

# Viscometric Studies of Some Amino Acids/Peptides in Aqueous $K_2SO_4/KNO_3$ Solutions at Different Temperatures (298.15 - 323.15 K)

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## Abstract

Viscosities of L-leucine/L-glutamine/L-alanine/glycylglycine + 0.512 mol·kg<sup>-1</sup> aqueous  $K_2SO_4/0.512\text{mol}\cdot\text{kg}^{-1}$  aqueous  $KNO_3$  solutions have been measured as a function of molal concentration of amino acids/peptides at different temperatures (298.15, 303.15, 308.15, 313.15, 318.15 and 323.15) K. Using the viscosity values of the studied systems the viscosity *B*-coefficients and activation parameters:  $\Delta\mu_1^0$ ,  $\Delta\mu_2^0$ ,  $\Delta S_2^0$  and  $\Delta H_2^0$  have been computed. The *B*-coefficient is a quantity of active solvodynamic measurements of solvated ion and also is overseen through magnitude and form properties of solute, and the basic effects made by means of the solute-solvent functioning. The experimental and computed parameters have been discussed in terms of ion-ion, hydrophilic-ion and hydrophobic-ion interactions operative in the systems.

## Keywords

Viscosity, Relative Viscosity, Specific Viscosity, *B*-Coefficient, Activation Parameter, Amino Acid, Peptide, Salt

## 1. Introduction

Proteins are complex molecules, and their behavior in mixed aqueous solutions is governed by a number of specific interactions. Amino acids as well as peptides are used such as probe molecules on the way to know the composite nature of protein. The utmost incredible object is that amino acids work not only as originators of hormones, nerves, purphysis pruines, alkaloids, and transition of en-

tire growth then numerous more biomolecules. Amino acids in aqueous solution are ionized and also able to perform as bases or acid. Information on acid-base properties of amino acids is enormously essential in accepting several properties of proteins. The accumulation of solvents/salts in protein solution is well-known to move their configuration and arrangement. Most of the biological and chemical roles of biomolecules take place in aqueous medium. Electrolytes remain estimated to affect water structure, as well as the significance of involvement after structural variations of the solvent to the thermodynamic properties of aqueous solutions of biological molecules takes every so often strained. Amino acids and peptides have been taken up as model compounds for studying the interactions of protein molecules in solutions by a number of researchers [1]-[7]. Amino acids and their derivatives are also known as compensatory (or compatible) solutes in stabilizing proteins and enhancing enzyme activity [8] [9] [10]. The viscosities of L-alanine and L-leucine in 0.5 mol·L<sup>-1</sup> aqueous CdCl<sub>2</sub> have been reported by Banipal [2]. Viscosities of glycylglycine have been reported by Badarayani [11] in 0.5 mol·L<sup>-1</sup> aqueous KCl, 0.5 mol·L<sup>-1</sup> aqueous KBr and 0.5 mol·L<sup>-1</sup> aqueous Na<sub>2</sub>SO<sub>4</sub> at 298.15 K and by Santosh [7] in 0.05 mol·L<sup>-1</sup> aqueous MnCl<sub>2</sub> at different temperatures. Sadeghi [6] reported viscosities of L-alanine in 0.5 mol·L<sup>-1</sup> aqueous (KH<sub>2</sub>Cit) and 0.5 mol·L<sup>-1</sup> aqueous (K<sub>3</sub>Cit). Wadi [12] reported viscosities of alanine in 5 mol·L<sup>-1</sup> aqueous KSCN at different temperatures. Yan [13] reported viscosities of L-alanine and L-leucine in aqueous solution. Viscosities of L-phenylalanine, L-proline, L-glutamic acid and L-leucine in 2.0 mol·L<sup>-1</sup> aqueous NaCl and 2.0 mol·L<sup>-1</sup> aqueous NaNO<sub>3</sub> [5] of L-histidine, L-glutamic acid, L-tryptophan, and glycylglycine in 2.0 mol·L<sup>-1</sup> aqueous KCl and 2.0 mol·L<sup>-1</sup> aqueous KNO<sub>3</sub> solutions<sup>1</sup> and of L-leucine, L-alanine, L-valine and L-proline in 2 mol·L<sup>-1</sup> aqueous KNO<sub>3</sub>/KCl solutions [14] have been measured for several molal concentrations of amino acids/peptides at different temperatures of (303.15, 308.15, 313.15, 318.15, and 323.15) K earlier in our laboratory. The viscosity *B*-coefficient measures the size, shape and structural effects, induced by the solute-solvent interactions in solutions [15]. The *B*-coefficient of the Jones Dole experiential equation of the relative viscosities of electrolyte solutions as a function of their concentration is imperative for numerous reasons: 1) They propose an exceptional basis of main statistics, in that dimension of the viscosity stipulate the uppermost accuracy on the part of the experimentalist. It is in the nature of the dimensions that they effortlessly disclose deprived experimental practices. 2) The *B*-coefficient is recognized to deliver data relating to the solvation of the ions also their impact on the construction of the solvent in the nearby environment of the solute subdivisions. 3) Owing to the behavior of *B*-coefficient and their ion preservative properties, possibly significant associations occur amid these coefficients also other ion preservative properties such as Entropies of hydration, Enthalpies, Gibb's free energies, solvation as well as transfer amongst solvents. In this comprehension, the *B*-coefficients might afford the vital for the validation of a host thermochemical data. A number of researchers have determined the viscosity *B*-coefficients of amino acid and peptide molecules in aqueous

medium [16]-[21] aqueous electrolytes [22] [23] [24] [25], and organic solvent systems [26] [27] [28] [29] [30]. As electrolytes are integral part of biological system, hence, the study of such systems may be very useful in understanding the mechanism of drug action that ultimately facilitates the illustration of drug—electrolyte chemistry [31]. This study is focused on the viscometric properties of L-leucine, L-glutamine, L-alanine, and glycylglycine in  $0.512 \text{ mol}\cdot\text{kg}^{-1}$  aqueous  $\text{K}_2\text{SO}_4/0.512 \text{ mol}\cdot\text{kg}^{-1}$  aqueous  $\text{KNO}_3$  solutions as a function of amino acids/peptides molal concentration at temperatures (298.15, 303.15, 308.15, 313.15, 318.15 and 323.15) K. The measured viscosity data have been used to compute the relative viscosity, specific viscosity, viscosity  $B$ -coefficient, activation free energy, activation enthalpy and activation entropy values with the view to understanding the ion-ion, ion-hydrophilic and ion-hydrophobic interactions in the systems.

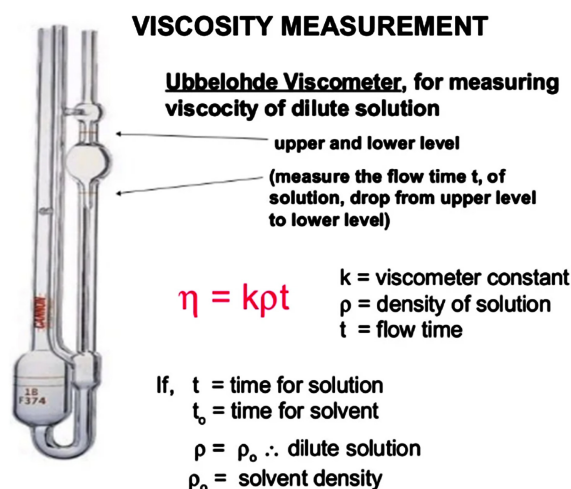
## 2. Experimental Section

The amino acids/peptides: L-leucine, L-glutamine, L-alanine, and glycylglycine and the salts: potassium sulphate and potassium nitrate of high purity (by mass fraction  $\geq 99\%$ ), used in the present studies, were purchased from SRL (India) and E. Merck (India), respectively. The amino acids/peptides were recrystallized twice in (ethanol + water) mixtures, dried at  $T = 383.15 \text{ K}$  and kept in a vacuum desiccator over  $\text{P}_2\text{O}_5$  for at least 72 h before use. The salts were recrystallized in triply distilled water, dried at  $T = 423.15 \text{ K}$  for at least 3 h and then kept over  $\text{P}_2\text{O}_5$  in a vacuum desiccator at room temperature for a minimum of 48 h prior to their use. Stock solutions of  $0.512 \text{ mol}\cdot\text{kg}^{-1}$  aqueous  $\text{K}_2\text{SO}_4$  and  $0.512 \text{ mol}\cdot\text{kg}^{-1}$  aqueous  $\text{KNO}_3$  solutions were prepared at 298.15 K in triply distilled water and were used as solvents for the preparation of L-leucine, L-alanine, L-glutamine and glycylglycine solutions. All the solutions were stored in special air tight bottles to prevent the exposure of solutions to air and evaporation.

The viscosity measurements were carried out using a suspended Ubbelohde viscometer (Figure 1), which was calibrated with triply distilled water at six temperatures between (298.15 and 323.15) K. A thoroughly cleaned and perfectly dried viscometer filled with the test solution was placed vertically in the glass walled thermostat maintained at a desired temperature ( $\pm 0.01 \text{ K}$ ). After the attainment of thermal equilibrium, efflux times of flow were recorded with an electronic watch with the resolution of 0.01 s. The average of at least four readings reproducible within 0.1 s was used as the final efflux time. The viscosity values of water at different temperatures were taken from the literature for calibration purposes [32]. The viscosity coefficient is defined as the following Poiseuille's equation,

$$\eta = \pi g h \rho r^4 / 8 v l \quad (1)$$

where  $g$ ,  $h$ ,  $\rho$ ,  $r$ ,  $l$  and  $t$  are acceleration due to gravity, height of the column in the viscometer, density of the liquid, radius of the viscometer's capillary, length and time of fall for the liquid of volume  $v$  through the capillary, respectively.



**Figure 1.** Ubbelohde viscometer.

The above equation can also be written as

$$\eta = \rho\beta t \quad (2)$$

where  $\beta = \pi ghr^4/8\nu l$  is constant for the given viscometer. The viscosity value of the test solution was calculated using the reported viscosity values of pure water at various temperatures.

Equation (3) given below was employed for the calculation of viscosities of solutions.

$$\eta_1 = (\rho_1 t_1 / \rho_2 t_2) \times \eta_2 \quad (3)$$

where  $\eta_1$ ,  $\rho_1$  and  $t_1$  are the viscosity coefficient, density and time of fall of the solution, respectively; whereas the  $\eta_2$ ,  $\rho_2$  and  $t_2$  are the viscosity coefficient, density and time of fall of the solvent at the given temperature, respectively. The uncertainty in the measurement of viscosity was  $\pm 3 \times 10^{-6}$  Pa.s.

### 3. Results and Discussion

The measured viscosity values of (L-leucine/L-glutamine/L-alanine/glycylglycine + 0.512 mol.kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub>/0.512 mol.kg<sup>-1</sup> aqueous KNO<sub>3</sub>) solutions as functions of amino acids/peptides molal concentration and temperature have been presented in **Table 1**. The viscosity values have been least-squares fitted to the following polynomial,

$$\eta = \eta_0 + \eta_1 m + \eta_2 m^2 \quad (4)$$

where  $\eta_0$ ,  $\eta_1$ ,  $\eta_2$ ; and  $m$  are the fitted coefficients and molal concentration of solutions, respectively. The fitted coefficients of Equation (1) have been given in **Table 2**. The  $\eta$  values of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol.kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub>/KNO<sub>3</sub> solution increase with increase in molal concentration in all the systems under examination.

The relative viscosity [33] [34] [35] and specific viscosity [36] values have been computed by retaining the following relations expending the viscosity values of solvent and solution,

**Table 1.** Viscosities ( $\eta/10^{-4}$ , Pa·s) as functions of amino acids/peptides molal concentration and temperature.

$m/\text{mol}\cdot\text{kg}^{-1}$	$T/K$					
	298.15	303.15	308.15	313.15	318.15	323.15
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0000	11.6460	11.0985	10.5219	9.9755	9.4062	8.8662
0.0188	11.9441	11.4032	10.8255	10.2622	9.7036	9.1219
0.0378	12.2865	11.6849	11.0855	10.5098	9.9641	9.4018
0.0568	12.6361	12.0239	11.4116	10.7961	10.2436	9.6382
0.0759	12.9889	12.4132	11.7613	11.1263	10.5232	9.8898
0.0957	13.3893	12.7687	12.0764	11.3983	10.7827	10.1523
0.1143	13.7975	13.1819	12.4918	11.8329	11.1487	10.5056
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0000	9.3082	8.8368	8.3472	7.8438	7.3264	6.8531
0.0195	9.9027	9.3859	8.8614	8.3082	7.7402	7.2591
0.0398	10.4492	9.9103	9.3714	8.8325	8.2646	7.6968
0.0588	10.8958	10.3542	9.7813	9.2778	8.6944	8.1076
0.0786	11.3340	10.7458	10.1632	9.6393	9.0593	8.4346
0.0984	11.7257	11.1424	10.5613	10.0139	9.4278	8.8438
0.1183	12.1492	11.5668	10.9989	10.4058	9.8229	9.1840
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0000	11.6460	11.0985	10.5219	9.9755	9.4062	8.8662
0.0472	12.0238	11.4219	10.8237	10.2273	9.6487	9.0759
0.0950	12.4412	11.8493	11.2148	10.6003	10.0143	9.4125
0.1429	12.8295	12.2049	11.5772	10.9527	10.3541	9.7134
0.1918	13.1563	12.5577	11.9174	11.3054	10.6777	10.0402
0.2408	13.4443	12.8295	12.2179	11.6193	10.9916	10.3791
0.2903	13.8876	13.2598	12.6483	12.0497	11.4219	10.8621
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0000	9.3082	8.8368	8.3472	7.8438	7.3264	6.8531
0.0481	9.5758	9.0937	8.6042	8.0868	7.5694	7.0816
0.0987	9.8594	9.3785	8.8611	8.3489	7.8281	7.3421
0.1499	10.1429	9.6667	9.1447	8.6325	8.1007	7.6024
0.2002	10.4265	9.9375	9.4059	8.8843	8.3952	7.8860
0.2521	10.6985	10.1748	9.6539	9.1678	8.6441	8.1233
0.3048	10.9705	10.4583	9.9375	9.4398	8.9277	8.4184

## Continued

L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0000	11.6460	11.0985	10.5219	9.9755	9.4062	8.8662
0.1901	11.8445	11.2925	10.7202	10.1479	9.5788	9.0186
0.3847	12.0775	11.4963	10.9489	10.3759	9.7937	9.2408
0.5849	12.2911	11.7103	11.1861	10.6131	10.0263	9.4540
0.7905	12.5146	11.9256	11.3988	10.8467	10.2776	9.7098
1.0017	12.7181	12.1451	11.6093	11.0468	10.4847	9.9048
1.2185	12.9506	12.3893	11.8413	11.2693	10.6866	10.1377
L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0000	9.3082	8.8368	8.3472	7.8438	7.3264	6.8531
0.1971	9.8809	9.3611	8.8320	8.3034	7.7789	7.2670
0.4038	10.3761	9.8652	9.3229	8.7817	8.2572	7.6952
0.6157	10.8719	10.3257	9.7676	9.2726	8.6978	8.1565
0.8362	11.2948	10.7704	10.1956	9.6544	9.1007	8.5341
1.0658	11.7731	11.2655	10.6739	10.1285	9.5537	8.9789
1.3028	12.2347	11.6766	11.1144	10.5229	9.9486	9.4068
Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0000	11.6460	11.0985	10.5219	9.9755	9.4062	8.8662
0.1911	11.7773	11.2639	10.7077	10.1215	9.5746	9.0035
0.3887	11.9414	11.4309	10.8725	10.2847	9.7436	9.1675
0.5932	12.1441	11.5859	11.0447	10.4569	9.9183	9.3468
0.8038	12.2878	11.7383	11.2095	10.6217	10.0535	9.5264
1.0178	12.4909	11.9424	11.4013	10.8233	10.2655	9.7535
1.2586	12.7319	12.2031	11.6227	11.0644	10.4766	9.9478
Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0000	9.3082	8.8368	8.3472	7.8438	7.3264	6.8531
0.1997	9.6441	9.1358	8.6801	8.1846	7.6457	7.1936
0.4102	10.0292	9.5309	9.0771	8.5535	8.0146	7.5483
0.6324	10.4436	9.9424	9.5156	8.9659	8.4414	7.9314
0.8674	10.8647	10.3403	9.8708	9.3348	8.7814	8.2714
1.1162	11.3024	10.7924	10.2824	9.7146	9.1648	8.6512
1.3801	11.7834	11.2734	10.7925	10.2390	9.6603	9.1214

**Table 2.**  $\eta_0$ ,  $\eta_1$  and  $\eta_2$  as a function of molal concentration of amino acids/peptides at different temperatures.

$T/K$	$\eta_0$ (Pa·s)	$\eta_1$ (Pa·s)/(mol·kg <sup>-1</sup> )	$\eta_2$ (Pa·s)/(mol·kg <sup>-1</sup> ) <sup>2</sup>	$\sigma_{[\eta]} \times 10^2$
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution				
298.15	11.6448	15.8387	25.7880	0.9
303.15	11.1029	14.5838	31.2343	1.8
308.15	10.5332	13.8986	27.0405	2.5
313.15	9.9938	12.4641	29.3304	3.7
318.15	9.4230	13.7743	9.4343	3.0
323.15	8.8802	12.5185	12.6064	3.1
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution				
298.15	9.3266	29.7035	-51.0405	2.5
303.15	8.8523	27.7586	-42.4914	2.8
308.15	8.3650	25.7165	-31.2149	3.3
313.15	7.8367	26.2898	-39.7986	2.8
318.15	7.3099	24.8522	-31.3894	3.2
323.15	6.8478	22.1512	-20.1973	2.2
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution				
298.15	11.6485	8.4481	-2.9729	4.3
303.15	11.0879	7.9611	-1.9869	4.2
308.15	10.5115	7.2773	0.0259	3.4
313.15	9.9562	6.4954	2.3236	3.3
318.15	9.3908	6.1797	2.6099	3.4
323.15	8.8606	4.8923	6.6135	3.3
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution				
298.15	9.3046	5.7427	-0.8751	0.5
303.15	8.8306	5.7311	-1.3312	1.3
308.15	8.3465	5.3480	-0.4631	0.9
313.15	7.8401	5.1998	0.1893	0.7
318.15	7.3208	5.2143	0.2219	1.3
323.15	6.8480	4.9765	0.5498	1.3
L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution				
298.15	11.6410	1.1433	-0.0584	0.9
303.15	11.0983	1.0243	0.0269	0.4
308.15	10.5141	1.1656	-0.0640	1.1

## Continued

313.15	9.9573	1.1356	-0.0444	1.9
318.15	9.3863	1.1207	-0.0341	2.3
323.15	8.8468	1.0318	0.0278	2.3
L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution				
298.15	9.3341	2.7029	-0.3767	3.1
303.15	8.8480	2.6174	-0.3420	1.9
308.15	8.3572	2.4421	-0.2539	1.8
313.15	7.8390	2.4730	-0.3159	2.4
318.15	7.3265	2.3923	-0.2916	1.5
323.15	6.8506	2.1769	-0.1672	1.8
Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution				
298.15	11.6415	0.7490	0.0903	1.7
303.15	11.1135	0.7211	0.1056	2.1
308.15	10.5327	0.8544	0.0047	1.2
313.15	9.9785	0.7338	0.0993	0.8
318.15	9.4142	0.8139	0.0202	1.7
323.15	8.8589	0.7770	0.0775	1.5
Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution				
298.15	9.2988	1.7932	0.0053	1.4
303.15	8.8201	1.7176	0.0445	1.9
308.15	8.3419	1.8051	-0.0314	3.3
313.15	7.8478	1.7178	-0.0023	3.2
318.15	7.3217	1.7135	-0.0244	3.3
323.15	6.8613	1.6721	-0.0355	2.5

$$\eta_r = \frac{\eta}{\eta_o} \quad (5)$$

$$\eta_{sp} = \frac{\eta - \eta_o}{\eta_o} \quad (6)$$

The calculated values of relative and specific viscosity have been registered in **Table 3** and **Table 4**, respectively. The  $\eta_r$  values increase with an increase in molal concentration of amino acids/peptides in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> and 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions but these values do not reveal regular developments of variation with an increase in temperature in the systems under investigation. The reported relative viscosity values of 0.03061 m L-leucine in 0.5 M aqueous magnesium acetate solution at 298.15 K is 1.0055 [37]



**Table 3.** Relative viscosity values ( $\eta_r$ ) as functions of amino acids/peptides molal concentration and temperature.

$m/\text{mol}\cdot\text{kg}^{-1}$	$T/\text{K}$					
	298.15	303.15	308.15	313.15	318.15	323.15
(i) L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0188	1.054	1.061	1.036	1.048	1.049	1.044
0.0378	1.091	1.108	1.074	1.087	1.098	1.084
0.0568	1.148	1.141	1.104	1.126	1.157	1.138
0.0759	1.189	1.198	1.131	1.168	1.198	1.184
0.0957	1.225	1.244	1.183	1.206	1.253	1.226
0.1143	1.264	1.279	1.219	1.239	1.295	1.273
(ii) L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0195	1.064	1.047	1.049	1.067	1.069	1.105
0.0398	1.119	1.104	1.091	1.122	1.139	1.192
0.0588	1.167	1.154	1.150	1.169	1.198	1.125
0.0786	1.218	1.193	1.187	1.211	1.239	1.285
0.0984	1.265	1.241	1.232	1.246	1.273	1.319
0.1183	1.303	1.279	1.271	1.285	1.311	1.368
(iii) L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0472	1.032	1.029	1.029	1.025	1.026	1.024
0.0950	1.068	1.067	1.066	1.063	1.065	1.062
0.1429	1.102	1.099	1.102	1.098	1.108	1.096
0.1918	1.121	1.131	1.133	1.133	1.135	1.132
0.2408	1.154	1.156	1.161	1.165	1.169	1.171
0.2903	1.192	1.195	1.202	1.208	1.214	1.225
(iv) L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0481	1.028	1.029	1.031	1.030	1.033	1.033
0.0987	1.059	1.061	1.062	1.064	1.069	1.071
0.1499	1.081	1.094	1.096	1.101	1.106	1.109
0.2002	1.121	1.125	1.127	1.133	1.146	1.151
0.2521	1.149	1.151	1.157	1.169	1.171	1.185
0.3048	1.179	1.184	1.191	1.203	1.219	1.228
(v) L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.1901	1.017	1.018	1.019	1.017	1.018	1.017
0.3847	1.037	1.036	1.046	1.041	1.042	1.042
0.5849	1.055	1.051	1.063	1.064	1.066	1.066

## Continued

0.7905	1.075	1.074	1.083	1.087	1.093	1.095
1.0017	1.092	1.094	1.103	1.107	1.115	1.117
1.2185	1.141	1.107	1.031	1.014	1.015	1.011
(vi) L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.1971	1.062	1.059	1.058	1.059	1.062	1.061
0.4038	1.115	1.116	1.117	1.111	1.127	1.123
0.6157	1.168	1.169	1.172	1.182	1.187	1.192
0.8362	1.213	1.219	1.221	1.231	1.242	1.245
1.0658	1.265	1.275	1.279	1.291	1.304	1.312
1.3028	1.314	1.321	1.332	1.342	1.358	1.373
(vii) glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.1911	1.011	1.015	1.018	1.015	1.018	1.016
0.3887	1.025	1.021	1.033	1.031	1.036	1.034
0.5932	1.043	1.044	1.041	1.048	1.054	1.052
0.8038	1.055	1.058	1.065	1.064	1.069	1.075
1.0178	1.073	1.076	1.084	1.085	1.091	1.101
1.2586	1.093	1.091	1.105	1.109	1.114	1.122
(viii) glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.1997	1.036	1.034	1.031	1.044	1.044	1.041
0.4102	1.077	1.079	1.087	1.091	1.094	1.101
0.6324	1.122	1.125	1.131	1.143	1.152	1.157
0.8674	1.167	1.171	1.183	1.191	1.199	1.207
1.1162	1.214	1.221	1.232	1.239	1.251	1.262
1.3801	1.266	1.276	1.293	1.305	1.319	1.331

**Table 4.** Specific viscosity values ( $\eta_{sp} \times 10^2$ ) as functions of amino acids/peptides molal concentration and temperature.

$m/\text{mol}\cdot\text{kg}^{-1}$	$T/K$					
	298.15	303.15	308.15	313.15	318.15	323.15
(i) L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0188	5.387	6.047	3.601	4.757	4.866	4.004
0.0378	9.961	10.758	7.401	8.686	9.823	8.420
0.0568	14.773	14.970	10.352	12.630	15.687	13.811
0.0759	18.861	19.775	13.979	16.840	19.792	18.358
0.0957	22.489	24.417	18.030	20.595	25.331	22.588
0.1143	26.351	27.894	21.894	23.911	29.508	27.264

## Continued

(ii) L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0195	6.387	4.721	4.934	6.745	6.957	10.531
0.0398	11.96	10.418	9.966	12.161	13.919	19.024
0.0588	16.694	15.437	15.008	16.884	19.821	24.693
0.0786	21.764	19.313	18.688	21.101	23.944	28.447
0.0984	26.466	24.051	23.155	24.612	27.324	31.952
0.1183	30.027	27.935	27.128	28.501	31.991	36.769
(iii) L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.0472	3.239	2.914	2.868	2.524	2.578	2.365
0.0950	6.823	6.765	6.583	6.263	6.465	6.162
0.1429	10.157	9.969	10.021	9.796	10.077	9.555
0.1918	12.963	13.148	13.263	13.332	13.518	13.241
0.2408	15.435	15.597	16.119	16.478	16.855	17.064
0.2903	19.242	19.474	20.209	20.793	21.421	22.511
(iv) L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.0481	2.875	2.907	3.079	3.099	3.317	3.334
0.0987	5.922	6.131	6.157	6.441	6.848	7.135
0.1499	8.967	9.391	9.554	10.056	10.569	10.934
0.2002	12.014	12.456	12.683	13.267	14.588	15.072
0.2521	14.936	15.141	15.654	16.881	17.986	18.535
0.3048	17.858	18.349	19.052	20.349	21.857	22.841
(v) L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.1901	1.699	1.748	1.885	1.728	1.835	1.719
0.3847	3.691	3.584	4.058	4.014	4.111	4.225
0.5849	5.534	5.512	6.313	6.311	6.592	6.621
0.7905	7.453	7.452	8.287	8.733	9.264	9.515
1.0017	9.201	9.431	10.335	10.739	11.466	11.171
1.2185	14.983	10.701	13.983	14.385	14.990	11.008
(vi) L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.1971	6.153	5.933	5.808	5.861	6.176	6.031
0.4038	11.473	11.638	11.689	11.959	12.705	12.288
0.6157	16.799	16.849	17.017	18.217	18.719	19.019
0.8362	21.343	21.881	22.144	23.085	24.218	24.529
1.0658	26.481	27.484	27.874	29.129	30.401	31.011
1.3028	31.440	32.136	33.151	34.157	35.791	37.281

## Continued

(vii) glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.1911	1.112	1.491	1.766	1.464	1.790	1.549
0.3887	2.531	2.995	3.332	3.091	3.587	3.398
0.5932	4.272	4.392	4.969	4.826	5.444	5.420
0.8038	5.505	5.765	6.535	6.478	6.882	7.446
1.0178	7.249	7.604	8.358	8.499	9.135	10.008
1.2586	9.319	9.953	10.462	10.916	11.371	12.199
(viii) glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.1997	3.609	3.384	3.988	4.346	4.358	4.969
0.4102	7.746	7.855	8.744	9.049	9.393	10.144
0.6324	12.198	12.511	13.998	14.307	15.219	15.734
0.8674	16.722	17.014	18.253	19.010	19.851	20.696
1.1162	21.424	22.131	23.184	23.852	25.093	26.238
1.3801	26.592	27.573	29.295	30.538	31.856	33.099

whereas the observed value of 0.0378 mL-leucine in 0.5 M aqueous K<sub>2</sub>SO<sub>4</sub> solution is 1.091. The relative viscosity of 1.0052 m L-alanine in 0.05 M aqueous MgCl<sub>2</sub> solution as 1.027 Banipal *et al.* has been reported by Banipal [38] whereas the detected value of 1.0017 m L-alanine in 0.5 M aqueous K<sub>2</sub>SO<sub>4</sub> solution is 1.092. The increasing trend of  $\eta_r$  values with an increase in solute concentration may be attributed to an increase in the zwitterion-ion (-COO<sup>-</sup>-K<sup>+</sup>, -NH<sub>3</sub><sup>+</sup>-SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup>) interactions in solutions.

The viscosity data have been fitted to the following Jones-Dole [39] equation,

$$\eta_r = 1 + Am^{1/2} + Bm \quad (7)$$

where  $\eta_r (= \eta/\eta_0)$  is the relative viscosity of the solution;  $m$  is the molal concentration of solution;  $A$ , the Falkenhagen coefficient, represents the solute-solute interactions; and  $B$ -coefficient reflects solute-solvent interactions [40] [41]. The  $B$ -coefficient values along with the standard deviations of linear regression have been listed in Table 5. The observed and the literature values of  $B$ -coefficients of the studied amino acids and peptides have been listed in Table 6 for comparison purpose. The  $B$ -coefficients of the amino acids and peptides reflect the net structural effects of the charged end groups (NH<sub>3</sub><sup>+</sup>, COO<sup>-</sup>) and the hydrophobic CH<sub>2</sub> groups on the solvent. The contribution of CH<sub>2</sub> groups in  $B$ -coefficient values varies with the number of carbon atoms in their alkyl chain at a given temperature. These two effects can be separated by noting the linear relationship [42] [43] of  $B$ -coefficient with the number of carbon atoms,  $n_c$ ,

$$B = B(\text{NH}_3^+, \text{COO}^-) + n_c B(\text{CH}_2) \quad (8)$$

**Table 5.** Viscosity A-coefficients ( $\text{molal}^{-1/2}$ ) values at different temperatures.

<i>T/K</i>					
298.15	303.15	308.15	313.15	318.15	323.15
<b>(i) L-leucine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> solution</b>					
0.141	0.172	0.007	0.095	0.007	-0.055
<b>(ii) L-leucine in 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solution</b>					
0.338	0.242	0.253	0.409	0.462	0.776
<b>(iii) L-glutamine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> solution</b>					
0.0251	0.001	-0.017	-0.054	-0.055	-0.092
<b>(iv) L-glutamine in 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solution</b>					
0.005	0.006	0.005	-0.008	-0.013	-0.019
<b>(v) L-alanine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> solution</b>					
-0.024	0.003	-0.014	-0.006	-0.004	-0.005
<b>(vi) L-alanine in 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solution</b>					
0.056	0.045	0.036	0.033	0.037	0.011
<b>(vii) glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> solution</b>					
-0.011	-0.005	0.006	-0.007	0.003	-0.013
<b>(viii) glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solution</b>					
-0.007	-0.018	-0.002	-0.002	-0.003	0.011

**Table 6.** Viscosity *B*-coefficients ( $\text{dm}^3\cdot\text{mol}^{-1}$ ) and ( $\text{dB}/\text{dT}$ ) values at different temperatures.

<i>T/K</i>						<i>(dB/dT)</i>
298.15	303.15	308.15	313.15	318.15	323.15	
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
2.669	2.502	1.958	1.921	1.858	1.832	-0.035
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
1.839	1.654	1.505	1.423	1.341	1.265	-0.022
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.916	0.834	0.813	0.726	0.671	0.615	-0.012
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.783	0.742	0.681	0.616	0.597	0.582	-0.009
L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.299	0.265	0.243	0.224	0.200	0.182	-0.005
L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.265	0.249	0.225	0.190	0.177	0.165	-0.004

## Continued

Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution						
0.372	0.358	0.339	0.314	0.288	0.230	-0.005
Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution						
0.322	0.304	0.286	0.267	0.235	0.200	-0.005

The *B*-coefficients of L-leucine, L-glutamine, L-alanine and glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> and 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions are positive at all temperatures of study. The temperature derivative of *B*-coefficient values (*dB/dT*) has been presented in **Table 6**. The positive values of *B*-coefficients of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> or 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions indicate the possibility of a strong alignment of zwitterions with ions/water dipoles [44] [45] [46]. The observed higher *B*-coefficients values of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> or 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions than those in the aqueous medium may be attributed to K<sup>+</sup>-SO<sub>4</sub><sup>2-</sup>, K<sup>+</sup>-NO<sub>3</sub><sup>-</sup> and -COO<sup>-</sup>-K<sup>+</sup>, -NH<sub>3</sub><sup>+</sup>-SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup> interactions operative in the solutions. The positive *B*-coefficients along with negative (*dB/dT*) values of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> or 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions indicate the structure making nature of solute in the solutions [41] [47] [48]. The trend of variation of viscosity *B*-coefficients of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> or 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions is found to be as:

L-leucine > L-glutamine > glycylglycine > L-alanine

The largest *B*-coefficient of L-leucine can be attributed to the domination of ion (K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup>) -ion (-COO<sup>-</sup>/NH<sub>3</sub><sup>+</sup>) interactions and ion-hydrophobic interactions between ions K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup> and hydrophobic group (-CH<sub>3</sub>-CH<sub>2</sub>-CH-CH<sub>3</sub>) of L-leucine over the ion-ion and ion-hydrophilic interactions between ions K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup> and hydrophilic group (-CONH<sub>2</sub>) of L-glutamine. The ion (K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup>) -ion(-COO<sup>-</sup>/NH<sub>3</sub><sup>+</sup>) interactions and ion-hydrophilic interactions between ions K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup> and hydrophilic group (-CONH<sub>2</sub>) of L-glutamine over the ion-ion and ion-hydrophilic interactions between ions K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup> and hydrophilic group -CONH of glycylglycine. The ion-hydrophilic interactions are absent in L-alanine—aqueous K<sub>2</sub>SO<sub>4</sub>/KNO<sub>3</sub> system. The ion-ion interactions and ion-hydrophobic group interactions of (L-leucine-aqueous salts) dominate over ion-hydrophilic interactions in (L-glutamine-aqueous salts)/(glycylglycine-aqueous salt) systems. In the case of L-alanine, the ion (K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup>) -ion (-COO<sup>-</sup>/NH<sub>3</sub><sup>+</sup>) interactions dominate over ion (K<sup>+</sup>/SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup>) -hydrophobic group (-CH<sub>3</sub>/CH<sub>2</sub>) interactions. The *B*-coefficients of studied amino acids and peptides in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> and 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions decrease with an increase in temperature thereby showing that the zwitterion-ion interactions further weakened with the increase in temperature. The observed and literature values of viscosity have been mentioned in **Table 7**.

**Table 7.** Observed and literature values of viscosity at 298.15 K.

Solute	This work		Literature values	
	Solvent	$B$ (dm <sup>3</sup> ·mol <sup>-1</sup> )	Solvent	$B$ (dm <sup>3</sup> ·mol <sup>-1</sup> )
L-leucine	0.512 mol·kg <sup>-1</sup> KNO <sub>3</sub>	1.839	CdCl <sub>2</sub>	0.552 <sup>2</sup>
			NaCl	0.924 <sup>5</sup>
			NaNO <sub>3</sub>	0.371 <sup>5</sup>
			Mg acetate	0.282 <sup>24</sup>
L-glutamine	0.512 mol·kg <sup>-1</sup> K <sub>2</sub> SO <sub>4</sub>	0.916		
	0.512 mol·kg <sup>-1</sup> KNO <sub>3</sub>	0.783	TMAB	4.074 <sup>50</sup>
L-alanine	0.512 mol·kg <sup>-1</sup> K <sub>2</sub> SO <sub>4</sub>	0.299	CdCl <sub>2</sub>	0.255 <sup>2</sup>
	0.512 mol·kg <sup>-1</sup> KNO <sub>3</sub>	0.265	KH <sub>2</sub> Cit	0.307 <sup>6</sup>
			K <sub>3</sub> Cit	0.316 <sup>6</sup>
			Na acetate	0.268 <sup>25</sup>
			MgCl <sub>2</sub>	0.269 <sup>49</sup>
Glycylglycine	0.512 mol·kg <sup>-1</sup> K <sub>2</sub> SO <sub>4</sub>	0.372		
	0.512 mol·kg <sup>-1</sup> KNO <sub>3</sub>	0.322	2 M KNO <sub>3</sub>	0.265 <sup>1</sup>
			2 M KCl	0.507 <sup>1</sup>
			0.05 M MnCl <sub>2</sub>	0.881 <sup>7</sup>

Thermodynamic activation parameters of viscous flow of the amino acids/peptides in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub>/KNO<sub>3</sub> solution have been evaluated by Feakins [49] extension of Eyring transition-state theory,

$$B = (V_{1,\phi}^0 - V_{2,\phi}^0)/1000 + (V_{1,\phi}^0/1000)(\Delta\mu_2^0 - \Delta\mu_1^0/RT) \quad (9)$$

where  $V_{1,\phi}^0$  and  $V_{2,\phi}^0$  are the standard partial molar volumes of the solvent and solute, respectively.  $\Delta\mu_1^0$  is the contribution per mole of solvent to the free energy of activation for viscous flow of the solution, and is given by

$$\Delta\mu_1^0 = RT \ln(\eta_o V_{1,\phi}^0 / h N_A) \quad (10)$$

where  $h$  is the Planck constant,  $N_A$  is Avogadro's number,  $\eta_o$  is the viscosity of the solvent,  $R$  is the gas constant and  $\Delta\mu_2^0$  is the contribution per mole of solute to the free energy of activation for viscous flow of the solution and Equation (9) can be rearranged as follows:

**Table 8.**  $V_{1,\phi}^0$ ,  $\Delta\mu_1^0$ ,  $\Delta\mu_2^0$ ,  $\Delta H_2^0$ , entropy,  $\Delta S_2^0$  for amino acids/peptides solutions at different temperatures.

T/K	$V_{1,\phi}^0$ ( $\text{cm}^3\cdot\text{mol}^{-1}$ )	$\Delta\mu_1^0$ ( $\text{kJ}\cdot\text{mol}^{-1}$ )	$\Delta\mu_2^0$ ( $\text{kJ}\cdot\text{mol}^{-1}$ )	$\Delta H_2^0$ ( $\text{kJ}\cdot\text{mol}^{-1}$ )	$\Delta S_2^0$ ( $\text{kJ}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$ )
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution					
298.15	18.27	9.89	374.66	1591.11	4.08
303.15	18.30	9.87	359.81	1589.66	
308.15	18.34	9.85	320.42	1577.67	
313.15	18.38	9.83	300.76	1574.41	
318.15	18.42	9.81	288.54	1570.59	
323.15	18.46	9.79	278.25	1566.70	
L-leucine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution					
298.15	18.26	9.37	261.98	988.27	2.44
303.15	18.30	9.35	241.90	980.37	
308.15	18.33	9.32	223.80	974.45	
313.15	18.37	9.30	216.34	970.17	
318.15	18.40	9.28	209.23	964.24	
323.15	18.44	9.26	197.80	960.99	
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution					
298.15	18.27	9.89	134.56	558.93	1.39
303.15	18.30	9.87	128.63	550.01	
308.15	18.34	9.85	122.64	545.97	
313.15	18.38	9.83	113.64	540.92	
318.15	18.42	9.81	107.31	534.54	
323.15	18.46	9.79	100.61	530.79	
L-glutamine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution					
298.15	18.26	9.37	116.57	381.92	0.89
303.15	18.30	9.35	112.63	380.43	
308.15	18.33	9.32	106.85	379.10	
313.15	18.37	9.30	101.62	375.32	
318.15	18.40	9.28	98.28	371.43	
323.15	18.44	9.26	95.06	367.66	
L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution					
298.15	18.27	9.89	34.76	204.71	0.57
303.15	18.30	9.87	30.57	203.37	



## Continued

308.15	18.34	9.85	27.89	203.03	
313.15	18.38	9.83	25.57	202.67	
318.15	18.42	9.81	22.45	202.43	
323.15	18.46	9.79	20.11	201.30	
L-alanine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution					
298.15	18.26	9.37	30.18	188.20	
303.15	18.30	9.35	28.40	188.07	
308.15	18.33	9.32	25.45	188.00	
313.15	18.37	9.30	20.83	186.79	0.53
318.15	18.40	9.28	19.55	186.65	
323.15	18.44	9.26	17.74	184.00	
Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous K <sub>2</sub> SO <sub>4</sub> solution					
298.15	18.27	9.89	42.56	239.34	
303.15	18.30	9.87	41.26	239.24	
308.15	18.34	9.85	39.16	238.54	
313.15	18.38	9.83	36.17	237.98	0.66
318.15	18.42	9.81	32.92	237.45	
323.15	18.46	9.79	24.91	236.19	
Glycylglycine in 0.512 mol·kg <sup>-1</sup> aqueous KNO <sub>3</sub> solution					
298.15	18.26	9.37	35.81	211.72	
303.15	18.30	9.35	33.84	210.69	
308.15	18.33	9.32	31.81	210.62	
313.15	18.37	9.30	29.55	210.45	0.59
318.15	18.40	9.28	25.77	209.26	
323.15	18.44	9.26	20.59	209.02	

$$\Delta\mu_2^0 = \Delta\mu_1^0 + \left( RT/V_{1,\phi}^0 \right) \left[ 1000B - (V_{1,\phi}^0 - V_{2,\phi}^0) \right] \quad (11)$$

where  $V_{1,\phi}^0 = \sum x_i M_i / \rho$  is the mean volume of the solvent. The terms  $x_i$  and  $M_i$  denote the mole fractions and molecular weights of water and K<sub>2</sub>SO<sub>4</sub>/KNO<sub>3</sub>. The calculated values of  $\Delta\mu_1^0$ ,  $\Delta\mu_2^0$  and  $V_{1,\phi}^0$  are given in **Table 8**. The positive and large value of  $\Delta\mu_2^0$  than  $\Delta\mu_1^0$  indicates that amino acids/peptides-solvent interaction in the ground state is stronger than in the transition state. This means that the formation of the transition state is accompanied by the rupture and distortion of the intermolecular forces in the solvent structure. Thus, amino acids/peptides molecules are acting as structure-makers. This is consistent with the conclusion obtained from *B*-coefficients. The structure making nature of

L-leucine and L-alanine in 0.05 mol·L<sup>-1</sup> aqueous magnesium chloride has been reported by Lark [50] and L-glutamine in 0.05 mol·L<sup>-1</sup> aqueous tetramethylammonium bromide by Anwar [51]. According to transition state theory [12] every solvent molecule in one mole of solution must pass through the transition state and interact more or less strongly with solute molecules. The positive  $\Delta\mu_2^0$  values of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> or 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions increase with an increase in temperature which suggests that the formation of transition state is less favoured in the presence of L-leucine, L-glutamine, L-alanine and glycylglycine. This is due to the breaking and distortion of intermolecular bonds, which effectively means that more solute-solvent bonds must be broken to form the transition state. Similar results for  $\alpha$ -amino acids in aqueous sodium acetate solutions have been reported by Feakins [52].

The entropy and enthalpy of activation for viscous flow of the amino acids/peptides have been calculated by

$$\Delta S_2^0 = -d(\Delta\mu_2^0)/dT \quad (12)$$

$$\Delta H_2^0 = \Delta\mu_2^0 + T\Delta S_2^0 \quad (13)$$

The  $\Delta S_2^0$  and  $\Delta H_2^0$  values at different temperatures are given in **Table 8**. The positive  $\Delta S_2^0$  and  $\Delta H_2^0$  values for all studied amino acids/peptides at each temperature of study indicate the formation of the activated complex which is associated with bond breaking and a decrease in order. This suggests that the ground states are in the ordered region.

#### 4. Conclusion

The *B*-coefficient of L-leucine, L-glutamine, L-alanine and glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> and 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions are found to be positive at all temperatures of study. The trend of variation of viscosity *B*-coefficients of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub> or 0.512 mol·kg<sup>-1</sup> aqueous KNO<sub>3</sub> solutions is found to be as: L-leucine > L-glutamine > glycylglycine > L-alanine. The variations of the trend have been discussed in terms of ion-ion, hydrophilic-ion and hydrophobic-ion interactions operative in the systems. The free energy of activation per mole of solute,  $\Delta\mu_2^0$  reinforce the structure-making ability of L-leucine/L-glutamine/L-alanine/glycylglycine in 0.512 mol·kg<sup>-1</sup> aqueous K<sub>2</sub>SO<sub>4</sub>/KNO<sub>3</sub> solutions. The effect of solute size on the *B*-coefficient is outward as of solvodynamic models. A “structure-modelling” solute sinks the usual operative kinetic energy of the solvent particles and thus rises the viscosity of the solution, then gives rise to high *B*-coefficient values. Due to the exponential affiliation amid viscosity and temperature, an increase in temperature of the solution as a whole causes *B*-coefficient to decrease. Such efforts have been used to classify “structure creation” solutes. On the contrary, “structure floating” solutes have relatively low *B*-coefficients, which upsurge with a rise in temperature. In the case of electrolytes, the

$B$ -coefficient is a quantity of the demand or disorder acquainted with ions into their co-ranges. Viscometric studies of amino acids in salts are also important for variety of applications including food science where it is helpful to study the behaviour of food ingredients and effect of salts on the texture and quality of food products, as well as in environmental science to study the behaviour of amino acids in natural water and their interactions with salts which can provide information on the environmental fate of amino acids. In the field of Industrial chemistry, it can be used to analyse the behaviour of surfactants and other chemicals in industrial process and to optimize their performance.

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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## Appendix

