8	258.2	253.5
0.2005	281.4	277.1	272.8	268.3	263.8
0.3004	291.3	287.2	283.0	278.7	274.2
0.3970	301.3	297.4	293.3	289.1	284.8
0.5025	313.1	309.4	305.5	301.5	297.4
0.5978	325.4	321.8	318.1	314.2	310.2
0.7012	340.7	337.3	333.7	330.0	326.2
0.7975	357.0	353.6	350.1	346.5	342.8
0.8993	375.1	371.8	368.3	364.8	361.1
1.0000	391.9	388.8	385.5	382.1	378.4

in Figure 2 the molar excess volumes at 298.15 K have been compared with literature data.[44]

Table 8. Numerical Values of Excess Molar Volumes $V^E(T,x)$ and Excess Molar Heat Capacities $C_p^E(T,x)$ as a Function of Mole Fraction x for {x 1,6-Dichlorohexane + (1 − x) Heptane} at Temperatures T/K = 293.15, 298.15, 303.15, 308.15, and 313.15

			$V^E \cdot 10^6/(\mathrm{m^3 \cdot mol^{-1}})$		
x	T = 293.15 K	T = 298.15 K	T = 303.15 K	T = 308.15 K	T = 313.15 K
0.0998	−0.075	−0.090	−0.097	−0.121	−0.133
0.1999	−0.177	−0.213	−0.226	−0.279	−0.306
0.2998	−0.259	−0.298	−0.327	−0.358	−0.398
0.4001	−0.331	−0.380	−0.437	−0.484	−0.546
0.5001	−0.364	−0.420	−0.463	−0.546	−0.600
0.6002	−0.384	−0.438	−0.476	−0.552	−0.626
0.7000	−0.347	−0.408	−0.453	−0.490	−0.554
0.8002	−0.273	−0.327	−0.341	−0.365	−0.409
0.9001	−0.157	−0.179	−0.201	−0.215	−0.226
			$C_p^E/(\mathrm{J \cdot K^{-1} \cdot mol^{-1}})$		
0.1033	−0.380	−0.346	−0.346	−0.378	−0.444
0.2005	−0.566	−0.559	−0.581	−0.634	−0.716
0.3004	−0.845	−0.856	−0.893	−0.956	−1.045
0.3970	−0.625	−0.634	−0.665	−0.718	−0.794
0.5025	−0.552	−0.591	−0.649	−0.726	−0.821
0.5978	−0.414	−0.470	−0.541	−0.627	−0.728
0.7012	−0.539	−0.524	−0.521	−0.528	−0.547
0.7975	−0.319	−0.319	−0.326	−0.340	−0.362
0.8993	−0.102	−0.117	−0.135	−0.157	−0.183

Because of the relatively small number of data points for $C_p^E(T,x)$, no smoothing function is provided for this property. The data points of excess molar heat capacities at constant pressure $C_p^E(T,x)$ calculated as indicated above for each temperature are plotted against x in Figure 3 (parts a, b, and c). In these figures only smoothing curves as a help to the eye have been drawn through the data points. No literature results could be found for comparison.

The excess molar volumes are all negative and somewhat skewed toward the 1,6-dichlorohexane side. They become more negative with increasing temperature. We note that V^E of {x 1,2-dichloroethane + (1 − x) heptane} at 298.15 K is positive and quite symmetric [$V^E(x = 0.5) = 0.918\ \mathrm{cm^3 \cdot mol^{-1}}$],[16] while V^E of {x 1,4-dichloroehane + (1 − x) heptane}is much smaller and S-shaped.[18] V^E of {x 1,6-dichlorohexane + (1 − x)octane} is also small and S-shaped, but positive excess volumes are only observed for $x \leq 0.157$.[17] As far as the temperature dependence of the excess volume is concerned, results obtained for {x 1,5-dibromopentane + (1 − x) heptane} also show a decrease of V^E with increasing temperature[19] [at 298.15 K, $V^E(x = 0.5) = -0.592\ \mathrm{cm^3 \cdot mol^{-1}}$].

Definitely the most interesting aspect of this work concerns the variation of the excess molar heat capacity at constant pressure with composition and with temperature. The shapes of the curves C_p^E versus x are strikingly similar to the W-shaped/almost W-shaped curves found previously within the series (1,2-dichloroethane + an n-alkane)[16] and (1,4-dichlorobutane + an n-alkane)[18] and for (1,6-dichlorohexane + n-octane).[17] As can be seen in Figures 3, the minima are situated around $x = 0.3$, while very broad shoulders are observed at higher mole fractions. With decreasing temperature, the $C_p^E(x)$ curves become less negative with more pronounced shoulders, which their behavior is reminiscent of the onset of W-shaped composition dependence. The discussion of the C_p^E is most profitably conducted along the lines indicated in the Introduction.[10] Using the Patterson approximation (which is based on Guggenheim's quasi-chemical theory[4]), the (almost) W-shape results from the superposition of a negative, parabolic random contribution due to the destruction of polar order existing in 1,6-dichlorohexane by adding the nonpolar heptane and a nonrandom contribution

Table 9. Coefficients of Equation 13 with Their Standard Deviations and Mean Deviations from the Regression Curve δV^E

T/K	A_0	A_1	A_2	A_3	A_4	δV^E
			$Q^E(T,x) = V^E \cdot 10^6/(\mathrm{m^3 \cdot mol^{-1}})$			
293.15	−1.471 ± 0.008	0.524 ± 0.019			0.445 ± 0.079	0.004
298.15	−1.700 ± 0.010	0.613 ± 0.024			0.395 ± 0.097	0.005
303.15	−1.877 ± 0.021	0.645 ± 0.049			0.590 ± 0.199	0.011
308.15	−2.160 ± 0.036	0.613 ± 0.071	0.485 ± 0.165			0.016
313.15	−2.425 ± 0.042	0.700 ± 0.083	0.633 ± 0.191			0.018

which is always positive with zero slopes against the x axis at both ends of the composition range. With decreasing temperature, the nonrandom contribution increases rapidly, thus making the W-shape more pronounced. However, it is important to note that many of the mixtures showing W-shaped C_p^E curves are fairly close to liquid−liquid phase separation with an upper critical solution temperature T_{UC}. When the T_{UC} is approached from the homogeneous region at constant pressure and constant critical composition x_c, the heat capacity along this path diverges weakly according to

$$C_p^E(x_c) = C_p^E(x_c, \text{non-diverging}) + A_c t^{-\alpha} \qquad (14)$$

where A_c is the critical amplitude, $t \equiv |(T - T_{UC})/T_{UC}|$ is the reduced distance from T_{UC}, and $\alpha = 0.11$ is a universal critical exponent. Evidently, the quasi-chemical approximation underestimates the nonrandom contribution to C_p^E, and increasingly so at low temperatures, and becomes qualitatively incorrect in the vicinity of T_{UC}. Thus, experiments should be performed at

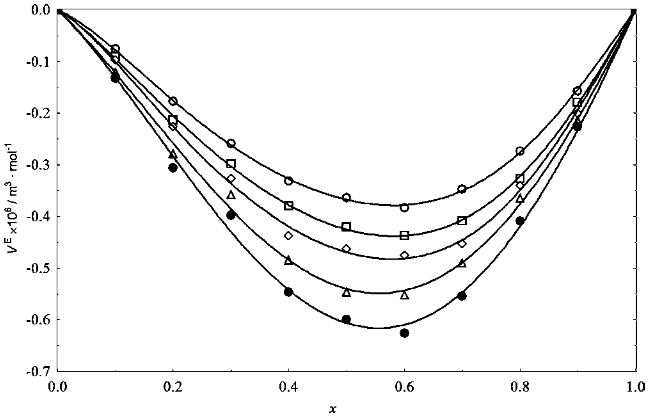

Figure 1. Excess molar volumes V_m^E for {x 1,6-dichlorohexane + (1 − x) heptane} at ○, 293.15 K; □, 298.15 K; ◇, 303.15 K; △, 308.15 K; ●, 313.15 K; —, values calculated from eq 13.

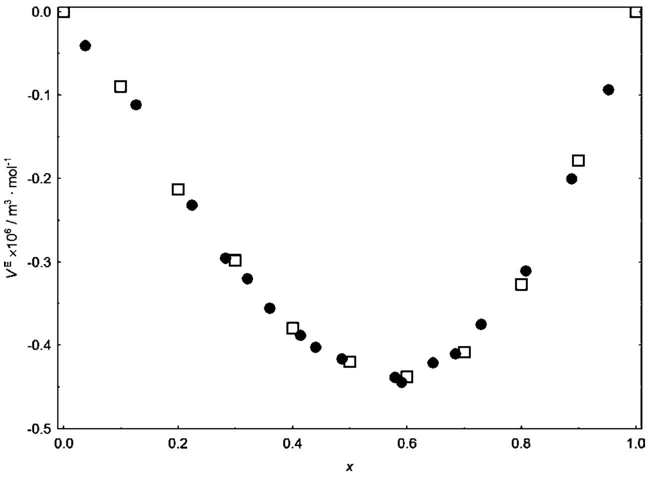

Figure 2. Excess molar volumes V_m^E for {x 1,6-dichlorohexane + (1 − x) heptane} at 298.15 K; □, experimental points from this work; ●, literature data.[44]

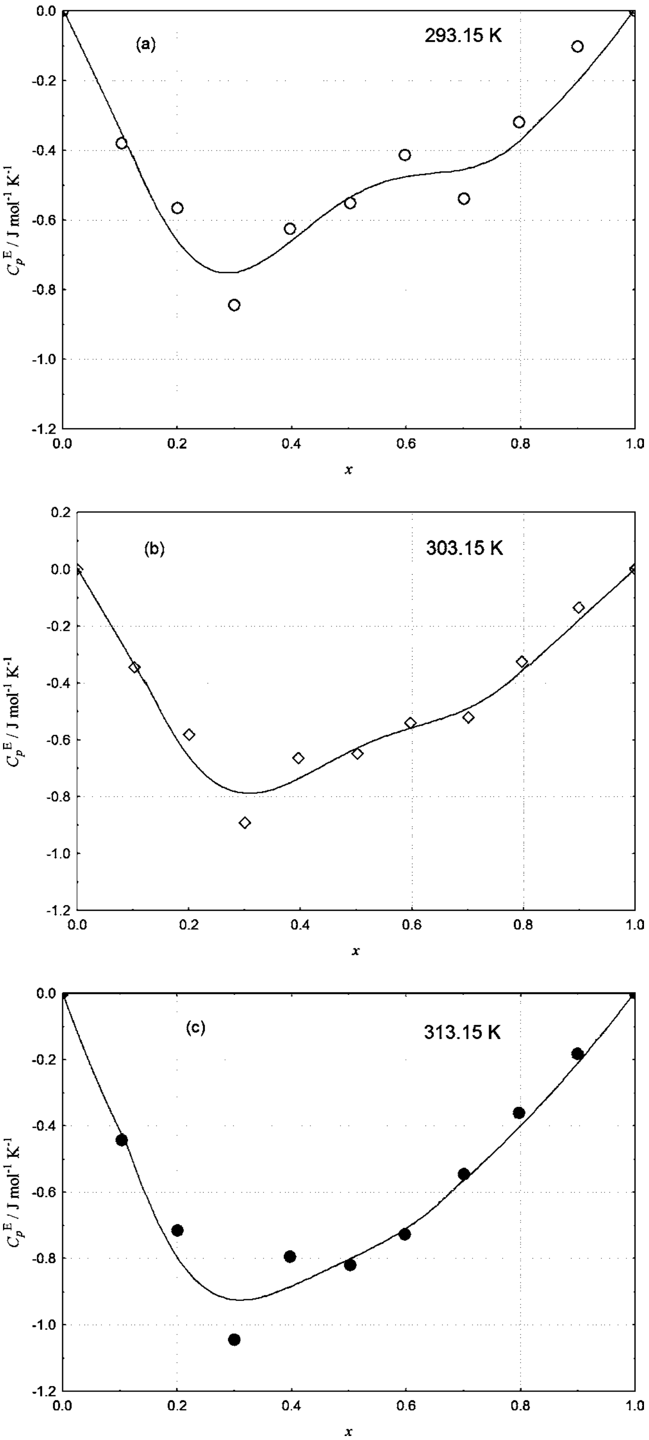

Figure 3. Excess isobaric molar heat capacities C_p^E for {x 1,6-dichlorohexane + (1 − x) heptane} at ○, 293.15 K; ◇, 303.15 K; ●, 313.15 K.

lower temperatures well below 293 K and are indeed planned for the future.

Literature Cited

(1) Pople, J. A. The statistical mechanics of systems with non-central force fields. *Discuss. Faraday Soc.* **1953**, *15*, 35–43.

(2) Kalali, H.; Kohler, F.; Svejda, P. Excess properties of the mixture bis(2-dichloroethyl)ether (chlorex) + 2,2,4-trimethylpentane (isooctane). *Monatsh. Chem.* **1987**, *118*, 1–18.

(3) Patterson, D. Structure and the thermodynamics of non-electrolyte mixtures. *J. Solution Chem.* **1994**, *23*, 105–120.

(4) Guggenheim, E. A. *Mixtures*; Oxford University Press: London, 1952.

(5) Saint-Victor, M.-E.; Patterson, D. The W-shape concentration dependence of C_p^{E} and solution non-randomness: ketones + normal and branched alkanes. *Fluid Phase Equilib.* **1987**, *35*, 237–252.

(6) Wilhelm, E. Thermodynamics of solutions: selected aspects. *Thermochim. Acta* **1990**, *162*, 43–57.

(7) Wilhelm, E. Thermodynamic properties of nonelectrolyte solutions. *High Temp. High Pressures* **1997**, *29*, 613–630.

(8) Cobos, J. C. An exact quasi-chemical equation for excess heat capacity with W-shaped concentration dependence. *Fluid Phase Equilib.* **1997**, *133*, 105–127.

(9) Wilhelm, E. The fascinating world of pure and mixed nonelectrolytes. *Pure Appl. Chem.* **2005**, *77*, 1317–1330.

(10) Wilhelm, E.; Grolier, J.-P. E. Heat Capacities and Related Properties of Liquid Mixtures. Presented in *Heat Capacities: Liquids, Solutions and Vapours*; Wilhelm, E., Letcher, T. M., Eds.; The Royal Society of Chemistry/IUPAC & IACT: Cambridge, UK, 2010; pp 54−85.

(11) Panayiotou, C.; Vera, J. H. The quasi-chemical approach for non-randomness in liquid mixtures. Expressions for local surfaces and local compositions with an application to polymer solutions. *Fluid Phase Equilib.* **1980**, *5*, 55–80.

(12) Grolier, J.-P. E.; Inglese, A.; Wilhelm, E. Excess molar heat capacities of (1,4-dioxane + an *n*-alkane): an unusual composition dependence. *J. Chem. Thermodyn.* **1984**, *16*, 67–71.

(13) Findenegg, G. H.; Kohler, F. Molar heat capacity at constant volume of binary mixtures of 1,2-dibromo- and 1,2-dichloroethane with benzene. *Trans. Faraday Soc.* **1967**, *63*, 870–878.

(14) Wilhelm, E.; Schano, R.; Becker, G.; Findenegg, G. H.; Kohler, F. Binary mixtures of 1,2-dichloroethane and 1,2-dibromoethane with cyclohexane. *Trans. Faraday Soc.* **1969**, *65*, 1443–1455.

(15) Wilhelm, E.; Grolier, J.-P. E.; Karbalai Ghassemi, M. H. Molar heat capacity of binary liquid mixtures: 1,2-dichloroethane + cyclohexane and 1,2-dichloroethane + methylcyclohexane. *Thermochim. Acta* **1979**, *28*, 59–69.

(16) Lainez, A.; Roux-Desgranges, G.; Grolier, J.-P. E.; Wilhelm, E. Mixtures of alkanes with polar molecules showing internal rotation: an unusual composition dependence of C_p^{E} of 1,2-dichloroethane + an n-alkane. *Fluid Phase Equilib.* **1985**, *20*, 47–56.

(17) Lainez, A.; Grolier, J.-P. E.; Wilhelm, E. Excess molar heat capacity and excess molar volume of 1,6-dichlorohexane + *n*-octane. *Thermochim. Acta* **1985**, *91*, 243–248.

(18) Lainez, A.; Wilhelm, E.; Roux-Desgranges, G.; Grolier, J.-P. E. Excess molar quantities of (a halogenated *n*-alkane + an *n*-alkane). A comparative study of mixtures containing either 1-chlorobutane or 1,4-dichlorobutane. *J. Chem. Thermodyn.* **1985**, *17*, 1153–1161.

(19) Chorążewski, M. A.; Tkaczyk, M. Heat capacity, speed of ultrasound, and density for 1,5-dibromopentane + heptane within the temperature range from 293.15 to 313.15 K. *J. Chem. Eng. Data* **2006**, *51*, 1825–1831.

(20) Chorążewski, M. A. Thermophysical and acoustical properties of the binary mixtures 1,2-dibromoethane + heptane within the temperature range from 293.15 to 313.15 K. *J. Chem. Eng. Data* **2007**, *52*, 154–163.

(21) Kehiaian, H. V. Thermodynamik flüssiger Mischungen von Kohlenwasserstoffen mit verwandten Substanzen. *Ber. Bunsen-Ges. Phys. Chem.* **1977**, *81*, 908–921.

(22) Kehiaian, H. V.; Grolier, J.-P. E.; Benson, G. C. Thermodynamics of organic mixtures. A generalized quasichemical theory in terms of group surface interactions. *J. Chim. Phys.* **1978**, *75*, 1031–1048.

(23) Kehiaian, H. V. Group contribution methods for liquid mixtures: a critical review. *Fluid Phase Equilib.* **1983**, *13*, 243–252.

(24) Wieser, M. E. Inorganic Chemistry Division, Commission on Isotopic Abundances and Atomic Weights. Atomic Weights of the Elements 2005. *Pure Appl. Chem.* **2006**, *78*, 2051–2066.

(25) Góralski, P.; Tkaczyk, M.; Chorążewski, M. A. DSC measurements of heat capacities of α,ω-dichloroalkanes within the temperature range from 284.15 to 353.15 K. A group additivity analysis. *J. Chem. Eng. Data* **2003**, *48*, 492–496.

(26) Marczak, W. Water as a standard in the measurements of speed of sound in liquids. *J. Acoust. Soc. Am.* **1997**, *102*, 2776–2779.

(27) Fortier, J.-L.; Benson, G. C.; Picker, P. Heat capacities of some organic liquids determined with the Picker flow calorimeter. *J. Chem. Thermodyn.* **1976**, *8*, 289–299.

(28) *TRC Databases for Chemistry and Engineering - Thermodynamic Tables*, Version 1998−2.d-1460, 1991; d-5000, 1966; Thermodynamic Research Center: Texas A&M University System, College Station, TX, 1998.

(29) Cerdeiriña, C. A.; Tovar, C. A.; González-Salgado, D.; Carballo, E.; Romani, L. Isobaric thermal expansivity and thermophysical characterization of liquids and liquid mixtures. *Phys. Chem. Chem. Phys.* **2001**, *3*, 5230–5236.

(30) Kiyohara, O.; Benson, G. C. Ultrasonic speeds and isentropic compressibilities of *n*-alkanol + *n*-heptane mixtures at 298.15 K. *J. Chem. Thermodyn.* **1979**, *11*, 861–873.

(31) Dzida, M.; Góralski, P. Excess molar heat capacities for (decan-1-ol + *n*-heptane) at temperatures from (290 to 318) K. Experimental results and theoretical description using the ERAS model. *J. Chem. Thermodyn.* **2006**, *38*, 962–969.

(32) Růžička, V.; Zabransky, M.; Majer, V. Heat capacities of organic compounds in liquid state. II. C1 to C18 *n*-alkanes. *J. Phys. Chem. Ref. Data* **1991**, *20*, 405–444.

(33) *CRC Handbook of Thermophysical and Thermochemical Data*; Lide, D. R., Kehiaian, H. V., Eds.; CRC Press: Boca Raton, FL, 1994.

(34) Treszczanowicz, A. J.; Halpin, C. J.; Benson, G. C. Excess volumes and isentropic compressibilities of 2,5,8-trioxanonane-*n*-heptane mixtures. *J. Chem. Eng. Data* **1982**, *27*, 321–324.

(35) Junquera, E.; Tardajos, G.; Aicart, E. Speeds of sound and isentropic compressibilities of (cyclohexane + benzene) and (1-chlorobutane + *n*-hexane or *n*-heptane or *n*-octane or *n*-decane) at 298.15 K. *J. Chem. Thermodyn.* **1988**, *20*, 1461–1467.

(36) Aicart, E.; Kumaran, M. K.; Halpin, C. J.; Benson, G. C. Ultrasonic speeds and isentropic compressibilities of *n*-heptane + each of the hexane isomers at 298.15 K. *J. Chem. Thermodyn.* **1983**, *15*, 919–925.

(37) Tamura, K.; Ohomuro, K.; Murakami, S. Speeds of sound, isotropic and isothermal compressibilities, and isochoric heat capacities of $\{x\text{c-C}_6\text{H}_{12} + (1-x)\text{C}_6\text{H}_6\}$, $\{x\text{CCl}_4 + (1-x)\text{C}_6\text{H}_6\}$, and $\{x\text{C}_7\text{H}_{16} + (1-x)\text{C}_6\text{H}_6\}$ at 298.15 K. *J. Chem. Thermodyn.* **1983**, *15*, 859–868.

(38) Zorębski, E.; Zorębski, M.; Ernst, S. *A pulse-echo-overlap system for ultrasound velocity measurements in liquids. Testing and discussions of the errors*; Papers of the World Congress on Ultrasonics: Berlin, 1995; pp 547−550.

(39) Blinowska, A.; Brostow, W. Experimental volumetric properties of liquid *n*-alkanes and their binary mixtures. *J. Chem. Thermodyn.* **1975**, *7*, 787–794.

(40) Díaz Peña, M.; Tardajos, G. Isothermal compressibilities of *n*-alkanes and benzene. *J. Chem. Thermodyn.* **1978**, *10*, 19–24.

(41) Aicart, E.; Tardajos, G.; Díaz Peña, M. Isothermal compressibility of cyclohexane + *n*-hexane, cyclohexane + *n*-heptane, cyclohexane + *n*-octane, and cyclohexane + *n*-nonane. *J. Chem. Eng. Data* **1980**, *25*, 140–145.

(42) Müller, A.; Vanc, W. 6-Chlor-hexanol-(1), Chlor-und Oxy-äther aus Hexandiol-(1,6). *Monatsh. Chem.* **1947**, *77*, 259–263.

(43) González-Salgado, D.; Peleteiro, J.; Troncoso, J.; Carballo, E.; Romaní, L. Heat capacities, densities, and speeds of sound for {(1,5-dichloropentane or 1,6-dichlorohexane) + dodecane}. *J. Chem. Eng. Data* **2004**, *49*, 333–338.

(44) Blanco, A. M.; Ortega, J. Excess volumes of α,ω-dichloroalkanes (C2−C6) + some normal alkanes (C5−C17) mixtures. *Int. DATA Ser., Sel. Data Mixtures, Ser. A* **1993**, *21*, 195–231.

Received for review June 1, 2010. Accepted July 26, 2010.

JE100610V