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Partial molal adiabatic compressibilities of transfer of some amino acids and peptides from water to aqueous sodium chloride and aqueous glucose solutions☆

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Abstract

Partial molal adiabatic compressibilities at infinite dilution have been determined for glycine, DL-alanine, diglycine and triglycine in water, 1 M aqueous sodium chloride and 1 M aqueous glucose solutions by measuring sound velocities at 298.15 K. In the case of water, our results show a non-linear relationship between the partial molal adiabatic compressibility at inifinite dilution ($K_{s,2}^{\ominus}$) and the number n of glycyl units for $n = 1$–3, and the results have been compared with the literature values. The data have been used to derive partial molal adiabatic compressibilities of transfer at infinite dilution ($K_{s,2,tr}^{\ominus}$) from water to 1 M aqueous sodium chloride and to 1 M aqueous glucose solutions. All transfer values are found to be positive which in the case of sodium chloride results from the dominant interactions between the ions of sodium chloride and the charged centres of amino acids or peptides. However, in the case of glucose these have been discussed in terms of the interactions between ions (charged centres), hydrophilic groups (OH and CONH) and hydrophobic groups.

Keywords: Adiabatic; Amino acid; Glucose; Peptide; Sodium chloride

1. Introduction

The denaturation of globular proteins in aqueous solutions is a fundamental biological process which is not yet completely understood and remains a subject of

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extensive investigations [1–3]. In the process of denaturation of a globular protein in aqueous solutions, the native folded conformation of protein is converted predominantly into an extended unfolded form and during this process various changes will occur in protein solvation. Thus the study of these solute–solvent and solute–solute interactions is essential due to their important contribution to the energetics of protein denaturation. As the proteins are large complex molecules, direct study of these interactions is difficult. One useful approach that can be used to understand these interactions is to study those compounds which mimic some aspects of the protein structure. In recent years there has been considerable interest in the determination of various thermodynamic properties of such model compounds, e.g. amino acids, small peptides and their derivatives [4–11]. One of the objectives of these studies is to devise some possible additivity schemes to estimate the thermodynamic properties of protein molecules.

Although a variety of thermodynamic properties [8–12] (such as partial molal heat capacities, partial molal volumes, heats of solution, partial molal compressibilities and expansibilities) have been determined for aqueous solutions of amino acids and their derivatives, a literature survey reveals that measurements on partial molal compressibilities and expansibilities are scarce [10, 13]. In order to fill these gaps in data and to obtain a better understanding of the hydration of biological systems, we report partial molal adiabatic compressibilities for glycine, DL-alanine, diglycine and triglycine in aqueous solutions.

Other neutral salts and sugars [11, 12, 14–16] have been known to produce remarkable effects on the stability of proteins; therefore to understand these effects we also report partial molal adiabatic compressibilities of the above solutes in aqueous solutions of sodium chloride and glucose. The results have been discussed in terms of various solute–solvent and solute–solute interactions.

2. Experimental

Glycine (G 7126), DL-alanine (A 750), diglycine (G 1002) and triglycine (G 1377) of highest purity were obtained from Sigma Chemical Co. and were used without further purification. However, before use these were dried over P_2O_5 in a vacuum desiccator. Analytical reagent grade sodium chloride (Ranbaxy Lab. Ltd., India) and glucose (Glaxo, Qualigens, India) were used after drying at 373 and 333 K (in a vacuum oven) for 48 h respectively. Water used for these investigations was deionized, doubly glass-distilled and degassed by boiling. All solutions were made on a weight basis with an accuracy of $\pm 1 \times 10^{-4}$ g.

Ultrasonic velocities in solutions were measured by determining the wavelength of sound in these media using a Multifrequency Ultrasonic Interferometer Model M-82 (Mittal Enterprises, India) working at 2 MHz. The temperature of the solution was controlled by circulating water through the jacket of a double-walled cell from a constant temperature bath controlled to ± 0.01 K. The measured sound velocities have an uncertainty of $\pm 0.5\ m\ s^{-1}$. The observed value of sound velocity for water at 298.15 K was in good agreement with literature values [17].

3. Results and discussion

The measured sound speeds (u) for solutions of glycine, DL-alanine, diglycine and triglycine as a function of molality in water, 1 M aqueous sodium chloride and 1 M glucose solutions are summarized in Table 1. Using these sound speeds, adiabatic

Table 1
Sound speeds and apparent molal adiabatic compressibilities of some amino acids and peptides in water, aqueous sodium chloride (1 M) and aqueous glucose (1 M) solution at 298.15 K

m/(mol kg^{-1})	u/(m s^{-1})	$-10^{15} K_{S,2,\phi}$/(m^3 mol^{-1} Pa^{-1})
In water		
Glycine		
0.05152	1499.43	26.56
0.06219	1500.03	26.79
0.07808	1500.70	26.61
0.07830	1500.70	25.52
0.11192	1502.93	26.47
0.17360	1505.63	25.81
DL-Alanine		
0.06624	1501.13	25.71
0.07557	1501.73	25.70
0.09317	1502.90	25.66
0.10406	1503.63	25.75
0.11624	1504.33	25.19
Diglycine		
0.04241	1498.96	39.63
0.05382	1499.92	39.75
0.06193	1500.56	39.41
0.09967	1503.72	39.73
0.10485	1504.09	39.33
0.11048	1504.52	39.15
0.14181	1507.08	39.08
Triglycine		
0.02979	1499.51	44.03
0.03105	1499.63	43.99
0.03666	1500.20	44.13
0.03758	1500.26	43.93
0.03768	1500.26	43.76
0.04758	1501.23	43.84
In 1 M sodium chloride solution		
Glycine		
0.10802	1563.53	11.80
0.11365	1563.67	11.54
0.13146	1564.28	11.54
0.23146	1568.14	11.26
0.23827	1568.36	11.18

Table 1 *(continued)*

m/(mol kg^{-1})	u/(m s^{-1})	$-10^{15} K_{S,2,\phi}$/(m^3 mol^{-1} Pa^{-1})
DL-Alanine		
0.07783	1563.23	9.30
0.07881	1563.28	9.34
0.08364	1563.98	9.24
0.09908	1564.28	9.08
0.10951	1564.80	9.02
Diglycine		
0.02338	1560.85	23.27
0.02793	1561.19	23.16
0.03571	1561.78	23.09
0.05925	1563.51	22.58
0.06474	1563.96	22.42
Triglycine		
0.02032	1561.52	29.24
0.02482	1561.95	29.23
0.02864	1562.32	29.01
0.02963	1563.42	29.03
0.04266	1563.70	28.91
0.04585	1563.99	28.58
In 1 M glucose solution		
Glycine		
0.08343	1562.10	16.48
0.09521	1562.67	16.35
0.12883	1564.35	16.38
0.15289	1565.48	16.18
DL-Alanine		
0.07789	1562.91	13.79
0.11572	1565.04	13.36
0.12844	1565.83	13.54
0.13649	1566.23	13.32
0.14682	1567.02	13.30
Diglycine		
0.02200	1558.97	18.97
0.03922	1560.16	18.81
0.05381	1561.18	18.88
0.05786	1561.43	18.64
0.07820	1562.83	18.67
Triglycine		
0.01542	1559.01	21.41
0.01800	1559.21	21.40
0.02137	1559.53	21.20
0.03215	1560.46	20.88
0.03262	1560.50	20.84

compressibility K_S was calculated from the relation

$$K_S = \frac{1}{u^2 d}$$

where d is the density of the solution which was taken from the literature [11, 12, 18, 19]. The apparent molal adiabatic compressibilities ($K_{S,2,\phi}$) of the solutes were determined using the relation

$$K_{S,2,\phi} = \frac{M_2 K_S}{d} - \frac{K^*_{S,1} d - K_S d^*_1}{m d d^*_1}$$

where M_2 is the solute molar mass, d and d^*_1 are the densities of solution and solvent, K_S and $K^*_{S,1}$ are the adiabatic compressibilities of solution and solvent, and m is the molality of the solution. $K_{S,2,\phi}$ values are also included in Table 1. For all solutes, a linear dependence of $K_{S,2,\phi}$ on m over the range studied was observed; therefore, linear regression analysis of $K_{S,2,\phi}$ was carried out to find the partial molal adiabatic compressibilities at infinite dilution ($K^{\ominus}_{S,2}$) as follows

$$K_{S,2,\phi} = K^{\ominus}_{S,2} + S_k m$$

where S_k is the experimental slope. Values of $K^{\ominus}_{S,2}$ are summarized in Table 2 along with standard deviations. Apparent molal adiabatic compressibilities of transfer ($K^{\ominus}_{S,2,tr}$)

Table 2
Values of $K^{\ominus}_{S,2}$ and S_k for some amino acids and peptides in water, 1 M aqueous sodium chloride and 1 M aqueous glucose solution at 298.15 K at infinite dilution

Amino acid/peptide	$10^{15} K^{\ominus}_{S,2}/(m^3\,mol^{-1}\,Pa^{-1})$	$10^{15} S_k/(m^3\,kg\,mol^{-2}\,Pa^{-1})$
In water		
Glycine	−27.09(0.16), −27.0 ± 0.4 [a], −27.3 ± 1.2 [b]	+6.73
DL-Alanine	−26.28(0.20), −25.2 ± 1.3 [c]	+7.53
Diglycine	−39.92(0.20), −35.91 ± 0.9 [d], −41.5 ± 0.5 [e] −40.2 ± 0.1 [f], −35.5 ± 0.5 [g]	+5.53
Triglycine	−44.10(0.13), −44.4 ± 0.8 [h], −44.9 ± 0.01 [i]	+3.58
In 1 M sodium chloride solution		
Glycine	−12.05(0.11)	+3.57
DL-Alanine	−10.08(0.03)	+9.84
Diglycine	−23.75(0.04)	+20.15
Triglycine	−29.71(0.11)	+22.21
In 1 M glucose solution		
Glycine	−16.73(0.08)	+3.36
DL-Alanine	−14.19(0.15)	+6.30
Diglycine	−19.06(0.09)	+5.35
Triglycine	−21.95(0.06)	+33.96

[a] Ref. [17]. [b] Ref. [20]. [c] Ref. [17]. [d] Ref. [21]. [e] Ref. [23]. [f] Ref. [6]. [g] Ref. [22]. [h] Ref. [21]. [i] Ref. [6].
Standard deviations are given in parentheses.

from water to 1 M aqueous sodium chloride or 1 M glucose solutions are listed in Table 3; they were evaluated as follows.

$$K^{\ominus}_{S,2,tr}\ (\text{water} \rightarrow \text{1 M aqueous sodium chloride or glucose})$$
$$= K^{\ominus}_{S,2}\ (\text{in 1 M aqueous sodium chloride or glucose}) - K^{\ominus}_{S,2}\ (\text{in water})$$

3.1. Partial molal compressibilities in water

Available literature values of $K^{\ominus}_{s,2}$ in water are also recorded in Table 2 for comparison. For glycine, DL-alanine and triglycine in water, the $K^{\ominus}_{S,2}$ values determined in the present work are in good agreement with those reported in the literature [6, 17, 20–23]. For diglycine, our value of $K^{\ominus}_{S,2}$ ($-39.92 \times 10^{-15}\ m^3\ mol^{-1}\ Pa^{-1}$) is close to those reported by Hedwig and Hoiland [6] ($-40.2 \pm 0.1 \times 10^{-15}\ m^3\ mol^{-1}\ Pa^{-1}$) and Hoiland [23] ($-41.5 \pm 0.5 \times 10^{-15}\ m^3\ mol^{-1}\ Pa^{-1}$), and is quite different from those reported by Iqbal and Verrall [21] ($-35.91 \pm 0.09 \times 10^{-15}\ m^3\ mol^{-1}\ Pa^{-1}$) and Cabani et al. [22] ($-35.5 \pm 0.5 \times 10^{-15}\ m^3\ mol^{-1}\ Pa^{-1}$). No data are available for comparison on apparent molal compressibilities of these compounds in aqueous 1 M sodium chloride and 1 M glucose solutions.

Although $K_{S,2,\phi}$ vs. m data for glycine and DL-alanine show similar behaviour in aqueous medium, slightly smaller negative magnitudes of $K^{\ominus}_{S,2}$ for DL-alanine indicates that glycine is in a more electrostricted environment as compared to DL-alanine. The hydrophobic hydration of a methyl group (non-polar) will result in the tightening of water molecules around it which will form less compressible water than the bulk water and this exhibits a negative contribution to $K^{\ominus}_{S,2}$. However, the observed positive contribution ($0.81\ m^3\ mol^{-1}\ Pa^{-1}$) shows that some other effect is also operative which outweighs the contribution from hydrophobic hydration of the methyl group itself. This may be due to the distortion or disruption of the hydrogen bonding interaction of zwitterionic charged centres with water. This is supported by the observation made by Hedwig and Hoiland [7, 9] from $K^{\ominus}_{S,2}$ values for some tripeptides that model protein side chains.

For diglycine and triglycine, large negative values of $K^{\ominus}_{S,2}$ may be attributed to the presence of extra peptide groups which participate in hydrogen bonding, resulting in negative contributions to $K^{\ominus}_{S,2}$ [9]. Iqbal and Verrall [21] have reported a linear

Table 3
Values of partial molal compressibilities of transfer ($10^{15}\ K^{\ominus}_{S,2,tr}/(m^3\ mol^{-1}\ Pa^{-1})$) from water to 1 M aqueous sodium chloride or 1 M aqueous glucose solution at 298.15 K

Amino acid/ Peptide	Water → 1 M sodium chloride solution	Water → 1 M glucose solution
Glycine	15.04	10.36
DL-Alanine	16.20	12.08
Diglycine	16.17	20.86
Triglycine	14.39	22.15

relation between $K^{\ominus}_{S,2}$ and n (where n is the number of glycyl units in a given solute) for a series from $n = 1$ to 4. In Fig. 1, the present data as well as those reported by Iqbal and Verrall [21] and by Hedwig and Hoiland [6] are plotted. It is observed that our results agree well with Hedwig and Hoiland [6] and a non-linear relationship between $K^{\ominus}_{S,2}$ and the number of glycyl units exists. For this non-linear relationship, Hedwig and Hoiland [6] have advanced the plausible explanation that in amino acids and short-chain dipeptides in water, the end-group hydration interferes with the hydration of all of the intervening chain because of the overlap of the cospheres. Various other workers [24–26] have also discussed these end-group effects manifested in the values of the partial molal volumes at infinite dilution.

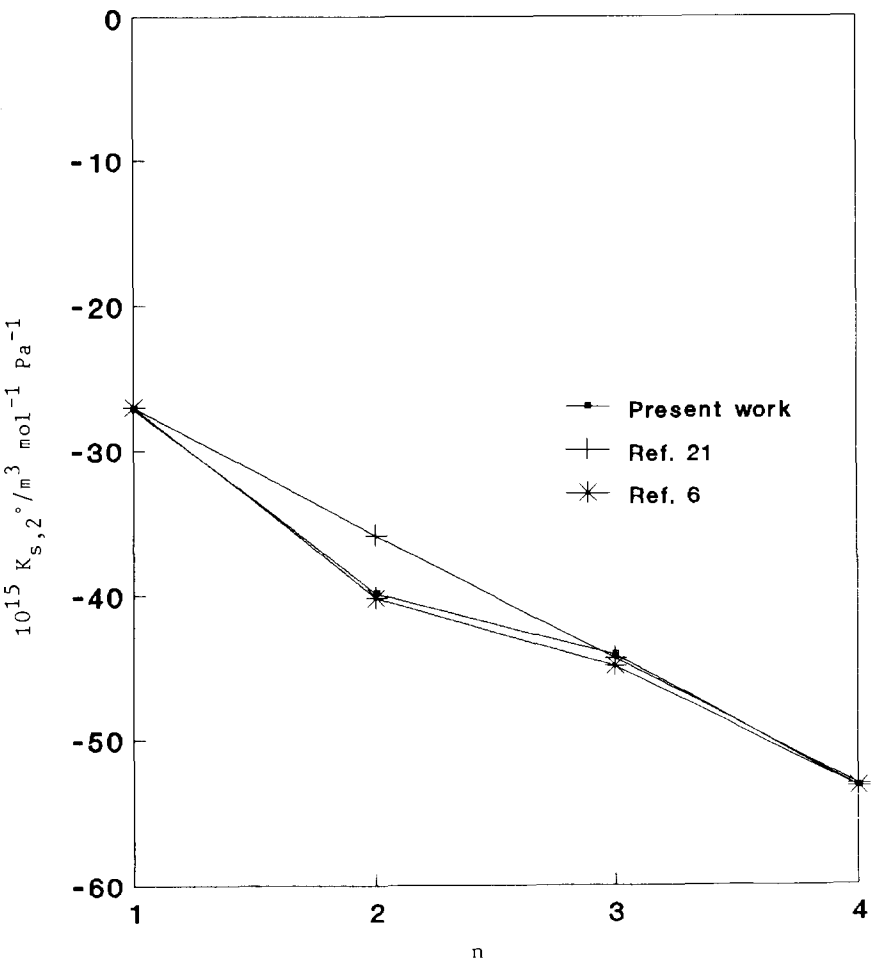

Fig. 1. Plot of $K^{\ominus}_{S,2}$ vs. n (number of glycyl units).

3.2. Partial molal compressibilities in 1 M aqueous sodium chloride solution

$K_{S,2}^{\ominus}$ values (Table 2) for all amino acids and peptides are negative and their magnitudes are less than the corresponding values in water. The apparent molal compressibilities of transfer $K_{S,2,tr}^{\ominus}$ from water to 1 M sodium chloride at infinite dilution are given in Table 3 and are found to be positive. These positive values of transfer may be attributed to the interactions occurring between Na^+ and COO^-, and Cl^- and NH_3^+ ions. Due to these interactions, the electrostriction of neighbouring water molecules around the charged centres of amino acids and peptides will be reduced in the presence of sodium chloride. Therefore, the electrostricted water goes out of the hydration spheres of these ions and enters into the bulk which is more compressible [9, 27, 28], thus making a positive contribution to $K_{S,2}^{\ominus}$. This explanation is in line with the conclusion drawn from the positive partial molal heat capacities and volumes of transfer for the above amino acids and peptides reported by Bhat and Ahluwalia [11].

3.3. Partial molal compressibilities in 1 M aqueous glucose solution

The $K_{S,2}^{\ominus}$ values for all the studied amino acids and peptides in 1 M glucose solution (Table 2) are negative and their magnitudes are less than the corresponding values in water which result in positive values of partial molal compressibilities of transfer. These positive values of transfer may be rationalized by first considering the behaviour of glucose in water and then the various types of interactions occurring between amino acids or peptides and glucose molecules.

Bernal and Van Hook [29] have reported a $K_{S,2}^{\ominus}$ value for glucose at 298.15 K which is large and negative (-17.80 ± 0.01 m^3 mol^{-1} Pa^{-1}) and, together with the apparent molal volumes, they indicate that the water molecules in contact with sugar, constituting the so-called first hydration cell, are considerably less compressible than the bulk solvent. Jasra and Ahluwalia [30, 31] have reported partial molal heat capacities, volumes and enthalpies of solutions of sugars in water and explained the results in terms of a specific hydration model. The high positive heat capacities of these compounds have been attributed to stronger and more extensive hydrogen bonding between solute hydroxyl groups and water molecules. The compatibility of the sugar structure with the tetrahedral structure of water has also been discussed.

Now it may be concluded that due to the interactions between amino acids or peptides and glucose, the less compressible water present in their hydration cells comes out into the bulk water (which is more compressible), exhibiting positive partial molal adiabatic compressibilities of transfer. The positive $K_{S,2,tr}^{\ominus}$ values may be the result of various interactions between solute molecules and glucose molecules which may be classified as [12]: (i) hydrophilic–ionic group interactions between OH groups of glucose molecules and zwitterionic centres of amino acids or peptides; (ii) hydrophilic–hydrophilic group interactions between OH groups of glucose molecules and the CONH group of the peptides mediated through hydrogen bonding; and (iii) hydrophilic–hydrophobic group interactions between the OH groups of glucose and non-polar groups (CH_3 or CH_2) of the amino acids or peptides. The first type of interaction will make a positive contribution to $K_{S,2}^{\ominus}$ because, due to the overlap of the

cospheres of an ion (in this case NH_3^+ and COO^-) and a hydrophilic OH group, the electrostriction of the solvent caused by these ions will be reduced. Similarly, the second type of interaction will contribute positively to $K^{\ominus}_{S,2}$ because due to the hydrogen bonding between OH and CONH groups, the hydration cospheres will also be reduced. However, the third type of interaction will make a negative contribution to $K^{\ominus}_{S,2}$ due to the reduction in the water structure that is formed around those groups as a result of their cosphere overlap. Therefore, it may be concluded that the first two types of interaction predominate over the third type of interaction. Also the magnitude of $K^{\ominus}_{S,2,tr}$ increases with the increase in glycyl units from glycine to triglycine which may be attributed to the contribution from the second type of interaction.

References

[1] T.E. Creighton, Protein Folding, W.H. Freeman and Co., New York, 1992.
[2] S. Lapanje, Physicochemical Aspects of Protein Denaturation, Wiley, New York, 1978.
[3] G. Rialdi and R. Biltonen, in H.A. Skinner (Ed.), International Review of Science, Physical Chemistry, Series 2, Vol. 10, Butterworth, London, 1975, p. 147–189.
[4] T.H. Lilley, in M.N. Jones (Ed.), Biochemical Thermodynamics, Elsevier, Amsterdam, 2nd edn., 1988, Chap. 1.
[5] F. Franks, in M.N. Jones (Ed.), Biochemical Thermodynamics, Elsevier, Amsterdam, 2nd edn., 1988, Chap. 2.
[6] G.R. Hedwig and H. Hoiland, J. Chem. Thermodyn., 23 (1991) 1029.
[7] G.R. Hedwig and H. Hoiland, J. Chem. Thermodyn., 25 (1993) 349.
[8] G.R. Hedwig, Pure Appl. Chem., 66(3) (1994) 387.
[9] G.R. Hedwig and H. Hoiland, Biophys. Chem., 49 (1994) 175.
[10] T.V. Chalikian, A.P. Sarvazyan and K.J. Breslauer, J. Phys. Chem., 97 (1993) 13017.
[11] R. Bhat and J.C. Ahluwalia, J. Phys. Chem., 99 (1985) 1099.
[12] R. Bhat, N. Kishore and J.C. Ahluwalia, J. Chem. Soc. Faraday Trans. 1, 84 (1988) 2651.
[13] A.A. Yayanos, J. Phys. Chem., 97 (1993) 13027.
[14] R. Bhat and J.C. Ahluwalia, Int. J. Pept. Protein Res., 30 (1987) 145.
[15] P.H. Von Hippel and T. Schleich, in S.N. Timasheff and G.D. Fasman (Eds.), Structure and Stability of Biological Macromolecules, Vol. 2, Marcel Dekker, New York, 1969, p. 417.
[16] K.B. Belibagli and E. Ayranci, J. Solution Chem., 19(9) (1990) 867.
[17] F.J. Millero, L.S. Antonio and S. Charles, J. Phys. Chem., 82 (1978) 784.
[18] R. Bhat, Ph.D. Thesis, Indian Institute of Technology, India, 1985.
[19] R.K. Wadi, A. Gupta and D.V.S. Jain, Indian J. Chem, 20A (1981) 21.
[20] B.S. Lark, S. Singh and K. Bala, Indian J. Pure Appl. Phys., 22 (1984) 404.
[21] M. Iqbal and R.E. Verrall, J. Phys. Chem., 91 (1987) 967.
[22] S. Cabani, G. Conti, E. Matteoli and M.R. Tine, J. Chem. Soc. Faraday Trans. 1, 77 (1981) 2385.
[23] H. Hoiland, in H.-J., Hinz (Ed.), Thermodynamic Data for Biochemistry and Biotechnology, Springer-Verlag, Berlin 1986, Chap. 4, p. 140.
[24] A.K. Mishra and J.C. Ahluwalia, J. Phys. Chem., 88 (1984) 86.
[25] C. Jolicoeur and J. Boileau, Can. J. Chem., 56 (1978) 2707.
[26] T.H. Lilley, in G.C. Barrett (Ed.), The Chemistry and Biochemistry of the Amino Acids, Chapman and Hall, London, 1985, Chap. 21.
[27] B.E. Conway and R.E. Verrall, J. Phys. Chem., 70 (1966) 3952.
[28] S. Cabani, G. Conti and E. Matteoli, J. Solution Chem., 8 (1979) 11.
[29] P. Bernal and W.A. Van Hook, J. Chem. Thermodyn., 18 (1986) 955.
[30] R.V. Jasra and J.C. Ahluwalia, J. Solution Chem., 11(2) (1982) 325.
[31] R.V. Jasra and J.C. Ahluwalia, J. Chem. Thermodyn., 16 (1984) 583.