

Volumetric and Viscometric Properties for the Ternary Systems L-Tryptophan, MCl (M=Li, Na, K) and H₂O at Temperatures 298.15 to 313.15 K

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Abstract

The data obtained from density (ρ) and viscosity (η) measurements is used for the determination of apparent molar volume (ϕ_v), viscosity B-coefficient of L-tryptophan in aqueous solution of alkali halides at temperatures $T=298.15$ K- 313.15 K under atmospheric pressure. From the apparent molar volume (ϕ_v) calculated from experimental density, the equation suggested by Masson is used for calculation of the limiting apparent molar volumes (ϕ_v^0) and experimental slopes (S_v^*) and its values are used to interplay solute-solvent and solute-solute interactions. The free energies of activation per mole of solvent ($\Delta\mu_1^{0\ddagger}$) and solute ($\Delta\mu_2^{0\ddagger}$) were calculated. The limiting partial molar volumes of transfer and the free energies of activation per mole of both solvent ($\Delta\mu_1^{0\ddagger}$) and solute ($\Delta\mu_2^{0\ddagger}$) were analyzed constructed on the transition state theory and cosphere overlap model, respectively. The hydration number of L-tryptophan in aqueous solution of LiCl, NaCl and KCl was determined using ϕ_v^0 and viscosity B-coefficient.

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1. Introduction

Tryptophan (Trp) is an aromatic amino acid that became located over 100 years ago (1901) while it was removed from a pancreatic digest of casein. The content of Trp inside the human body is the bottom of all of the amino acids and, it could play a price restricting position in protein synthesis. Tryptophan no longer most effectively serves as a subunit of protein, it also acts as a precursor for neurotransmitters and hormones [1]. Within the mind, Trp is the precursor for serotonin (5-hydroxyl tryptamine), that is thought to inhibit a variety of behaviors such as aggression, feed intake, and pressure marks. Also, in individuals, the management of mood is related to serotonin levels. Interactions between different ions and protein, inclusive of electrostatic interactions, are the critical factors that decide the complex conformational and configurational systems of protein and remarkably have an effect on their denaturalization, solubility, as well as folding/unfolding behavior. Because of huge and complex molecule structure of the protein, the examination on the molecular interactions remains still tough. The volumetric and viscometric behavior of solutes has been validated to be very beneficial in elucidating the various interactions going on in answers. Researchers at the impact of attention (molality), the obvious molar volumes of solutes, were considerably used to obtain facts on solvent–solvent, ion–solvent and ion–ion interactions [2–8]. In view of the above, we've undertaken a systematic take a look at on the density, viscosity and refractive index of L-tryptophan in aqueous solution of LiCl, NaCl and KCl at temperature range from 298.15 K to 313.15 K, and we've got attempted to file the proscribing apparent molar volume (ϕ_v^0), experimental slopes (S_v^*), viscosity A and B-coefficients for the noted amino acid.

2. Materials and Methods

2.1. Reagents source and purity of samples

The analytical grade LiCl, NaCl and KCl were used. The purity of L-tryptophan was verified by several techniques HPLC, UV, MS, ^1H NMR, and ^{13}C NMR. Experimental solutions were formed by using triply distilled water. The specifications of the working chemicals are listed in Table 1. There is no further purifications are performed and the chemicals are used as received.

2.2. Apparatus and procedure

Densities measurements were carried out at atmosphere pressure using a vibrating tube densimeter (Anton Paar DMA4500M, Austria), and the temperature was spontaneously kept up inside ± 0.01 K amid the estimation through two incorporated Pt100 platinum thermometers with implicit peltier components. Density value has uncertainty equal to ± 0.0005 g \cdot cm $^{-3}$. The density of each sample was measured three times and the average value is considered. Deionized water and dry air was used to calibrate the apparatus, and the vibrating tube was cleaned automatically after each measurement by using the distilled H $_2$ O and anhydrous ethyl alcohol. Once an hour from a Fortin barometer, the atmospheric pressure was documented. 1.0 kPa was the pressure standard uncertainty. The viscosity of L-tryptophan in aqueous alkali halide solution was measured by means of an iVisc capillary viscometer (LAUDA, Germany), and Shanghai Glass Instruments Factory of China is used to provide the Ubbelohde capillary (1835A) with a diameter equal to 0.54 mm. The clean and dry Ubbelohde capillary was placed vertically in a thermostat (Lauda Eco Sliver) with uncertainty equal to ± 0.01 K. The infrared is used to measure the sample flow time automatically that has an uncertainty equal to ± 0.01 s, and a deviation equal to 0.2 s was taken at the specified temperature and atmospheric pressure for at least four sets of flow time. The kinetic energy and the end corrections were found to be negligible due to all flow time was greater than 100 s. The viscosities of L-tryptophan in aqueous solution of LiCl, NaCl and KCl were computed by the following equation:

$$\frac{\eta}{\eta_0} = \frac{\rho t}{\rho_0 t_0} \quad (1)$$

Table1. Specifications of used chemicals

Chemical name	Chemical formula	Source	Mass fraction purity(CAS)	Molecular weight(g.mol ⁻¹)
L-Tryptophan	C ₁₁ H ₁₂ N ₂ O ₂	Sigma-Aldrich Co.	≥0.980(73-22-3)	204.225
Lithium chloride	LiCl	Aladdin Co.	≥0.998(7447-41-8)	42.394
Sodium chloride	NaCl	Sigma-Aldrich Co.	≥0.995(7647-14-5)	58.44
Potassium chloride	KCl	Sinopharm Co.	≥0.995(7447-40-70)	74.551

Table 2

Comparison of physical properties of aqueous alkali halide solutions with literature at working temperatures and pressure 0.1 MPa

Solvent	m (mol· kg ⁻¹)	$\rho \times 10^{-3}(\text{kg.m}^{-3})$				$\eta(\text{mPa.s})$			
		298.15K	303.15K	308.15K	313.15K	298.15K	303.15K	308.15K	313.15K
0.2 LiCl	exptl	1.00188	1.00047	0.99891	0.99735	0.9797	0.8988	0.8195	0.6765
	lit ^[8]	1.001873	1.000451	0.998848	--	0.909	0.818	0.743	--
0.1 LiCl	exptl	0.99947	0.99805	0.99615	0.99478	0.9687	0.8898	0.8115	0.6684
	lit ^[9]	0.99944	0.99802	0.99612	--	0.9684	0.8896	0.8112	--
0.05 LiCl	exptl	0.99826	0.99682	0.99525	0.99349	0.8870	0.7941	0.7090	0.6617
	lit ^[9]	0.99823	0.99680	0.99522	--	0.8869	0.7939	0.7089	--
0.025 LiCl	exptl	0.99780	0.99631	0.99481	0.99284	0.8627	0.7210	0.6947	0.65
	lit ^[9]	0.99790	0.99631	0.99379	--	0.8625	0.7207	0.6945	--
--									
0.2 NaCl	exptl	1.00517	1.00367	1.00196	1.00025	0.9801	0.8999	0.8201	0.7765
	lit ^[8]	1.005144	1.003651	1.001984	--	0.901	0.812	0.738	--
0.1 NaCl	exptl	1.00119	0.99979	0.99815	0.99650	0.9718	0.8925	0.8141	0.7496
	lit ^[9]	1.00117	0.99978	0.99811	--	0.9714	0.8922	0.8139	--
0.05 NaCl	exptl	0.99927	0.99725	0.99610	0.99494	0.8930	0.7833	0.6874	0.6633
	lit ^[9]	0.99925	0.9972	0.99608	--	0.8927	0.7830	0.6870	--
0.025 NaCl	exptl	0.99826	0.99689	0.99530	0.99370	0.8385	0.7765	0.6763	0.6599
	lit ^[9]	0.99824	0.99687	0.99527	--	0.8382	0.7760	0.6760	0.6760
--									
0.2 KCl	exptl	1.00636	1.00487	1.00322	1.00157	0.9811	0.9004	0.8221	0.7775
	lit ^[8]	1.006325	1.004852	1.003193	--	0.896	0.801	0.723	--
0.1 KCl	exptl	1.00152	1.00122	0.99930	0.99738	0.9746	0.8980	0.8169	0.7524
	lit ^[9]	1.00149	1.00119	0.99928	--	0.9742	0.8979	0.8167	--
0.05 KCl	exptl	1.00139	1.00101	0.99910	0.99719	0.8901	0.7965	0.6918	0.6773
	lit ^[9]	1.00138	1.00029	0.999--	0.8899	0.7963	0.6917	--	--
0.025 KCl	exptl	1.00051	0.99975	0.99865	0.99691	0.8810	0.7255	0.6975	0.665
	lit ^[9]	0.99838	0.99728	0.99695	--	0.8806	0.7250	0.6973	--

where η , ρ , t and η_0 , ρ_0 , t_0 are viscosities, densities, and flow times of the measured solution and viscosity standard solution, respectively. Air tight stopper bottles were used to prepare the mixtures by mixing known volume of solutions. To reduce dehydration losses during the investigational measurements, suitable precautions were performed. Mass measurements for stock solutions were done on Mettler AG-285 electronic balances with a precision of $\pm 0.01 \times 10^{-3}$ kg. Investigated density values were used in the transformation of molar conc. into molal conc. The molality uncertainty is found to be ± 0.0005 mol.

kg⁻¹. Table 2 includes a comparison between values of used aqueous alkali halide Densities and viscosities at working temperatures and that reported in literature. There was an agreement between experimental densities and viscosities variation tendencies with values reported in literatures [9].

3. Results and discussion

To understand the behavior of solutions effectively, viscosity and density are two vital sources of experimental physicochemical information. The structural changes of solvents, solute-solute and solute – solvent interactions nature and mechanisms could be better understood on the basis of interpreting the liquids molecular interactions. [10-13]

3.1. Volumetric properties.

The physical property density describes the mass of one substance per unit volume. Data on the shape, various chemical behavior, size, solute-solvent intermolecular interactions and structural properties can provided in a useful manner by density [14-16]. Different properties such as the apparent molar volumes, limiting partial molar volumes, and transfer partial molar volumes are calculated from density data that are necessary in creating dependable equations of states. The experimental values of densities (ρ), along with the apparent molar volume (ϕ_v) of L-tryptophan in aqueous solution of LiCl, NaCl and KCl at working temperatures under atmospheric pressure, are described in Table 3. The same behavior is showed for the triple aqueous mixtures under investigation as obtained from the measured density data. At constant temperature the density is increased by increasing the mass of alkali halide and L-tryptophan while increasing the temperature made the density to be decreased. This means that the driving force of the density value is the concentration and the temperature. The reason of density decreasing by increasing the temperature is the increasing of intermolecular distances as a result of increased thermal energy of molecules. At constant L-tryptophan molality and temperature the three mixtures under investigation density have the order ρ (pure water) < ρ (LiCl) < ρ (NaCl) < ρ (KCl), which proved that the highest molecular weight solution has the highest density value. The density order was matched with alkali halide size order in which, LiCl < NaCl < KCl. Partial molar volumes and the apparent molar volumes of the examined mixtures provide an excellent picture about Solute – solvent, solute – solute, and solvent – solvent interactions inside the studied system; valuable facts about the interaction environment between charged particles and surrounded solvent molecules is provided from previously mentioned parameters [16-18]. The solution densities are used for the determination of apparent molar volumes (ϕ_v) according to the following equation [10, 19]

$$\phi_v = \frac{M}{\rho} - 1000(\rho - \rho_0)/m\rho\rho_0 \quad (2)$$

where m is the molal concentration of the solute (L- tryptophan), ρ and ρ_0 denote to the density of the solution and the solvent, respectively; M is the molar mass of the solute (L-tryptophan). At the same temperature for a certain solvent, ϕ_v found to be increased as the molality of alkali halide LiCl/NaCl/KCl. Also, ϕ_v increased with the rise of temperature. At constant temperature, ϕ_v decreased by increasing the molality of solute (L-tryptophan). Frank model [20] can be used to explain the order of the apparent molar volumes ϕ_v (LiCl) > ϕ_v (NaCl) > ϕ_v (KCl) of L-tryptophan at a particular temperature as follows, the hydrogen-bonding network of the water molecules surrounding ions during hydration process found to be reduced due to the destruction of the water molecule structure. This destruction of hydrogen network is known to be the shrinkage effect of the ion to the water. Thus, a positive contribution to the volume was produced due to smaller volume of water molecules inside hydration shell than that of normal water. So, L-tryptophan could be seen to have the same tendency in aqueous alkali halide LiCl, NaCl or KCl solvents.

The linear equation that described by Masson in 1929 found that the apparent molar volumes ϕ_v vary with the square root of the molal concentration \sqrt{m} according to the following equation. [12, 13]

$$\phi_v = \phi_v^0 + S_v \sqrt{m} \quad (3)$$

The plots of ϕ_v against \sqrt{m} as in Figure 1 of L-tryptophan in aqueous solution of LiCl, NaCl and KCl at 298.15 K, 303.15 K, 308.15 K and 313.15 K respectively provides intercept equal to ϕ_v^0 (the limiting apparent molar volume) and a negative slopes equal to S_v^* . As the concentration of L-tryptophan in any electrolytic solution decreases besides temperature increases, the ϕ_v values increase. The values of ϕ_v^0 along with S_v^* of L-tryptophan in aqueous solution of LiCl, NaCl and KCl at 298.15 K, 303.15 K, 308.15 K and 313.15 K respectively, are reported in Table 4. ϕ_v^0 values by definition are free from (solute + solute) interactions and therefore provide a measure of (solute + solvent) interactions, whereas the experimental slope, S_v^* provides information regarding (solute + solute) interaction. [21-23]. An inspection of ϕ_v^0 values in Table 4 and Figure S1 in the Supplementary Material shows that its values for L-tryptophan are positive and increase with dilution and temperature. The presence of strong solute–solvent interactions is indicated from ϕ_v^0 values and this interaction reached its maximal value at lower molar conc. of LiCl solution of L-tryptophan and higher working temperature 313.15 K and the minimal occurs at higher molar conc. of KCl solution of L-tryptophan and lower working temperature 298.15 K. The values of ϕ_v^0 increased with a rise in the molalities of salt in the mixtures and with the temperature increasing. The decrease of water electrostriction and the loose of solvation layers solvent molecules from of the solutes in solution may be the reason. Thus the presence of solute –solvent interactions is indicated, that is assumed to be high at greater concentration of salts in the solutions owing to higher amounts of dissolved ions in the solution [13-23]. Amino acids have zwitterions behavior in aqueous solutions with two terminals NH_4^+ and COO^- groups at two sides of the amino acid. There is an electrostatic interaction between Na^+ , K^+ , Li^+ and Cl^- ions with NH_4^+ and COO^- terminal groups of amino acids. Additionally, dipoles of water are strongly associated to the cations/anions besides to the amino acids' zwitterions by electrostatic attraction. The cohesion of solution under investigation is introduced due to these interactions. The presence of attraction between Li^+ , Na^+ , K^+ ions and terminal carboxylic group of amino acid and between Cl^- ion and the terminal amino group is indicated from the positive value of ϕ_v^0 . So, the interactions between L-tryptophan and the water molecule in electrolytic solution follows the order $\text{LiCl} > \text{NaCl} > \text{KCl}$ at any specific temperature. Moreover, solute –solute interactions that represented by S_v^* were negative and negativity increased by alkali halides salts addition. Thus, weak solute-solute interactions were indicated from S_v^* values. S_v^* values were decreased with increasing the molality of alkali halides and increased with increasing the temperature. Increasing the molality of alkali halide weakens the solute-solute interaction between L-tryptophan molecules. The hydrogen bond interactions between L-tryptophan molecules are rare compared to the hydrophobic – hydrophobic interactions and the hydrophobic –hydrophilic interactions which indicated by the negative values of S_v^* . According to Table 4, the S_v^* order were $S_v^*(\text{LiCl}) > S_v^*(\text{NaCl}) > S_v^*(\text{KCl})$.

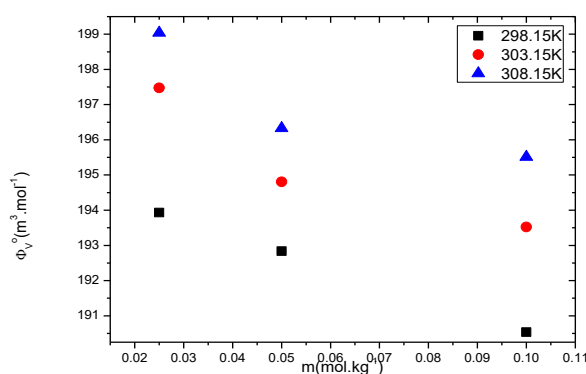


Figure1. Variations of limiting partial molar volumes (ϕ_v^0) of L-tryptophan versus the molality of LiCl aqueous solution at temperatures $T = 298.15 - 308.15$ K. (Since the tendency of ϕ_v^0 versus the molality of NaCl/KCl was very close to LiCl, ϕ_v^0 versus m (NaCl/KCl) can be omitted.)

The variation of ϕ_v^0 with temperature of L-tryptophan follows the polynomial,

$$\phi_v^0 = a_0 + a_1T + a_2T^2 \quad (4)$$

Over the temperature range under investigation where a_0 , a_1 and a_2 are the coefficients and T is the temperature in K. Values of the coefficients of the above equation for L-tryptophan in aqueous solution of LiCl, NaCl and KCl at 298 K, 303 K, 308 K and 313.15K respectively, are reported in Table 5. The limiting apparent molar expansibilities (Φ_E^0) can be obtained by the following equation:

$$\Phi_E^0 = (\delta\phi_v^0/\delta T)_P = a_1 + 2a_2T \quad (5)$$

The values of Φ_E^0 that is an indicator of solute – solvent interaction [24-27] of the studied compounds at 298.15, 303.15, 308.15 K and 313.15K are determined and reported in Table 5. It is found from Table 5 that the values of Φ_E^0 decrease with a rise in temperature, which may be ascribed to the absence of caging or packing effects. All through the beyond few years, it has been emphasized with the aid of specific people that S_v^* isn't always the only criterion for determining the structure-making or shape-breaking nature of any solute. Hepler [24] advanced a technique of inspecting the sign of $(\delta^2\phi_v^0/\delta T^2)_P$ for the solute in phrases of long-range shape-making and structure-breaking ability of the solute inside the mixed solvent structures the usage of the general thermodynamic expression [25-28]

$$(\partial \Phi_E^0 / \partial T)_P = (\partial^2 \phi_v^0 / \partial T^2)_P = 2a_2 \quad (6)$$

Depending on the previous formula, it has been assumed that the solutes with structure-making ability should have positive values, whereas solutes with structure-breaking ability should have negative values [25-27]. For L- tryptophan in aqueous solution of LiCl, NaCl and KCl investigated here, suggesting there by that L-tryptophan acts as a structure breaker.

The qualitative properties about solute-solvent interactions without the effects of solute-solute interactions can be provided via the limiting transfer properties. Eq. 7 [25-29] was used to calculate the limiting partial molar volume of transfer (Δ_{trsv}^0) in order to determine transfer interaction properties of L-tryptophan from water to aqueous alkali halide solvent.

$$\Delta_{trsv}^0 = \phi_v^0(\text{in aqueous MCl}) - \phi_v^0(\text{in pure water}) \quad (7)$$

Table 4 summarizes the values of Δ_{trsv}^0 . The solute-solvent interactions pure measuring parameter is Δ_{trsv}^0 that is completely free of the solute-solute interactions. The dominance of the polar-polar and ion –polar interactions between L-tryptophan and alkali halide salts was indicated from the positive values of Δ_{trsv}^0 according to Friedman and Krishnan [30, 31] cosphere overlap model. According to Table 4, increasing the molality of MCl in the ternary system (L-tryptophan+ MCl + H₂O) leads to positive and monotonically increased of Δ_{trsv}^0 values while its values decreased with temperature expanding. H₂O molecules properties in the solvation shell that determined by the nature of the encapsulated solute can be used to explain Δ_{trsv}^0 results.

Table 3

Molality (m), experimental values of densities (ρ) along with the apparent molar volume (ϕ_v) of L-tryptophan in aqueous LiCl, NaCl, and KCl solutions at 298.15 K, 303.15 K, 308.15 K and 313.15K and pressure $p=0.1$ MPa

m (mol· kg ⁻¹) $\rho \times 10^{-3}(\text{kg.m}^{-3})$ $\phi_v \times 10^6(\text{m}^3.\text{mol}^{-1})$			m (mol·kg ⁻¹) $\rho \times 10^{-3}(\text{kg.m}^{-3})$		
$\phi_v \times 10^6(\text{m}^3.\text{mol}^{-1})$					
L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		
0.01	1.00207	184.8780	0.01	1.00064	187.1132
0.02	1.00231	182.3441	0.02	1.00087	184.0743
0.04	1.00281	180.5114	0.04	1.00131	182.9951
0.06	1.00339	178.5004	0.06	1.00188	180.3969
0.08	1.00402	176.8144	0.08	1.00259	177.2783
0.10	1.00481	174.1424	0.10	1.00328	175.5624
L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl		
T=308.15K			T=313.15K		

0.01	0.99906	189.3867	0.01	0.99750	189.6593
0.02	0.99927	186.3414	0.02	0.99769	187.6132
0.04	0.99969	184.7610	0.04	0.99811	185.5252
0.06	1.00019	182.8336	0.06	0.99861	183.4242
0.08	1.00079	180.5567	0.08	0.99918	181.4380
0.10	1.00151	177.9280	0.10	0.99995	178.1648
L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		
0.01	0.99965	186.2806	0.01	0.99821	188.5312
0.02	0.99984	185.7449	0.02	0.99838	187.9973
0.04	1.00029	183.6608	0.04	0.99880	185.6611
0.06	1.00079	182.0694	0.06	0.99930	183.4793
0.08	1.00137	180.2155	0.08	0.99987	181.4541
0.10	1.00200	178.5544	0.10	1.00049	179.6892
L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl		
T=308.15K			T=313.15K		
0.01	0.99630	189.8692	0.01	0.99493	190.1101
0.02	0.99648	188.3241	0.02	0.99509	189.5745
0.04	0.99686	186.993	0.04	0.99549	187.2262
0.06	0.99734	184.8066	0.06	0.99593	185.7136
0.08	0.99797	181.7560	0.08	0.99651	182.1022
	0.10	0.99870	0.10	0.99731	179.2745
L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl		
mol· kg ⁻¹ LiCl			L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		
	0.01	0.99841		0.01	0.99696
	0.02	0.99859		0.02	0.99713
	0.04	0.99897		0.04	0.99752
	0.06	0.99943		0.06	0.99799
	0.08	0.99995		0.08	0.99845
0.10	1.00042	182.5107	0.10	0.99905	182.0268
L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl		
mol· kg ⁻¹ LiCl			L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl		
T=308.15K			T=313.15K		
	0.01	0.99538		0.01	0.99361
	0.02	0.99553		0.02	0.99375
	0.04	0.99592		0.04	0.99407
	0.06	0.99637		0.06	0.99447
	0.08	0.99688		0.08	0.99492
0.10	0.99732	183.9191	0.10	0.99538	182.0268
L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		
0.01	0.99794	190.5867	0.01	0.99643	192.8691
0.02	0.99813	188.0403	0.02	0.99659	190.8239
0.04	0.99849	187.2197	0.04	0.99699	187.7271
0.06	0.99896	185.0415	0.06	0.99746	185.4584
0.08	0.99942	184.0371	0.08	0.99788	184.9193
0.10	1.00001	182.0745	0.10	0.99853	182.2106
L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl		
T=308.15K			T=313.15K		
0.01	0.99493	193.1416	0.01	0.99295	194.5170
0.02	0.99506	192.6113	0.02	0.99309	192.9683
0.04	0.99542	189.7646	0.04	0.99345	190.1102
0.06	0.99590	186.7291	0.06	0.99385	188.4291

0.08	0.99641	184.7840	0.08	0.99431	186.7803
0.10	0.99699	182.8617	0.10	0.99475	185.9636
L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=298.15K			L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=303.15K		
0.01	1.00538	182.3520	0.01	1.00385	185.5763
0.02	1.00562	180.8245	0.02	1.00409	182.5551

Table 3 Continued

m (mol· kg ⁻¹) φ _v ×10 ⁶ (m ³ .mol ⁻¹)	ρ×10 ⁻³ (kg.m ⁻³)	φ _v ×10 ⁶ (m ³ .mol ⁻¹)	m (mol·kg ⁻¹)	ρ×10 ⁻³ (kg.m ⁻³)	
0.04	1.00615	178.7517	0.04	1.00459	180.4807
0.06	1.00677	176.5006	0.06	1.00515	178.7281
0.08	1.00743	174.8214	0.08	1.00591	175.2914
0.10	1.00822	172.4642	0.10	1.00662	173.6831
L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=308.15K			L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=313.15K		
0.01	1.00212	187.8580	0.01	1.00041	188.1519
0.02	1.00235	184.3300	0.02	1.00061	186.1160
0.04	1.00281	182.5037	0.04	1.00104	184.2883
0.06	1.00336	180.3314	0.06	1.00154	182.4494
0.08	1.00396	178.5668	0.08	1.00209	180.8528
0.10	1.00463	176.7588	0.10	1.00279	178.3338
L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=298.15K			L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=303.15K		
0.01	1.00138	184.9923	0.01	0.99996	187.2289
0.02	1.00162	182.4550	0.02	1.00017	185.1895
0.04	1.00211	180.8707	0.04	1.00061	183.6087
0.06	1.00268	178.9416	0.06	1.00113	181.6817
0.08	1.00333	176.9177	0.08	1.00172	179.7857
0.10	1.00405	174.9504	0.10	1.00237	177.9977
L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=308.15K			L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=313.15K		
0.01	0.99831	188.5139	0.01	0.99664	190.8170
0.02	0.99851	186.4695	0.02	0.99682	188.7691
0.04	0.99893	184.8867	0.04	0.99722	186.6808
0.06	0.99934	182.9564	0.06	0.99768	184.9183
0.08	0.99999	181.1842	0.08		0.998
182.0828					
0.10	1.00067	178.8585	0.10	0.99885	180.8504
L-tryptophan in m=0.05 mol· kg ⁻¹ NaCl T=298.15K			L-tryptophan in m=0.05 mol· kg ⁻¹ NaCl T=303.15K		
0.01	0.99945	186.3143	0.01	0.99741	188.6695
0.02	0.99967	184.9613	0.02	0.99762	186.1169
0.04	1.00014	182.4336	0.04	0.99804	184.7827
0.06	1.00071	180.0796	0.06	0.99855	182.7636
0.08	1.00129	178.7260	0.08	0.99913	180.8175
0.10	1.00187	177.8734	0.10	0.99979	178.7925
L-tryptophan in m=0.05 mol· kg ⁻¹ NaCl T=308.15K			L-tryptophan in m=0.05 mol· kg ⁻¹ NaCl T=313.15K		
0.01	0.99624	190.8879	0.01	0.99507	192.1060
0.02	0.99643	188.3327	0.02	0.99524	190.0534
0.04	0.99683	186.4947	0.04	0.99559	188.7246
0.06	0.99731	184.4756	0.06	0.99603	186.7072
0.08	0.99778	183.5503	0.08	0.99653	184.8905

0.10	0.99826	182.8586	0.10	0.99711	182.9433
L-tryptophan in m=0.025 mol· kg ⁻¹ NaCl			L-tryptophan in m=0.025 mol· kg ⁻¹ NaCl		
T=298.15K			T=303.15K		
0.01	0.99842	188.4949	0.1	0.99703	190.7478
0.02	0.99862	186.4509	0.02	0.99722	188.1967
0.04	0.99905	184.6160	0.04	0.99763	186.1084
0.06	0.99958	182.2632	0.06	0.99811	184.1763
0.08	1.00017	180.2777	0.08	0.99867	182.1478
0.10	1.00081	178.5359	0.10	0.99931	180.0738
L-tryptophan in m=0.025 mol· kg ⁻¹ NaCl			L-tryptophan in m=0.025 mol· kg ⁻¹ NaCl		
T=308.15K			T=313.15K		
0.01	0.99543	192.0412	0.01	0.99381	194.3583
0.02	0.99559	190.4966	0.02	0.99396	192.304
0.04	0.99595	188.6623	0.04	0.99428	190.724
0.06	0.99642	186.1366	0.06	0.99468	188.792
0.08	0.99687	185.0866	0.08	0.99515	186.891
0.10	0.99744	183.1929	0.10	0.99571	184.790
L-tryptophan in m=0.2 mol· kg ⁻¹ KCl			L-tryptophan in m=0.2 mol· kg ⁻¹ KCl		
T=298.15K			T=303.15K		
0.01	1.00659	180.1829	0.01	1.00508	182.4002
0.02	1.00686	178.1608	0.02	1.00533	180.3751
0.04	1.00742	176.5822	0.04	1.00586	178.5487
0.06	1.00805	174.8290	0.06	1.00647	176.5453
0.08	1.00881	172.2758	0.08	1.00715	174.6146
0.10	1.00956	170.7944	0.10	1.00793	172.4061
L-tryptophan in m=0.2 mol· kg ⁻¹ KCl			L-tryptophan in m=0.2 mol· kg ⁻¹ KCl		
T=308.15K			T=313.15K		
0.01	1.00341	184.6563	0.01	1.00174	186.9264
0.02	1.00365	182.1292	0.02	1.00196	184.3942

At the same molality and temperature, $(\text{LiCl}) < \Delta_{\text{trs}}\phi_{\text{V}}^0 (\text{NaCl}) < \Delta_{\text{trs}}\phi_{\text{V}}^0 (\text{KCl})$ was the trend of $\Delta_{\text{trs}}\phi_{\text{V}}^0$ while the negativity of S_{V}^* values increased in the direction of $\text{LiCl} \rightarrow \text{NaCl} \rightarrow \text{KCl}$ due to the dominant position of interactions between the three components of the ternary system charged amino acid L-tryptophan, water and alkali halide salt. The electrical shrinkage effect for cations with the same charge Li^+ , Na^+ , and K^+ was the same but here the driving force is the ionic radius of the cation. Since the ionic radius of cations has the order $\text{Li}^+ < \text{Na}^+ < \text{K}^+$, water molecules of the L-tryptophan molecular hydration shell were affected with cations according to its radius. K^+ has the strongest destruction effect while Li^+ has the weakest effect. The oxygen atom of the strong polar solvent carries the partial negative charge that makes the cations solvation easier as reported by Owensby [32]. The electric shrinkage effect of the solvent was greater for Li^+ than that of Na^+ and K^+ due to the higher surface charge density of Li^+ . Thus, the solute-solute interactions between L-tryptophan molecules via hydrogen bonds weakened due to the solute-solvent interactions that decreasing S_{V}^* values. Furthermore, the small contribution of temperature to volume was indicated by the little effects of temperature on the ϕ_{V}^0 and S_{V}^* values. Increasing the molality of alkali halide leads to increased values of ϕ_{V}^0 while the S_{V}^* values have opposite trend due to the order of radius in the electrically induced contraction effect. The limiting partial molar volume of transfer ($\Delta_{\text{trs}} \phi_{\text{V}}^0$) different values for salts with the same anions mainly depend on different cations. Also, the charge density on the surface of the cation determines the interactions between salts and the amino acid L-tryptophan. The contribution to $\Delta_{\text{trs}} \phi_{\text{V}}^0$ was greater due to greater charge density that associated with a greater electrostatic effect. The ionic radius was K^+ (0.133 nm) > Na^+ (0.095 nm) > Li^+ (0.068 nm) with the same charge so the ionic radius was responsible of positive contribution to $\Delta_{\text{trs}} \phi_{\text{V}}^0$ values that has the order of $\text{Li}^+ > \text{Na}^+ > \text{K}^+$. Moreover, the hydration enthalpy [33] plays important role of this order: $\Delta_{\text{trs}} \phi_{\text{V}}^0$

(LiCl) < $\Delta_{\text{trs}} \varphi_{\text{V}}^0$ (NaCl) < $\Delta_{\text{trs}} \varphi_{\text{V}}^0$ (KCl) in which Li^+ (–522 kJ/mol), Na^+ (–375 kJ/mol), and K^+ (–324 kJ/mol) that makes the hydration ability was easier for K^+ than that of Na^+ and Li^+ .

Table 3 Continued

m (mol·kg ^{–1}) ³ (kg·m ^{–3})	$\rho \times 10^{-3}$ (kg·m ^{–3}) $\phi_{\text{V}} \times 10^6$ (m ³ ·mol ^{–1})	$\phi_{\text{V}} \times 10^6$ (m ³ ·mol ^{–1})	m (mol·kg ^{–1})	$\rho \times 10^{-3}$	
0.04	1.00415	180.3014	0.04	1.00243	182.3157
0.06	1.00472	178.4629	0.06	1.00298	180.2248
0.08	1.00539	176.2371	0.08	1.00361	178.1220
0.10	1.00606	174.8565	0.10	1.00428	176.4124
L-tryptophan in $m=0.1$ mol·kg ^{–1} KCl			L-tryptophan in $m=0.1$ mol·kg ^{–1} KCl		
T=298.15K			T=303.15K		
0.01	1.00173	182.9404	0.01	1.00140	
185.9866					
0.02	1.00198	180.9017	0.02	1.00162	
183.9514					
0.04	1.00253	178.5616	0.04	1.00211	
181.6189					
0.06	1.00315	176.5435	0.06	1.00266	
179.7760					
0.08	1.00382	174.8507	0.08	1.00328	
177.9228					
0.10	1.00458	172.8797	0.10	1.00402	
175.5534					
L-tryptophan in $m=0.1$ mol·kg ^{–1} KCl			L-tryptophan in $m=0.1$ mol·kg ^{–1} KCl		
T=308.15K			T=313.15K		
0.01	0.99947	187.3124	0.01	0.99754	
188.6470					
0.02	0.99967	185.7733	0.02	0.99774	
186.5994					
0.04	1.00013	183.4366	0.04	0.99819	
184.2553					
0.06	1.00063	181.9282	0.06	0.99869	
182.5735					
0.08	1.00122	179.9886	0.08	0.99927	
180.6698					
0.10	1.00199	176.9540	0.10	0.99992	
178.7726					
L-tryptophan in $m=0.05$ mol·kg ^{–1} KCl			L-tryptophan in $m=0.05$ mol·kg ^{–1} KCl		
T=298.15K			T=303.15K		
0.01	1.00158	184.9591	0.01	1.00119	
186.0218					
0.02	1.00181	182.9231	0.02	1.00140	184.4864
0.04	1.00231	180.8392	0.04	1.00187	182.4056
0.06	1.00288	178.9109	0.06	1.00241	180.4803
0.08	1.00346	177.6447	0.08	1.00309	177.7021
0.10	1.00406	176.8441	0.10		1.00379
175.7868					
L-tryptophan in $m=0.05$ mol·kg ^{–1} KCl			L-tryptophan in $m=0.05$ mol·kg ^{–1} KCl		
T=308.15K			T=313.15K		
0.01	0.99926	188.3500	0.01	0.997	

190.6947					
	0.02	0.99945	186.8120	0.02	0.997
188.1451					
	0.04	0.99988	184.7296	0.04	0.997
186.3111					
	0.06	1.00039	182.6344	0.06	0.998
184.4656					
	0.08	1.00097	180.6537	0.08	0.998
182.3545					
0.10		1.00163	178.6111	0.10	0.999
180.7419					
L-tryptophan in m=0.025 mol· kg ⁻¹ KCl			L-tryptophan in m=0.0		
mol· kg ⁻¹ KCl			mol· kg ⁻¹ KCl		
	T=298.15K			T=303.15	
0.01		1.00069	186.1058	0.01	0.99991
188.2379					
0.02		1.00091	184.0677	0.02	1.00011
186.2000					
0.04		1.00137	182.4860	0.04	1.00054
184.3705					
0.06		1.00189	180.8948	0.06	1.00102
182.8665					
0.08		1.00251	178.7890	0.08	1.00153
181.6914					
0.10		1.00321	176.6716	0.10	1.00219
179.4260					
L-tryptophan in m=0.025 mol· kg ⁻¹ KCl			L-tryptophan in m=0.0		
mol· kg ⁻¹ KCl			mol· kg ⁻¹ KCl		
	T=308.15K			T=313.15	
0.01		0.99879	189.4320	0.01	0.99704
0.02		0.99897	188.3974	0.02	0.997
189.2029					
0.04		0.99935	186.8228	0.04	0.997
187.1180					
0.06		0.99976	185.7446	0.06	0.998
185.3585					
0.08		1.00024	184.2789	0.08	0.998
183.4185					
0.10		1.00091	181.4293	0.10	0.999
181.7058					

3.2. Viscometric properties

Different salt concentrations in various solvents at working temperatures with the obtained viscosity data are valuable to understand both the solute –solute and solute –solvent interactions [34, 35]. Table 6 shows the ternary system (aqueous alkali halide+ L-tryptophan) experimental viscosities at working temperatures T= 298.15-313.15K. From Table 6, it is showed that increasing the molality of alkali halide LiCl/NaCl/KCl leads to nonlinearly increase of the viscosity. Also, the increased molality of L-tryptophan amino acid leads to an increase of the viscosity value at constant temperature. When the temperature was increased, the molecular rapid motions also increased that leading to a decrease of the viscosity value confirming that temperature and concentration are the main controllers of viscosity values. The viscosity has the order: η (KCl) > η (NaCl) > η (LiCl) for amino acid L-tryptophan at constant molality and temperature. The following equation reported by Jones-Dole and used for analyzing the viscosity data [36, 37].

$$\eta_r - 1/\sqrt{m} = A + B\sqrt{m} \quad (8)$$

$$\eta_r = \eta/\eta_0 \quad (9)$$

where η_0 and η are the solvent mixture and solution viscosities, respectively. A & B values as reported in Table 7 are the viscosity coefficients estimated by a least square method. The A and B values are obtained from the straight line by plotting $(\eta/\eta_0 - 1)/\sqrt{m}$ against \sqrt{m} for L-tryptophan in aqueous solution of LiCl, NaCl and KCl at 298.15, 303.15, 308.15 K and 313.15K respectively. η_r was calculated by eq. 7. Some physicochemical characteristics of solutions can be obtained from the Jones –Dole constants A and B. The solute –solvent interactions are reflected from value of viscosity B-Coefficient. B-Coefficients are an important method describing the solute behavior in various liquids and give data about solute effects on the solvent arrangement in the neighboring environment of the solute molecules [38, 39]. Falkenhagen coefficients (A-Coefficients) are usually very small and can be determined empirically which value reflecting solute-solute interactions. According to Table 7, B-Coefficients of the studied system increased with the rise of working temperature. When the molality of alkali halide LiCl/NaCl/KCl increased, the value of B-Coefficients also found to be increased. The solute-solvent interactions are indicated by the positive value of B-Coefficients. Table 7 shows B-Coefficients values of L-tryptophan in aqueous alkali halide solvent that indicated strong solute-solvent interactions. An increase of LiCl/NaCl/KCl in the solvent mixtures strengthened these interactions between solute and solvent.

Table 4

Limiting apparent molar volume (ϕ_v^0), experimental slope (S_v^*) and limiting partial molar volume ($\Delta_{\text{trs}}\phi_v^0$) of L-tryptophan in aqueous LiCl, NaCl, KCl solutions at 298.15 K, 303.15 K, 308.15 K and 313.15K

m/mol.kg ⁻¹	$\phi_v^0 \times 10^6 (\text{m}^3 \cdot \text{mol}^{-1})$				$S_v^* \times 10^6 (\text{m}^3 \cdot \text{mol}^{-3/2} \cdot \text{Kg}^{1/2})$			$\Delta_{\text{trs}}\phi_v^0 \times 10^6 (\text{m}^3 \cdot \text{mol}^{-1})$			
	298.15K	303.15K	308.15K	313.15K	298.15K	303.15K	308.15K	298.15K	303.15K	308.15K	313.15K
0.2 LiCl	189.419	192.250	194.084	194.951				-46.153	-51.407	-48.776	-49.6
	8.44			8.10	7.85			7.43			
0.1 LiCl	190.536	193.523	195.511	196.249	-36.324	-42.265	-48.589	-49.394	11.34	11.6	
	10.57	10.11									
0.05 LiCl	192.837	194.803	196.328	197.658	-33.098		-39.343	-40.726	-37.671		
	21.33	21.09	20.97	20.55							
0.025 LiCl	193.932	197.474	199.037	198.551	-36.246	-47.326	-50.047	-40.873	34.98	34.52	34.4
	33.95										
0.2 NaCl	187.166	190.753	192.046	192.489	-44.564	-53.060	-48.180	-42.589		12.11	
	11.92	11.52	11.04								
0.1 NaCl	189.267	191.387	192.835	195.522	-43.934		-41.101	-42.121	-45.909	14.6	
	13.98	13.41	13.11								
0.05 NaCl	190.516	192.857	193.965	196.223	-41.006	-42.943	-36.713	-40.386	25.56	24.1	
	24.05	23.88									
0.025 NaCl	193.138	195.323	196.283	198.667	-45.271		-47.058	-40.536	-42.119	40.4	
	38.29	38.09	37.75								
0.2 KCl	184.545	186.958	188.857	191.502	-42.357	-44.235	-43.956	-47.159		14.1	
	13.88	13.65	13.24								
0.1 KCl	187.478	190.691	192.204	193.053	-45.270		-46.163	-44.989	-44.187	15.1	
	15.08	14.99	14.55								
0.05 KCl	188.452	191.185	193.123	194.926	-37.802	-46.853	-44.303	-44.223	26.19	26.1	
	25.89	25.64									
0.025 KCl	190.319	191.904	193.263	195.966	-41.153	-37.833	-33.820	-44.530	44.63		
	44.15	43.51	43.12								

Table 5

Values of coefficients and limiting apparent molar expansibilities (Φ_E^0) for L -tryptophan in aqueous LiCl, NaCl and KCl solutions at different temperatures

m/mol.kg ⁻¹	a ₀ x 10 ⁶		a ₁ x 10 ⁶	a ₂	x1	Φ _E ⁰ x 10 ⁶ (m ³ .mol ⁻¹ .K ⁻¹)				(∂ Φ _E ⁰ /∂T) _P
	(m ³ .mol ⁻¹)		(m ³ .mol ⁻¹)	(m ³ .mol ⁻¹)			298.15K	303.15K	308.15K	
0.20 LiCl	-1781.47		12.5549	-0.01993			0.67	0.47	0.27	0
Negative										
0.10 LiCl	-1790.94	12.5946			-0.01995	0.69	0.49		0.29	0.0
Negative										
0.05 LiCl	-721.578	5.69664			-0.00882	0.43	0.34		0.26	0.1
Negative										
0.025 LiCl	-3594.25	24.5049			-0.03958	0.90	0.50		0.11	-0.1
Negative										
0.20 NaCl	-4173.13		28.3022	-0.04587			0.94	0.49	0.03	-0.1
Negative										
0.10 NaCl	-1152.11	8.5067	-0.01344	0.49	0.35	0.22	0.08		Negative	
0.05 NaCl	-2176.84	15.2889			-0.02465	0.59	0.34		0.09	-0.1
Negative										
0.025 NaCl	-2153.1	15.1772	-0.02451	0.58	0.31	0.07	-0.17		Negative	
0.20 KCl	-888.39		6.6633	-0.01027			0.53	0.43	0.33	0
Negative										
0.10 KCl	-3078.72	21.0976	-0.04302	0.81	0.47	0.13	-5.84		Negative	
0.05 KCl	-1410.81	10.1024	-0.01589	0.62	0.46	0.30	0.15		Negative	
0.025 KCl	-312.135	3.03124	-0.00451	0.34	0.29	0.25	0.20		Negative	

This conclusion was approved from earlier discussed and drawn values of φ_v^0 limiting apparent molar volume. The influences of alkali halide molality on water structure and the enrichment of the hydrogen bonding between solvent and L -tryptophan were also indicated from positive B-coefficient values. B-coefficient values are lower positively in aqueous KCl solvent than that of aqueous NaCl and LiCl solvent. This behavior of B-coefficient values may be related to K^+ easier polarized properties than that of Na^+ and Li^+ . The structure –making or breaking nature of any solute can be determined from the value of dB/dT that used to compare B-Coefficients as reported in previous works [40, 43]. The negative value of dB/dT indicates the structure maker properties of solute, while the positive value of dB/dT indicates structure breaker features [13]. The positive dB/dT value corresponded to B-Coefficients values that increased with the temperature that indicates structure breaker features of solute (L -tryptophan) in the studied ternary system. The earlier drawn values of $(\partial \Phi_E^0 / \partial T)_P$ in Table 5 enhances this conclusion. The L -tryptophan solvation number in the aqueous ternary system can be calculated from (B/φ_v^0) value and tabulated in Table 8. If the (B/φ_v^0) value is 0-2.5, this an indication of un-solvated species while the higher value is an indication of well-oriented solvation shells of the solute [41]. The (B/φ_v^0) value of L -tryptophan in the aqueous ternary system is smaller than 2.5 indicating poor solvation of the solute amino acid. Feakins et al [44, 45] suggest the transition state treatment for the viscosity data; this theory calculates the B-coefficient according to eq. 10:

$$B = \frac{\bar{v}_1^0 - \bar{v}_2^0}{1000} + \frac{\bar{v}_1^0 (\Delta \mu_2^{SE} - \Delta \mu_1^{SE})}{1000RT} \quad (10)$$

where $\bar{v}_1^0 = \sum X_i M_i / \rho^0$ and $\bar{v}_2^0 (= \varphi_v^0)$ are the molar volume of the solvents (MCl + H₂O) and the standard partial molar volume of the solute at infinite dilution, respectively.

Table 6

Experimental values of viscosities (η) and relative viscosities (η_r) values of L-tryptophan in aqueous LiCl, NaCl and KCl solutions at 298.15 K, 303.15 K, 308.15 K and 313.15K and pressure $p=0.1$ MPa

m (mol·kg ⁻¹)	η (mPa.s)	η_r (mPa.s)	m (mol·kg ⁻¹)	η (mPa.s)	η_r (mPa.s)
L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		
0.01	0.9820	1.002	0.01	0.9005	1.001
0.02	0.9847	1.005	0.02	0.9031	1.004
0.04	0.9896	1.010	0.04	0.9080	1.010
0.06	0.9949	1.015	0.06	0.9135	1.016
0.08	1.0003	1.021	0.08	0.9189	1.022
0.1	1.0067	1.027	0.1	0.9237	1.027
L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.2 mol· kg ⁻¹ LiCl		
T=308.15K			T=313.15K		
0.01	0.8217	1.002	0.01	0.6789	1.003
0.02	0.8248	1.006	0.02	0.6822	1.008
0.04	0.8303	1.013	0.04	0.6879	1.016
0.06	0.8367	1.020	0.06	0.6935	1.025
0.08	0.8421	1.027	0.08	0.6991	1.033
0.1	0.8487	1.035	0.1	0.7058	1.043
L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		
0.01	0.9710	1.002	0.01	0.8915	1.001
0.02	0.9737	1.005	0.02	0.8941	1.004
0.04	0.9786	1.010	0.04	0.8989	1.010
0.06	0.9839	1.015	0.06	0.9043	1.016
0.08	0.9893	1.021	0.08	0.9098	1.022
0.1	0.9957	1.027	0.1	0.9164	1.029
L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.1 mol· kg ⁻¹ LiCl		
T=308.15K			T=313.15K		
0.01	0.8136	1.002	0.01	0.6706	1.003
0.02	0.8167	1.006	0.02	0.6739	1.008
0.04	0.8222	1.013	0.04	0.6796	1.016
0.06	0.8284	1.020	0.06	0.6860	1.026
0.08	0.8345	1.028	0.08	0.6923	1.035
0.1	0.8424	1.038	0.1	0.6953	1.040
L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		
0.01	0.8892	1.002	0.01	0.7960	1.002
0.02	0.8918	1.005	0.02	0.7987	1.005
0.04	0.8973	1.011	0.04	0.8042	1.012
0.06	0.9027	1.017	0.06	0.8097	1.019
0.08	0.9082	1.023	0.08	0.8156	1.027
0.1	0.9140	1.030	0.1	0.8220	1.035
L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.05 mol· kg ⁻¹ LiCl		
T=308.15K			T=313.15K		
0.01	0.7105	1.002	0.01	0.6634	1.002
0.02	0.7130	1.005	0.02	0.6661	1.006
0.04	0.7178	1.012	0.04	0.6711	1.014
0.06	0.7230	1.019	0.06	0.6765	1.022
0.08	0.7286	1.027	0.08	0.6823	1.031
0.1	0.7343	1.035	0.10	0.6882	1.040
L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl			L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl		
T=298.15K			T=303.15K		

0.01	0.8648	1.002	0.01	0.7228	1.002
0.02	0.8674	1.005	0.02	0.7250	1.005
0.04	0.8724	1.011	0.04	0.7305	1.013
0.06	0.8777	1.017	0.06	0.7360	1.020
0.08	0.8831	1.023	0.08	0.7417	1.028
0.1	0.8891	1.030	0.1	0.7485	1.038
L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl T=308.15K			L-tryptophan in m=0.025 mol· kg ⁻¹ LiCl T=313.15K		
0.01	0.6961	1.002	0.01	0.6599	1.002
0.02	0.6988	1.005	0.02	0.6628	1.006
0.04	0.7038	1.013	0.04	0.6680	1.014

Table 6 Continued

m (mol·kg ⁻¹)	η(mPa.s)	η _r (mPa.s)	m (mol·kg ⁻¹)	η(mPa.s)	η _r (mPa.s)
0.06	0.7093	1.021	0.06	0.6737	1.023
0.08	0.7153	1.029	0.08	0.6799	1.032
0.1	0.7221	1.039	0.1	0.6869	1.043
L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=298.15K			L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=303.15K		
0.01	0.9822	1.002	0.01	0.9020	1.002
0.02	0.9849	1.004	0.02	0.9048	1.005
0.04	0.9896	1.009	0.04	0.9095	1.010
0.06	0.9945	1.014	0.06	0.9145	1.016
0.08	0.9999	1.020	0.08	0.9199	1.022
0.1	1.0064	1.026	0.1	0.9264	1.029
L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=308.15K			L-tryptophan in m=0.2 mol· kg ⁻¹ NaCl T=313.15K		
0.01	0.8222	1.002	0.01	0.7786	1.002
0.02	0.8249	1.005	0.02	0.7814	1.006
0.04	0.8296	1.011	0.04	0.7861	1.012
0.06	0.8346	1.017	0.06	0.7911	1.018
0.08	0.8401	1.024	0.08	0.7965	1.025
0.1	0.8466	1.032	0.1	0.8020	1.032
L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=298.15K			L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=303.15K		
0.01	0.9741	1.002	0.01	0.8943	1.002
0.02	0.9766	1.004	0.02	0.8970	1.005
0.04	0.9816	1.010	0.04	0.9021	1.010
0.06	0.9869	1.015	0.06	0.9073	1.016
0.08	0.9923	1.021	0.08	0.9129	1.022
0.1	0.9978	1.026	0.1	0.9194	1.030
L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=308.15K			L-tryptophan in m=0.1 mol· kg ⁻¹ NaCl T=313.15K		
0.01	0.8164	1.002	0.01	0.7520	1.003
0.02	0.8193	1.006	0.02	0.7551	1.007
0.04	0.8251	1.013	0.04	0.7611	1.015
0.06	0.8314	1.021	0.06	0.7676	1.024
0.08	0.8379	1.029	0.08	0.7743	1.032
0.1	0.8446	1.037	0.10	0.7812	1.042
L-tryptophan in m=0.05 mol· kg ⁻¹ NaCl T=298.15K			L-tryptophan in m=0.05 mol· kg ⁻¹ NaCl T=303.15K		
0.01	0.8952	1.002	0.01	0.7851	1.002

0.02	0.8979	1.005	0.02	0.7878	1.005
0.04	0.9031	1.011	0.04	0.7929	1.012
0.06	0.9085	1.017	0.06	0.7983	1.019
0.08	0.9140	1.023	0.08	0.8043	1.026
0.1	0.9189	1.029	0.1	0.8098	1.033
L-tryptophan in m=0.05 mol· kg ⁻¹ NaCl T=308.15K			L-tryptophan in 0.05 mol· kg ⁻¹ NaCl T=313.15K		
0.01	0.6888	1.002	0.01	0.6649	1.002
0.02	0.6912	1.005	0.02	0.6675	1.006
0.04	0.6964	1.013	0.04	0.6729	1.014
0.06	0.7014	1.020	0.06	0.6781	1.022
0.08	0.7064	1.027	0.08	0.6833	1.030
0.1	0.7114	1.034	0.1	0.6904	1.040
L-tryptophan in m=0.025 mol· kg ⁻¹ NaCl T=298.15K			L-tryptophan in 0.025 mol· kg ⁻¹ NaCl T=303.15K		
0.01	0.8406	1.002	0.01	0.7785	1.002
0.02	0.8430	1.005	0.02	0.7815	1.006
0.04	0.8481	1.011	0.04	0.7875	1.014
0.06	0.8533	1.017	0.06	0.7935	1.021
0.08	0.8583	1.023	0.08	0.7995	1.029
0.1	0.8637	1.030	0.1	0.8060	1.037
L-tryptophan in m=0.025 mol· kg ⁻¹ NaCl T=308.15K			L-tryptophan in m=0.025 mol· kg ⁻¹ NaCl T=313.15K		
0.01	0.6780	1.002	0.01	0.6618	1.002
0.02	0.6805	1.006	0.02	0.6645	1.006
0.04	0.6861	1.014	0.04	0.6703	1.015
0.06	0.6913	1.022	0.06	0.6757	1.023
0.08	0.6973	1.031	0.08	0.6819	1.033
0.1	0.7033	1.039	0.1	0.6881	1.042
L-tryptophan in m=0.2 mol· kg ⁻¹ KCl T=298.15K			L-tryptophan in 0.2 mol· kg ⁻¹ KCl T=303.15K		
0.01	0.9831	1.002	0.01	0.9024	1.002
0.02	0.9859	1.004	0.02	0.9052	1.005

Table 6 Continued

Table 6. Continued						
m (mol·kg ⁻¹)	η(mPa.s)	η _r (mPa.s)		m (mol·kg ⁻¹)	η(mPa.s)	η _r (mPa.s)
0.04	0.9906	1.009	0.04	0.9099	1.010	
0.06	0.9956	1.014	0.06	0.9149	1.016	
0.08	1.0010	1.020	0.08	0.9203	1.022	
0.1	1.0061		1.025	0.1	0.9255	1.027
L-tryptophan in m=0.2 mol· kg ⁻¹ KCl				L-tryptophan in 0.2 mol· kg ⁻¹ KCl		
T=308.15K				T=313.15K		
0.01	0.8241	1.002	0.01	0.7795	1.002	
0.02	0.8268	1.005	0.02	0.7822	1.006	
0.04	0.8315	1.011	0.04	0.7869	1.012	
0.06	0.8365	1.017	0.06	0.7919	1.018	
0.08	0.8419	1.024	0.08	0.7974	1.025	
0.1	0.8478	1.031	0.1	0.8020	1.031	
L-tryptophan in m=0.1 mol· kg ⁻¹ KCl				L-tryptophan in m=0.1 mol· kg ⁻¹ KCl		
T=298.15K				T=303.15K		
0.01	0.9770	1.002	0.01	0.9001	1.002	
0.02	0.9796	1.005	0.02	0.9026	1.005	
0.04	0.9845	1.010	0.04	0.9076	1.010	
0.06	0.9899	1.015	0.06	0.9130	1.016	
0.08	0.9953	1.021	0.08	0.9187	1.023	
0.1	1.0006	1.026	0.1	0.9251	1.030	

L-tryptophan in m=0.1 mol· kg ⁻¹ KCl T=308.15K			L-tryptophan in m=0.1 mol· kg ⁻¹ KCl T=313.15K		
0.01	0.8193	1.002	0.01	0.7544	1.002
0.02	0.8223	1.006	0.02	0.7571	1.006
0.04	0.8281	1.013	0.04	0.7618	1.012
0.06	0.8343	1.021	0.06	0.7668	1.019
0.08	0.8408	1.029	0.08	0.7733	1.027
0.1	0.8476	1.037	0.1	0.7818	1.039
L-tryptophan in m=0.05 mol· kg ⁻¹ KCl T=298.15K			L-tryptophan in m=0.05 mol· kg ⁻¹ KCl T=303.15K		
0.01	0.8924	1.002	0.01	0.7981	1.002
0.02	0.8947	1.005	0.02	0.8004	1.004
0.04	0.8997	1.010	0.04	0.8050	1.010
0.06	0.9047	1.016	0.06	0.8096	1.016
0.08	0.9102	1.022	0.08	0.8149	1.023
0.1	0.9152	1.028	0.1	0.8200	1.029
L-tryptophan in m=0.05 mol· kg ⁻¹ KCl T=308.15K			L-tryptophan in m=0.05 mol· kg ⁻¹ KCl T=313.15K		
0.01	0.6934	1.002	0.01	0.6793	1.002
0.02	0.6958	1.005	0.02	0.6820	1.006
0.04	0.7008	1.013	0.04	0.6867	1.013
0.06	0.7060	1.020	0.06	0.6910	1.020
0.08	0.7110	1.027	0.08	0.6964	1.028
0.1	0.7165	1.035	0.1	0.7057	1.041
L-tryptophan in m=0.025 mol· kg ⁻¹ KCl T=298.15K			L-tryptophan in m=0.025 mol· kg ⁻¹ KCl T=303.15K		
0.01	0.8832	1.002	0.01	0.7273	1.002
0.02	0.8856	1.005	0.02	0.7296	1.005
0.04	0.8905	1.010	0.04	0.7344	1.012
0.06	0.8955	1.016	0.06	0.7395	1.019
0.08	0.9010	1.022	0.08	0.7452	1.027
0.1	0.9064	1.028	0.1	0.7503	1.034
L-tryptophan in m=0.025 mol· kg ⁻¹ KCl T=308.15K			L-tryptophan in m=0.025 mol· kg ⁻¹ KCl T=313.15K		
0.01	0.6991	1.002	0.01	0.6671	1.003
0.02	0.7014	1.005	0.02	0.6699	1.007
0.04	0.7064	1.012	0.04	0.6746	1.014
0.06	0.7117	1.020	0.06	0.6796	1.021
0.08	0.7171	1.028	0.08	0.6850	1.029
0.1	0.7226	1.035	0.10	0.6929	1.041

Table 7

Values of Jones–Dole coefficients, A and B of L-tryptophan in aqueous LiCl, NaCl and KCl solutions at 298.15 K, 303.15 K, 308.15 K and 313.15K

m/mol.kg ⁻¹		A(kg . mol ⁻¹)				B(kg ^{1/2} . mol ^{-1/2})		
		298.15K	303.15K	308.15K	313.15K	298.15K	303.15K	308.15K
LiCl								
0.20		-0.0055	-0.0122	-0.0110	-0.0073	0.286	0.319	0.389
0.10		-0.0056		-0.0151	-0.0164	-0.0082		0.289
0.421	0.455							0.339
0.05		-0.0081	-0.0158		-0.0207	-0.0198		0.328
0.418	0.459							0.397

0.025		-0.0088	-0.0214	-0.0270	-0.0261	0.329	0.440		
0.470	0.507								
NaCl									
0.20		-0.0068	-0.0073	-0.0087	-0.0066	0.281	0.308	0.340	0.345
0.10		-0.0050	-0.0134	-0.0140	-0.0146		0.281	0.337	0.4
0.463									
0.05		-0.0058		-0.0152	-0.0199	-0.0225		0.311	0.385
0.416	0.469								
0.025		-0.0075	-0.0163	-0.0215	-0.0199			0.323	0.431
0.464	0.487								
KCl									
0.20		-0.0059	-0.0065	-0.0088	-0.0071	0.273	0.298	0.334	0.340
0.10		-0.0032		-0.0106		-0.0120	-0.0182		0.275 0.327
0.409	0.421								
0.05		-0.0047		-0.0132	-0.0178	-0.0155		0.295	0.323
0.412	0.432								
0.025		-0.0063	-0.0148	-0.0197	-0.0148			0.304	0.387
0.420	0.442								

Table 8

Free Energies of Activation for Solvent ($\Delta\mu_1^{0\#}/\text{kJ}\cdot\text{mol}^{-1}$) and for Solute ($\Delta\mu_2^{0\#}/\text{kJ}\cdot\text{mol}^{-1}$) and Solvation Number of L -tryptophan in Different Molalities of LiCl/NaCl/KCl Aqueous Solutions at $T = 298.15 - 313.15$ K

T/K	B/ φ_V^0	$\Delta\mu_1^{0\#}$	$\Delta\mu_2^{0\#}$	T/K	B/ φ_V^0	$\Delta\mu_1^{0\#}$	$\Delta\mu_2^{0\#}$	T/K	B/ φ_V^0	$\Delta\mu_1^{0\#}$	$\Delta\mu_2^{0\#}$
m(LiCl=0.2 mol· kg ⁻¹)				m(NaCl=0.2 mol· kg ⁻¹)				m(KCl=0.2 mol· kg ⁻¹)			
298.15	0.001	15.114	74.940	298.15	0.001	15.115	74.257	298.15	0.001	15.123	73.045
303.15	0.001	15.154	80.498	303.15	0.001	15.157	78.964	303.15	0.001	15.164	77.448
308.15	0.002	15.171	91.393	308.15	0.001	15.174	84.449	308.15	0.001	15.185	83.475
313.15	0.002	14.922	101.159	313.15	0.001	15.282	86.279	313.15	0.001	15.291	85.433
m(LiCl=0.1 mol· kg ⁻¹)				m(NaCl=0.1 mol· kg ⁻¹)				m(KCl=0.1 mol· kg ⁻¹)			
298.15	0.001	15.086	79.370	298.15	0.001	15.094	77.737	298.15	0.001		15.1
76.391											
303.15	0.001	15.129	87.821				303.15	0.001	15.136	86.857	303.1
0.001	15.152	85.214									
308.15	0.002	15.147	100.849	308.15	0.002	15.154	99.119	308.15			0.0
15.164	98.069										
313.15	0.002	14.891	101.693	313.15	0.002	15.899	103.150	313.15	0.002	15.201	97.072
m(LiCl=0.05 mol· kg ⁻¹)				m(NaCl=0.05 mol· kg ⁻¹)				m(KCl=0.05 mol· kg ⁻¹)			
298.15	0.001	14.868	83.452				298.15	0.001	14.884	80.248	298.1
0.001	14.873	77.752									
303.15	0.002	14.842	94.402				303.15	0.001	14.808	91.947	303.1
0.001	14.843	83.052									
308.15	0.002	14.800	98.750				308.15	0.002	14.721	97.621	308.1
0.002	14.732	96.867									
313.15	0.002	14.865	102.235	313.15	0.002	14.870	103.733	313.15	0.002	14.920	98.591
m(LiCl=0.025 mol· kg ⁻¹)				m(NaCl=0.025 mol· kg ⁻¹)				m(KCl=0.025 mol· kg ⁻¹)			
298.15	0.001	14.798	81.807				298.15	0.001	14.728	80.057	298.1
0.001	14.846	76.717									
303.15	0.002	14.598	98.662				303.15	0.002	14.785	96.783	303.1
0.002	14.607	89.360									
308.15	0.002	14.748	104.547				308.15	0.002	14.679	102.731	308.1
0.002	14.750	95.620									
313.15	0.002	14.852	109.107	313.15	0.002	14.857	106.284	313.15	0.002	14.870	100.076

Table9.Activation enthalpy $\Delta H_2^{0\#}$ and entropy $\Delta S_2^{0\#}$ for viscous flow of L-tryptophan in aqueous alkali halides

m (mol·kg ⁻¹)	$\Delta H_2^{0\#}$ (kJ·mol ⁻¹)	$\Delta S_2^{0\#}$ (J·mol ⁻¹ ·K)
LiCl		
0.2	-459.059	-1791.1
0.1	-561.026	
2147.9		
0.05	-278.484	
1213.9		
0.025	-441.655	
1755.7		
NaCl		
0.2	-173.512	-831.02
0.1	-449.994	
1770.02		
0.05	-373.709	
1522.5		
0.025	-424.586	
1692.5		
KCl		
0.2	-184.503	-863.8
0.1	-370.226	
1497.9		
0.05	-377.416	
1526.6		
0.025	-378.481	
1526.7		

ρ_0 denotes the solvent density (H₂O + MCl). The M_i and x_i symbolize the molar weight mole fraction and mole fraction of MCl and H₂O in mixed solvent, in that order. $\Delta\mu_1^{0\#}$ and $\Delta\mu_2^{0\#}$ represent the activation free energy of solvent and the activation free energy of solute, respectively and could be considered by equations 11 and 12

$$\Delta\mu_1^{0\#} = \Delta G_1^{0\#} = RT \ln(\eta_0 \bar{v}_1^0 / h N_A) \quad (11)$$

where η_0 is the solvent viscosity, h is the Planck constant, R is the gas constant, N_A is the Avogadro number, also the further symbols have their common denotations.

$$\Delta\mu_2^{0\#} = \Delta G_2^{0\#} = \Delta\mu_1^{0\#} + RT[1000B - (\bar{v}_1^0 - \bar{v}_2^0)]/\bar{v}_1^0 \quad (12)$$

Table 8 includes $\Delta\mu_1^{0\#}$ and $\Delta\mu_2^{0\#}$ values at the working temperatures. The structure breaker features of the solute are represented by the small $\Delta\mu_2^{0\#}$ value that is in harmony with dB/dT results [25-28]. $\Delta\mu_2^{0\#}$ value represents the facility to form the transition state according to the model of Feakins in which the transition state formation difficulty appears at high $\Delta\mu_2^{0\#}$ value due to strong solvent-solute interactions. Both values of $\Delta\mu_1^{0\#}$ and $\Delta\mu_2^{0\#}$ were positive and $\Delta\mu_1^{0\#}$ values were smaller than $\Delta\mu_2^{0\#}$ values. This behavior indicates a weaker interaction between solute L-tryptophan and aqueous alkali halide solvent in the transition state than the interaction in the ground state meaning favored solvation of the solute in the ground state. $\Delta\mu_2^{0\#}$ values have the order: LiCl > NaCl > KCl indicates stronger interaction between solute and solvent in the case of LiCl solvent than that of NaCl and KCl. These results are in harmony with B-Coefficients values. Over the

temperature range concerned, the entropy and enthalpy of activation for viscous flow of the amino acids were calculated by equations 13 and 14

$$\Delta S_2^{0\#} = -d(\Delta\mu_2^{0\#})/dT \quad (13)$$

$$\Delta H_2^{0\#} = \Delta\mu_2^{0\#} + T\Delta S_2^{0\#} \quad (14)$$

The results for these activation parameters are presented in Table 9. The negative $\Delta S_2^{0\#}$ and $\Delta H_2^{0\#}$ values indicate that the formation of the activated complex is associated with bond formation [46-50] and a decrease in order. This suggests that the ground states are in the ordered region.

4. Conclusion

Understanding the mechanism of the intermolecular interactions is required the thermodynamic and transport properties to be investigated. In this study, the densities and viscosities for *L*-tryptophan, in aqueous LiCl, NaCl, KCl solutions were measured at $T = (298.15, 303.15, 308.15 \text{ and } 313.15) \text{ K}$. The apparent molar volume ϕ_V , the limiting partial molar volume ϕ_V^0 , Helper's constant $(\partial^2\phi_V^0/\partial T^2)_P$, the apparent molar isobaric expansions (ϕ_E^0) and limiting partial molar volume of transfer $\Delta_{tr}\phi_V^0$ were determined. Both the values of ϕ_V and ϕ_V^0 for *L*-tryptophan increase in the order: $\text{KCl} < \text{NaCl} < \text{LiCl}$ and the strength of solute –hydrophilic and hydrophilic –hydrophilic interactions is suggested by the positive $\Delta_{tr}\phi_V^0$ values over other possible hydrophobic interactions. The viscosity B coefficients are calculated from the experimental viscosities according to the extended Jones-Dole equation. Sequentially, the free energies of activation per mole of solvent ($\Delta\mu_1^{0\#}$) and solute ($\Delta\mu_2^{0\#}$) and hydration number (n_H) were obtained. Structure-breaking properties of *L*-tryptophan in aqueous alkali halide solutions are indicated by the analysis of both volumetric and viscometric properties. Multicomponent thermodynamical properties and transport properties obtained in this study were helpful to understand the ternary solutions (*L*-tryptophan + salts + H_2O) structural change and solute –solvent interaction.

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