

EXPERIMENTAL AND CALCULATED THERMODYNAMIC PROPERTIES OF L-ALANINE IN AQUEOUS NaCl SOLUTIONS AT $T = (293.15 \text{ to } 323.15)\text{K}$

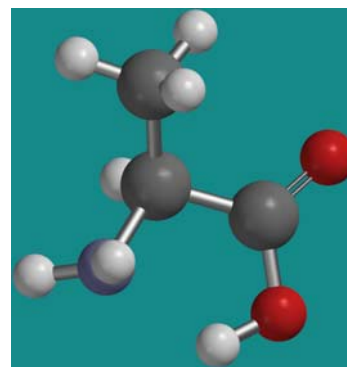
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The density and the viscosity for L-alanine in NaCl aqueous solutions have been measured at $T = (293.15, 303.15, 313.15 \text{ and } 328.15) \text{ K}$. In order to assess the effect of NaCl concentration and the increasing temperature influence of the L-alanine behaviour in ternary mixtures (L-alanine + water + NaCl), different salt concentrations have been used: 0.5027, 1.0000 and 1.4970 mol·kg⁻¹. The investigated properties were also been measured as a function of the concentration of amino acid. The obtained experimental data have been used to calculate their derived properties: the apparent molar volumes, the transfer volumes, the Falkenhagen (*A*) coefficients and the Jones-Dole viscosity coefficients (*B*) for L-alanine in water and in water + NaCl systems, respectively. An attempt has been made to interpret the solutes behaviour in these systems, in terms of the concept of the kosmotropicity (water-structure promoting capability).



INTRODUCTION

Amino acids and small peptides are considered as model compounds, useful to assess thermodynamic behavior of complex macromolecules, such as polypeptides, proteins and enzymes, becoming a key to understand the interactions occurring in these systems. Amino acids physico-chemical properties in various solvents, starting with water at standard investigated temperature (298.15 K), were studied in order to evaluate the possible interactions and the main physico-chemical parameters. The obtained information is useful to elaborate mathematical models for predicting the variation of properties in systems containing water and electrolyte and for evaluating the solutes-solvent interactions.

L-alanine, also known as 2-amino propionic acid or L-2-aminopropionic acid is a nonessential amino acid, monoamine, monocarboxylic, contain-

ing the hydrophobic (non-polar) methyl radical. It is one of the most important amino acids, functioning as a major source of energy. The excess of alanine may be converted by the organisms to glucose and used as an energy source. Alanine is also a neurotransmitter. In its free crystalline form, alanine is soluble in water. The maximum solubility of L-alanine in water at 298.15K is 1.867 mol·kg⁻¹ and 2.443 mol·kg⁻¹ at 323.15K.¹ In industry, alanine is mainly used as raw material for pharmaceutical products, e.g. for obtaining vitamin B6 or as ingredients and / or food supplement.

Various papers report experimental and calculated data for system containing amino acids in aqueous solutions of: KCl,^{2,3} NaCl,² KCl/KNO₃,⁴ ammonium sulfate,⁵ potassium thiocyanate,⁶ sodium acetate, magnesium acetate,^{7,8} sodium butyrate,⁹ tetra-*n*-alkylammonium bromides,¹⁰⁻¹² cetyltrimethylammonium bromide,¹³ surfactants,¹⁴ sucrose,¹⁵ glucose.¹⁶

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Our earlier works²⁵⁻²⁷ present the thermodynamic properties as densities, viscosities, partial molar volumes and their derived calculated properties from specific correlations, for some amino acids in aqueous NaCl solutions at different temperatures.

Thermodynamic properties of alanine were investigated in aqueous: NaBr, KCl, KBr and MgCl₂,¹⁷ (C₂H₅)₄NBr,¹⁰ KSCN,⁶ metformin hydrochloride,¹⁸ 1, 4-dioxane,¹⁹ NaCl.²⁰⁻²⁵ The system water + alanine + NaCl is partially studied, over limited temperature domain, generally at 298.15 K. Thus, the density data for binary system water + L alanine,^{21,22} and for ternary system water + alanine + NaCl at 298.15K^{23,24} are known. Also, at standard temperature, for system containing water + DL alanine + NaCl, we found data for viscosity and refractive index at 0.2-1.0 mol · kg⁻¹ NaCl.²⁰

To complement the previous studies with new data, this paper presents our results concerning the measurement of density (ρ) and viscosity (η) of L-alanine in water and in water + (0.5027 - 1.4970) mol · kg⁻¹ NaCl in the temperature range between 293.15K and 323.15 K. An analysis of volumetric and transport properties of these systems has been conducted, as an attempt to evaluate their behavior as a function of temperature, correlated with electrolyte concentration. From experimental density data we have calculated molar volumes, standard apparent molar volumes and transfer volumes for L-alanine in pure water and in aqueous NaCl systems. From the viscosity data, the *A* and *B* viscosity coefficients for L-alanine in these systems were obtained and analyzed. The solute – solute and solute – solvent interactions occurring in the binary (L-alanine+ water) and ternary (L-alanine + water + NaCl) systems and the structure making/breaking tendency of the solutes in the studied solvent have been discussed.

EXPERIMENTAL

Material and reagents. L-alanine, from Sigma-Aldrich, having >99% mass fraction purity, was kept at room temperature, and used without additional purification. Before use, NaCl, provided by Merck, with > 99.8% purity, was dried in vacuum desiccators for 24 hours, at room temperature. For calibration of the apparatus, sample preparation and property measurements, fresh bi-distilled, deionised and degassed water with a specific conductance of $5 \cdot 10^{-5} \text{ S} \cdot \text{m}^{-1}$ at 298.15 K was used.

Preparation of solutions. The solutions under investigation, containing different L-alanine and NaCl amounts, were prepared by weighing on a HR-120 (A&D Japan) electronic balance with a precision of $\pm 0.1 \cdot 10^{-6} \text{ kg}$. Firstly, stock aqueous salt solutions, ranging from (0.0000 to 1.4970) mol · kg⁻¹, were prepared. Next, the required amount of

L-alanine were added at each stock solution to obtain the desired amino acid molality, ranging from (0 to 1.5648) mol · kg⁻¹. Cautious measures were taken to avoid air humidity or evaporation. The experimental uncertainty in molality was estimated to be less than of $2 \cdot 10^{-4} \text{ mol} \cdot \text{kg}^{-1}$.

Property measurements. The density measurements were performed using an Anton Paar digital density meter (DMA 4500), with an accuracy of $\pm 0.05 \cdot 10^{-3} \text{ g} \cdot \text{cm}^{-3}$. For each set of measurements, the apparatus was manually calibrated, with dry air and ultra pure water at atmospheric pressure, according to the operating manual. The considered value of dry air density at atmospheric pressure and 293.15 K is $10^{-3} \cdot 1.205 \text{ g} \cdot \text{cm}^{-3}$. The uncertainty in the density determination is $\pm 0.05 \cdot 10^{-3} \text{ g} \cdot \text{cm}^{-3}$. For the apparent molar volume calculations, the resulting uncertainties from the various measured quantities vary from 0.02 to $0.05 \cdot 10^{-6} \text{ m}^3 \cdot \text{mol}^{-1}$. Viscosity measurements were carried out using an Anton-Paar AMVn falling ball viscometer. Experimental determinations were performed using a capillary with $d = 1.6 \text{ mm}$ and a 70° angle. The repeatability in the measurement of the viscosity is $\pm 0.1 \%$, and the uncertainty is $\pm 0.35\%$. The temperature stability of samples during determinations was maintained within $\pm 0.01 \text{ K}$, by means of a built-in Peltier thermostat. Each experimental value for density and viscosity is the average value from triplicate measurements. The reproducibility was found within the limits of apparatus precision.

RESULTS AND DISCUSSION

Volumetric and viscometric measurements were carried out over a wide range of L-alanine concentrations, between 0 and 1.5648 mol · kg⁻¹ at different electrolyte concentrations, between 0 and 1.4970 mol · kg⁻¹, at 293.15K, 303.15, 313.15 and 323.15K. The obtained values of measured densities (ρ), experimental and calculated apparent molar volume (V_ϕ), kinematic viscosity (η), and dynamic viscosity (ν) for L-alanine in water and L-alanine in aqueous NaCl solutions having different molalities of amino acid (m_A) and salt (m_S), at 293.15, 303.15, 313.15 and 323.15 K, are listed in Table 1.

The apparent molar volumes, V_ϕ , of L-alanine in solution with NaCl at different salt concentrations, were obtained from the experimental densities data and calculated using the equation:

$$V_\phi = \frac{M}{\rho} - \frac{\rho - \rho_0}{m_A \rho \rho_0} \quad (1)$$

where M represents the molecular weight of L-alanine, m_A is the molality of the L-alanine solution, ρ is the density of the solution under study and ρ_0 is the density of the solvent (mixture of water + NaCl).

The correlation of apparent molar volume data was performed using a linear equation (2),²⁸⁻³⁰

recommended in the literature for systems containing water, electrolyte and amino acid.

$$V_{\phi} = V_{\phi}^0 + S_V m \quad (2)$$

where V_{ϕ}^0 and S_V are the fitting coefficients. S_V is the experimental slope and V_{ϕ}^0 is the infinite dilution apparent molar volume or the standard partial molar volume of amino acid in aqueous NaCl solutions. At infinite dilution V_{ϕ}^0 reflects the interactions between the amino acid molecules and the mixed solvent.

The transfer volume ΔV_{ϕ}^0 of L-alanine from water to water + NaCl solutions is calculated by the following relation:^{23, 24, 29}

$$\Delta_{tr} V_{\phi}^0 = V_{\phi}^0 (II) - V_{\phi}^0 (I) \quad (3)$$

where $V_{\phi}^0 (II)$ is the standard apparent molar volume of amino acid in solution II (water + NaCl) and $V_{\phi}^0 (I)$ is the standard apparent molar volume of amino acid in solution I (pure water).

The correlations were made with a standard deviation, σ , defined as:

$$\sigma = \left[\frac{\sum_{i=1}^n (Y_i^{\text{exp}} - Y_i^{\text{calc}})^2}{N_{\text{exp}}} \right]^{0.5} \quad (4)$$

where N_{exp} is the number of experimental data, Y_{ϕ}^{exp} and Y_{ϕ}^{calc} are the experimental and the calculated property, respectively.

The results of the density correlations are listed in Table 2: the standard partial molar volume values, V_{ϕ}^0 , along with their standard deviations.

From the viscosity data, we have calculated the main physical parameters, A and B from Jones – Dole equation which was used to correlate the experimental data:^{31, 32}

$$\eta_r = \frac{\eta}{\eta_0} = 1 + Am_A^{1/2} + Bm \quad (5)$$

where m_A is the molality of the amino acid, η_r is the relative viscosity, η is the viscosity of the ternary system (water + electrolyte + amino acid) and η_0 is the viscosity of the solvent (water + NaCl).

The values of the coefficients A and B were obtained from the intercept and slope of the plot $(\eta_r - 1)/m_A^{1/2}$ versus $m_A^{1/2}$, respectively.^{25, 26}

The densities and the viscosities of the L-alanine solutions in aqueous NaCl increase in their value with increasing amino acid and salt molalities (Table 1). The same behavior is retrieved for all studied temperatures. The apparent molar volumes of L-alanine in aqueous electrolyte solutions are different from their values in pure water. The apparent molar volumes of L-alanine acid increase with increasing concentration of added salt over the entire studied range salt concentrations, but the variation is less important with the amino acid concentration. The increase of temperature has low influence on the apparent molar volumes values.

Table 1

Experimental volumetric and viscometric properties of L-alanine solutions in water and water + NaCl at different temperatures, amino acid and salt concentrations

m_A , $\text{mol} \cdot \text{kg}^{-1}$	$10^{-3} \cdot \rho$, $\text{kg} \cdot \text{m}^{-3}$	$10^6 \cdot V_{\phi}$, $\text{m}^3 \cdot \text{mol}^{-1}$	η , $\text{mPa} \cdot \text{s}$	ν , $\text{m}^2 \cdot \text{s}^{-1}$	$10^{-3} \cdot \rho$, $\text{kg} \cdot \text{m}^{-3}$	$10^6 \cdot V_{\phi}$, $\text{m}^3 \cdot \text{mol}^{-1}$	η , $\text{mPa} \cdot \text{s}$	ν , $\text{m}^2 \cdot \text{s}^{-1}$
$T = 293.15 \text{ K}$					$T = 303.15 \text{ K}$			
$m_S = 0.0000 \text{ mol} \cdot \text{kg}^{-1}$					$m_S = 0.0000 \text{ mol} \cdot \text{kg}^{-1}$			
0.0000	0.99820		1.0024	1.0042	0.99564		0.8053	0.8088
0.1240	1.00179	59.98	1.0041	1.0023	0.99918	60.52	0.8050	0.8056
0.2100	1.00408	60.82	1.0280	1.0238	1.00150	60.99	0.8226	0.8214
0.2917	1.00640	60.55	1.0503	1.0436	1.00372	61.06	0.8403	0.8372
0.4350	1.01005	61.18	1.0911	1.0802	1.00750	61.26	0.8700	0.8635
0.6907	1.01702	60.76	1.1650	1.1455	1.01417	61.28	0.9270	0.9140
0.9967	1.02497	60.67	1.2538	1.2233	1.02199	61.20	0.9976	0.9761
$m_S = 0.5027 \text{ mol} \cdot \text{kg}^{-1}$					$m_S = 0.5027 \text{ mol} \cdot \text{kg}^{-1}$			
0.0000	1.01856	61.32	1.0381	1.0192	1.01557		0.8383	0.8254
0.0514	1.01995	62.72	1.0470	1.0265	1.01694	61.80	0.8457	0.8316
0.1992	1.02361	62.46	1.0930	1.0678	1.02055	63.18	0.8802	0.8625
0.4036	1.02877	62.17	1.1377	1.1059	1.02564	62.91	0.9131	0.8903
0.7050	1.03627	62.36	1.2461	1.2025	1.03303	62.63	0.9960	0.9642

Table 1 (continued)

1.0338	1.04383	62.57	1.3357	1.2796	1.04050	62.80	1.0633	1.0219
1.3353	1.05035	62.48	1.4414	1.3723	1.04693	63.01	1.1428	1.0916
1.5302	1.05470	61.32	1.5061	1.4280	1.05123	62.92	1.1943	1.1361
$m_S = 1.0000 \text{ mol} \cdot \text{kg}^{-1}$				$m_S = 1.0000 \text{ mol} \cdot \text{kg}^{-1}$				
0.0000	1.03779		1.0727	1.0336	1.03443		0.8686	0.8397
0.1072	1.04033	63.69	1.0986	1.0560	1.03694	64.09	0.8884	0.8568
0.4262	1.04781	63.40	1.1941	1.1396	1.04433	63.81	0.9616	0.9208
0.7371	1.05462	63.61	1.3246	1.2560	1.05106	64.01	1.0620	1.0104
1.0541	1.06148	63.53	1.4310	1.3481	1.05789	63.88	1.1418	1.0793
1.3676	1.06790	63.56	1.5535	1.4547	1.06420	63.94	1.2349	1.1650
1.5648	1.07195	63.49	1.6291	1.5198	1.06818	63.88	1.2916	1.2092
$m_S = 1.4970 \text{ mol} \cdot \text{kg}^{-1}$				$m_S = 1.4970 \text{ mol} \cdot \text{kg}^{-1}$				
0.0000	1.05626		1.1209	1.0612	1.05258		0.9113	0.8658
0.1003	1.05860	63.29	1.1479	1.0844	1.05489	63.71	0.9303	0.8819
0.3020	1.06301	63.90	1.2131	1.1412	1.05923	64.36	0.9801	0.9253
0.6770	1.07078	64.24	1.3392	1.2507	1.06696	64.59	1.0752	1.0077
0.7889	1.07304	64.26	1.3755	1.2819	1.06920	64.60	1.1041	1.0326
0.9521	1.07596	64.59	1.4284	1.3276	1.07209	64.94	1.1431	1.0662
$T = 313.15 \text{ K}$				$T = 323.15 \text{ K}$				
$m_S = 0.0000 \text{ mol} \cdot \text{kg}^{-1}$				$m_S = 0.0000 \text{ mol} \cdot \text{kg}^{-1}$				
0.0000	0.99221		0.6702	0.6755	0.98803		0.5741	0.5811
0.1240	0.99564	61.53	0.6678	0.6707	0.99147	61.58	0.5699	0.5748
0.2100	0.99793	61.78	0.6811	0.6825	0.99377	61.82	0.5805	0.5841
0.2917	1.00020	61.48	0.6948	0.6947	0.99590	62.04	0.5914	0.5938
0.4350	1.00386	61.87	0.7174	0.7147	0.99968	62.01	0.6094	0.6096
0.6907	1.01054	61.70	0.7618	0.7539	1.00624	62.02	0.6443	0.6403
0.9967	1.01829	61.59	0.8177	0.8030	1.01368	62.19	0.6893	0.6800
$m_S = 0.5027 \text{ mol} \cdot \text{kg}^{-1}$				$m_S = 0.5027 \text{ mol} \cdot \text{kg}^{-1}$				
0.0000	1.01183		0.6982	0.6900	1.00745		0.6007	0.5963
0.0514	1.01319	62.12	0.7033	0.6941	1.00876	63.24	0.6027	0.5975
0.1992	1.01677	63.52	0.7310	0.7189	1.01236	63.83	0.6230	0.6154
0.4036	1.02181	63.27	0.7576	0.7414	1.01736	63.61	0.6449	0.6339
0.7050	1.02914	62.99	0.8200	0.7968	1.02466	63.30	0.6944	0.6777
1.0338	1.03654	63.16	0.8737	0.8429	1.03202	63.47	0.7352	0.7124
1.3353	1.04292	63.36	0.9356	0.8971	1.03837	63.66	0.7842	0.7552
1.5302	1.04718	63.27	0.9749	0.9310	1.04260	63.58	0.8145	0.7812
$m_S = 1.0000 \text{ mol} \cdot \text{kg}^{-1}$				$m_S = 1.0000 \text{ mol} \cdot \text{kg}^{-1}$				
0.0000	1.03043		0.7244	0.7030	1.02582		0.6168	0.6013
0.1072	1.03292	64.43	0.7393	0.7157	1.02833	64.44	0.6306	0.6132
0.4262	1.04026	64.13	0.7969	0.7661	1.03564	64.34	0.6761	0.6528
0.7371	1.04694	64.33	0.8761	0.8368	1.04229	64.58	0.7222	0.6929
1.0541	1.05368	64.24	0.9391	0.8913	1.04900	64.49	0.7907	0.7538
1.3676	1.05997	64.27	1.0104	0.9532	1.05527	64.53	0.8471	0.8027
1.5648	1.06392	64.22	1.0544	0.9911	1.05920	64.48	0.8813	0.8320
$m_S = 1.4970 \text{ mol} \cdot \text{kg}^{-1}$				$m_S = 1.4970 \text{ mol} \cdot \text{kg}^{-1}$				
0.0000	1.04835		0.7609	0.7258	1.04360		0.6523	0.6250
0.1003	1.05064	64.07	0.7755	0.7381	1.04591	64.08	0.6642	0.6350
0.3020	1.05499	64.57	0.8140	0.7716	1.05023	64.80	0.6937	0.6605
0.6770	1.06264	64.89	0.8890	0.8366	1.05784	65.17	0.7537	0.7125
0.7889	1.06487	64.90	0.9110	0.8555	1.06008	65.16	0.7711	0.7274
0.9521	1.06773	65.25	0.9407	0.8810	1.06293	65.51	0.7943	0.7473

The correlation parameters of volumetric analysis, V_{ϕ}^0 , S_V and σ are presented in Table 2. The values of standard deviation show that the linear equation (2) correlates satisfactorily the experimental data. The calculated standard apparent molar volumes, V_{ϕ}^0 , are positive, showing an increasing trend with the increasing electrolyte concentration. Consequently, the transfer volumes

of L-alanine from water to NaCl solutions were found to be positive, the increase of added salt amount leading to an increase of transfer volumes of L-alanine. It is well known that L-alanine has a double charged molecule, presenting zwitterionic form in water, having positive charge on amino groups and negative charge on its carboxyl groups. This dual character induces electrostatic interactions with the ions resulting from the

solvent. Also, the non-polar methyl group induces the occurrence of synergistic hydrophobic interactions. In addition, the water dipoles are strongly aligned to the cations / anions as well to the zwitterions by strong electrostatic forces.

The positive values of standard apparent molar volumes show that the salt interacts directly by strong electrostatic interactions with the charged centers of amino acid, leading to a reduction in their electrostriction effects. The ion – ion interactions and ion – hydrophilic group interactions are stronger than ion – non polar group interactions in the ternary system water + alanine + salt.

Table 2 presents also the viscosity coefficients: the Falkenhagen coefficient, A , and the Jones – Dole coefficient, B , for L-alanine in the NaCl aqueous solutions at different temperatures together with R^2 , the obtained correlation coefficients of linear regressions. The Falkenhagen coefficient, A , represents the solute – solute interactions coupled with the size and the shape effects of the solute, while B coefficient illustrates

solute – solvent interactions. The values found for A coefficients, are negative for all studied conditions, indicating the presence of ion – ion interactions in water + alanine + salt systems. The values of A coefficients become more positive and increase with salt amount added to the solvent, suggesting the increasing ion – ion interaction strength.

It can be observed that the B coefficients values are positive, illustrating strong solute – solvent interactions in these mixtures. Positive values for B coefficients are correlated with a kosmotropic behavior (structure making) of the solutes. The B values are much larger than A values, suggesting stronger solute – solvent interactions as compared to solute – solute interactions. Temperature affects less the values of viscosity coefficients. Both, the viscosity B coefficients and the apparent molar volumes, V_{ϕ}^0 , reflect the solute-solvent interactions in the studied L-alanine + water + NaCl ternary mixtures, our results being in good agreement.

Table 2

Parameters of volumetric and viscometric analyses for L-alanine in water and water + NaCl between 293.15 and 323.15 K

m_s , $\text{mol} \cdot \text{kg}^{-1}$	$10^6 \cdot V_{\phi}^0$, $\text{m}^3 \cdot \text{mol}^{-1}$	ΔV_{ϕ}^0 , $\text{m}^3 \cdot \text{mol}^{-1}$	$10^6 \cdot S_V$, $\text{kg} \cdot \text{m}^3 \cdot \text{mol}^{-2}$	$10^6 \cdot \sigma^*$, $\text{m}^3 \cdot \text{mol}^{-1}$	A , $\text{kg}^{1/2} \cdot \text{mol}^{-1/2}$	B , $\text{kg} \cdot \text{mol}^{-1}$	R^{2*}
$T = 293.15 \text{ K}$							
0.0000	60.106 60.078 ^{**a} 59.985 ^{**b} 60.030 ^{**c}	-	0.955	0.410	-0.119	0.376	0.997
0.5027	61.968	1.862	0.145	0.456	-0.036	0.321	0.994
1.0000	63.429	3.323	0.238	0.238	-0.056	0.375	0.996
1.4970	63.161	3.055	1.483	0.139	-0.022	0.313	0.999
$T = 303.15 \text{ K}$							
0.0000	60.576 60.532 ^{**a} 60.693 ^{**b} 60.696 ^{**c}	-	1.135	0.279	-0.129	0.374	0.997
0.5027	62.436	1.860	0.122	0.452	-0.031	0.297	0.993
1.0000	63.988	3.412	-0.072	0.467	-0.051	0.351	0.996
1.4970	63.305	2.729	1.879	0.261	-0.027	0.297	0.999
$T = 313.15 \text{ K}$							
0.0000	61.278 61.140 ^a 61.200 ^d	-	0.755	0.352	-0.133	0.359	0.997
0.5027	62.778	1.500	0.135	0.456	-0.031	0.280	0.994
1.0000	64.157	2.879	0.280	0.239	-0.050	0.331	0.996
1.4970	63.892	2.614	1.388	0.125	-0.027	0.279	0.999
$T = 323.15 \text{ K}$							
0.0000	61.412	-	1.183	0.294	-0.140	0.346	0.995
0.5027	61.444	0.032	1.860	1.186	-0.044	0.266	0.996
1.0000	64.410	2.998	0.069	0.466	-0.043	0.305	0.988
1.4970	63.990	2.578	1.589	0.161	-0.024	0.255	0.999

* σ for Eq. 2, R^2 for equation (5); ** calculated values by data interpolation from: ^a Ref ³³ for 293.15 and 303.15K; ^b Ref ²³ for DL alanine; ^c Ref ⁵ for DL alanine at 278-308.15K; ^d Ref ³⁴

CONCLUSIONS

The experimental data of density and viscosity in aqueous NaCl solutions of L-alanine at different temperatures have been reported. From the density data, the apparent molar volumes for L-alanine were calculated and correlated with linear equation. In the studied range of composition the apparent molar volumes increase with NaCl molality increasing. The transfer volumes values of L-alanine from water to NaCl solutions are positive and increase with NaCl concentration in ternary systems.

The viscosity data were used to accurately calculate the viscosity parameters from Jones – Dole equation for the relative viscosity as a function of temperature in the range from 293.15 K to 323.15 K in the L-alanine + NaCl aqueous solutions. The amino acid acts as structure maker for water and for water – electrolyte solutions as well. The behaviour of the systems can be attributed to the zwitterion structure of L-alanine in aqueous solutions and to the electrostriction occurring effects.

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