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Thermo-Acoustic Investigation of Molecular Interactions in Aqueous Solutions of L-Histidine at Different Temperatures

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Abstract

The present study investigates the acoustic and thermodynamic behavior of aqueous solutions of L-Histidine across a concentration range of 0.01 m to 0.1 m and temperatures varying from 293.15 K to 318.15 K in 5 K intervals. Ultrasonic velocity (μ), density (ρ), and viscosity (η) measurements were conducted with high precision to understand the solution behavior under different thermal conditions. Temperature constancy during measurements was ensured using a refrigerated circulatory bath with water as the thermal medium, thereby enhancing the reliability of the experimental data. From the primary measurements, various acoustic and thermodynamic parameters were derived using established theoretical equations. These include isentropic compressibility (β_a), isothermal compressibility (β_i), apparent molar volume (Φ_v), partial molar volume at infinite dilution (Φ_v^0), viscosity coefficients A and B (based on Jones–Dole relation), and hydration number (n_h). The analysis reveals complex molecular interactions within the L-Histidine aqueous system, including solute–solvent and solute–solute interactions. Anomalies or deviations in trends suggest the possible formation of hydration shells or structured water molecules around the zwitterionic centers of L-Histidine. These results contribute to a deeper understanding of biomolecular solvation phenomena and the physicochemical behavior of amino acid solutions under varying thermodynamic conditions. The insights are especially relevant for biochemical, pharmaceutical, and solution chemistry applications where knowledge of solute behavior at different temperatures is essential for formulation, stability studies, and reaction kinetics.

Keywords: Ultrasonic velocity (u), apparent molar volume (Φ_v), partial molar volume (Φ_v^0), viscosity coefficients, hydration number (n_h), L-histidine

INTRODUCTION

It is well established that various substances can induce conformational changes in proteins within aqueous solutions. Due to the complexity of conformational and configurational factors influencing protein structure, direct investigation of proteins in solutions poses significant challenges. As an alternative, researchers often study the fundamental building blocks of proteins – amino acids – in both aqueous and mixed solvent systems [1–4]. The physicochemical behavior of amino acids in such environments offers crucial insights into solute–solute and solute–solvent interactions, as well as the nature of hydrogen bonding, van der Waals forces, and other intermolecular interactions that play a pivotal role in protein stability [5]. Thermodynamic investigations of amino acids in aqueous media serve as valuable tools for probing these intermolecular forces. They help elucidate

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mechanisms underlying key biochemical processes such as protein denaturation, hydration, and aggregation [6–8]. Among amino acids, L-Histidine holds particular significance. It is an essential aromatic amino acid primarily obtained through dietary intake. Characterized by its imidazole side chain, L-Histidine functions as a common coordinating ligand in metalloproteins and plays a vital role in the catalytic activity of certain enzymes. In addition to its biochemical relevance, L-Histidine contributes to various physiological functions, including immune system enhancement, hemoglobin synthesis, tissue repair, vasodilation, and the mitigation of hypertension and cardiovascular disorders [9–12]. The objective of the present study is to investigate the physicochemical behavior of aqueous solutions of L-Histidine across a range of temperatures. This work focuses on the determination of key thermodynamic and acoustic parameters, including isentropic compressibility (β_a), isothermal compressibility (β_i), apparent molar volume (Φ_v), partial molar volume at infinite dilution (Φ_v^0), viscosity coefficients (A and B), and hydration number (n_h). These parameters were evaluated over varying concentrations and temperatures to analyze their dependence and to gain insight into the nature and extent of molecular interactions present in the system. The variations observed in these properties with changes in concentration and temperature provide valuable information about solute–solvent and solute–solute interactions in aqueous L-Histidine solutions [1–5].

MATERIALS AND METHOD

Analytical grade L-Histidine (CAS No. 71-00-1) was procured from Merck and used as received without any further purification to maintain the consistency of the results. Deionized Milli-Q water (Millipore SAS 67/20 Mosheim) with a specific conductance of 10^{-7} S cm^{-1} was used as the solvent for the preparation of all solutions. All glassware used in the experimental procedures were thoroughly cleaned using standard laboratory protocols, followed by drying to constant weight. The complete dryness of the apparatus was confirmed using anhydrous copper sulfate ($CuSO_4$), ensuring the absence of residual moisture. Aqueous solutions of L-Histidine were prepared at varying molal concentrations ranging from 0.01 m to 0.1 m using a high-precision digital balance (Model AJO20, Aiwa) with a weighing accuracy of ±0.001 g. The density (ρ) of each solution was measured using a calibrated digital densitometer (Mettler Toledo), offering an accuracy of ±0.001 g/cm^3. Viscosity (η) was determined by employing an Ostwald viscometer, and each measurement was performed in triplicate to ensure reproducibility. Ultrasonic velocity (μ) was measured using a Mittal-type ultrasonic interferometer (Model M-83), operating at a fixed frequency of 2 MHz. The interferometer's sample cell was surrounded by a water-jacketed system connected to a thermostat, which maintained the temperature of the experimental setup with high precision. The temperature of all measurements was controlled and recorded at six discrete points: 293.15 K, 298.15 K, 303.15 K, 308.15 K, 313.15 K, and 318.15 K [6–10].

RESULTS AND DISCUSSION

The experimental data collected includes measured properties such as ultrasonic velocity (μ), density (ρ), and viscosity (η), and derived thermodynamic and acoustic parameters such as isentropic compressibility (β_a), isothermal compressibility (β_i), and hydration number (n_h), presented in Table 1. Additional derived parameters – apparent molar volume (Φ_v), partial molar volume at infinite dilution (Φ_v^0), and viscosity coefficients A and B (obtained from the Jones–Dole equation) – are summarized in Table 2. To visualize the dependence of these parameters on solute concentration and temperature, graphical representations are provided in Figures 1–5. The results indicate a systematic variation of acoustic and volumetric parameters with increasing concentration and temperature. A general increase in ultrasonic velocity and decrease in compressibility values with concentration suggests strong solute–solvent interactions, likely due to hydrogen bonding and electrostatic attractions between the zwitterionic centers of L-Histidine and water molecules. Furthermore, the apparent and partial molar volumes provide insights into the solution and structural organization of the solute in aqueous media. Viscosity trends analyzed through the A and B coefficients reflect the ion-solvent interactions and support the proposed model of hydration and structuring of water around L-Histidine molecules. These observations collectively contribute to a comprehensive understanding of the molecular behavior of L-Histidine in aqueous solutions and provide valuable data for interpreting biomolecular interactions in similar systems [11, 12].

Table 1. Density (ρ), viscosity (η), ultrasonic velocity (u), adiabatic compressibility (βa), isothermal compressibility (βi), hydration number (nh) values for aqueous L-Arginine solutions at different temperatures.

T K	m Mol Kg^{-1}	ρ × 10^3 kg m^{-3}	$\eta \times 10^{-3}$ N s m^{-2}	U m s^{-1}	Ba × 10^{-7} Kg m^2 S^1	Bi × 10^{-7} N^{-1} m^2	n_h
293.15	0.0000	0.9983	1.1369	1482.6	4.56	5.47	0.000
	0.0096	0.9979	1.2177	1492.8	4.50	5.4	75.930
	0.0201	0.9992	1.2333	1493.0	4.49	5.39	40.564
	0.0303	1.0002	1.2379	1493.4	4.48	5.38	29.581
	0.0392	1.0009	1.2452	1493.7	4.48	5.37	24.333
	0.0500	1.0014	1.2510	1494.0	4.47	5.37	19.980
	0.0600	1.0020	1.2549	1494.4	4.47	5.36	17.541
	0.0699	1.0025	1.2631	1494.8	4.46	5.36	15.851
	0.0792	1.0032	1.2825	1495.2	4.46	5.35	14.775
	0.0895	1.0038	1.2984	1495.8	4.45	5.34	13.876
	0.1003	1.0044	1.3085	1496.4	4.45	5.34	13.067
298.15	0.0000	0.9971	1.0022	1497.2	4.47	5.37	0.000
	0.0096	0.9960	1.0445	1509.0	4.41	5.29	82.958
	0.0201	0.9974	1.0595	1510.2	4.40	5.28	47.766
	0.0303	0.9987	1.0667	1510.8	4.39	5.26	35.337
	0.0392	0.9994	1.0788	1511.0	4.38	5.26	28.581
	0.0500	0.9999	1.0847	1511.4	4.38	5.25	23.434
	0.0600	1.0004	1.0931	1511.8	4.37	5.25	20.303
	0.0699	1.0009	1.1028	1512.2	4.37	5.24	18.216
	0.0792	1.0016	1.1126	1512.8	4.36	5.24	17.027
	0.0895	1.0021	1.1197	1513.4	4.36	5.23	15.799
	0.1003	1.0026	1.1273	1514.4	4.35	5.22	14.993
303.15	0.0000	0.9941	0.8011	1520.2	4.35	5.22	0.000
	0.0096	0.9940	0.8203	1528.0	4.31	5.17	57.677
	0.0201	0.9948	0.8244	1529.4	4.30	5.16	34.740
	0.0303	0.9957	0.8286	1530.0	4.29	5.15	26.007
	0.0392	0.9964	0.8314	1531.2	4.28	5.14	23.192
	0.0500	0.9968	0.8368	1532.0	4.27	5.13	19.675
	0.0600	0.9973	0.8402	1533.4	4.26	5.12	18.349
	0.0699	0.9978	0.8433	1534.8	4.25	5.11	17.528
	0.0792	0.9981	0.8490	1535.8	4.25	5.10	16.496
	0.0895	0.9987	0.8543	1536.8	4.24	5.09	15.690
	0.1003	0.9994	0.8597	1537.8	4.23	5.08	14.991
313.15	0.0000	0.9923	0.7259	1529.4	4.31	5.17	0.000
	0.0096	0.9926	0.7456	1536.8	4.27	5.12	56.722
	0.0201	0.9931	0.7477	1537.6	4.26	5.11	31.323
	0.0303	0.9938	0.7520	1538.4	4.25	5.10	23.851
	0.0392	0.9944	0.7409	1539.8	4.24	5.09	21.742
	0.0500	0.9947	0.7435	1541.2	4.23	5.08	19.269
	0.0600	0.9952	0.7464	1542.4	4.22	5.07	17.775
	0.0699	0.9959	0.7504	1543.2	4.22	5.06	16.589
	0.0792	0.9964	0.7538	1544.4	4.21	5.05	15.974
	0.0895	0.9968	0.7581	1545.8	4.20	5.04	15.413
	0.1003	0.9973	0.7614	1547.0	4.19	5.03	14.773
318.15	0.0000	0.9903	0.6638	1537.2	4.27	5.13	0.000
	0.0096	0.9902	0.6584	1544.8	4.23	5.08	55.624
	0.0201	0.9910	0.6647	1545.6	4.22	5.07	31.609
	0.0303	0.9917	0.6684	1546.4	4.22	5.06	24.033
	0.0392	0.9924	0.6722	1547.2	4.21	5.05	20.940
	0.0500	0.9928	0.6800	1548.0	4.20	5.04	17.909
	0.0600	0.9933	0.6814	1549.6	4.19	5.03	17.106
	0.0699	0.9937	0.6848	1550.6	4.19	5.02	15.980
	0.0792	0.9942	0.6888	1551.4	4.18	5.01	15.090
	0.0895	0.9947	0.6924	1552.8	4.17	5.00	14.689
	0.1003	0.9953	0.6987	1554.0	4.16	4.99	14.180

Table 2. Apparent molar volume, partial molar volume, and the experimental slope of Eq. 2 and values of parameters of the Jone–Dole equation for different aqueous L-Arginine solutions.

M mol Kg^{-1}	$\sqrt{C}$	Φv (m^3 mol^{-1})					
		293.15K	**298.15K**	**303.15K**	**308.15K**	**313.15K**	**318.15K**
0.0096	0.0980	196.812	274.931	234.235	170.470	127.461	170.016
0.0201	0.1418	110.238	142.602	133.075	122.611	117.156	122.394
0.0303	0.1741	92.208	103.677	100.648	103.699	106.781	110.269
0.0392	0.1980	88.512	97.379	97.615	97.394	102.373	102.471
0.0500	0.2236	92.832	99.803	97.984	101.884	107.859	105.933
0.0600	0.2449	93.143	100.639	100.821	102.401	107.397	105.810
0.0699	0.2644	94.709	101.153	102.767	102.688	104.075	107.107
0.0792	0.2814	92.881	98.568	102.548	105.051	103.721	106.409
0.0895	0.2992	93.184	99.356	102.892	103.985	105.095	106.349
0.1003	0.3167	93.814	100.332	102.485	102.454	105.483	105.594
Φ_v^o	(m^3 mol^{-1})	174.8328	174.8328	248.7903	210.7216	160.1164	127.9065
S_v^*	(m^3 Kg$^{1/2}$ mol$^{-3/2}$)	–311.548	–311.5478	–565.0025	–414.872	–217.4303	–85.30446
$(\eta/\eta_o-1)/\sqrt{c}$ *versus* $\sqrt{c}$	B (dm^3 mol^{-1}) A (dm$^{3/2}$ mol$^{-1/2}$)	*B* = –1.02225 *A* = 0.72922	*B* = –0.09586 *A* = 0.40876	*B* = –0.49961 *A* = 0.42504	*B* = 0.00065 *A* = 0.20933	*B* = –0.537 *A* = 0.27914	*B* = 1.02692 *A* = –0.1496

RESULTS FROM DENSITY DATA

The apparent molar volumes of aqueous solutions of L-Histidine have been computed from the solution density values using the relation:

$$\varphi_v = \frac{M}{\rho_0} + \frac{1000 \times (\rho_0 - \rho)}{m\rho_0} \quad (1)$$

The apparent molar volume (Φ_v) values were analyzed using the least-squares method and fitted to the following linear equation:

$$\Phi_v = \Phi_v^o + S_v \sqrt{c}^* \quad (2)$$

The parameter S_v represents the experimental slope and provides insight into volumetric pairwise interaction coefficients between solute particles in solution [13, 14]. The evaluated Φ_v^o and S_v^* values for L-Histidine in water at various temperatures are summarized in Tables 1 and 2.

Positive values of Φ_v^o across all temperatures for the L-Histidine + water system suggest strong *solute*–solvent interactions, indicating that hydration and structural reorganization occur in the solution. However, the Φ_v^o values show a somewhat irregular trend with increasing temperature, likely due to the complex behavior of zwitterionic amino acids in aqueous environments. It is well established that in neutral aqueous solutions, amino acids exist predominantly as zwitterions [15–18], where water molecules are electrostricted around the terminal NH_3^+ and COO^- groups.

The observed decrease in Φ_v^o with rising temperature in some cases may be attributed to volume contraction or expansion associated with changes in the electrostriction effect. This could result from the disruption or weakening of secondary solution layers surrounding the solute, particularly at elevated temperatures [19].

The information concerning solute–solute interactions is given by S_v^*. Its value is not of much importance for non-electrolytes but is of great significance for electrolytes. S_v^* is found to be dependent on temperature, solute and solvent [20–21].

RESULTS FROM ULTRASONIC SPEED DATA

As observed in Figures 1-5, the ultrasonic velocity increases with the concentration of L-Histidine. This increase suggests stronger molecular interactions within the solution. The rise in ultrasonic velocity typically indicates enhanced association between the molecular species in the solution. This trend can be attributed to the ionic hydration effect, where proton transfer reactions might play a significant role. L-Histidine exists as both neutral molecules (NH_2CH_2COOH) and zwitterions ($NH_3^+CH_2COO^-$). Upon dissolving water, the zwitterions interact with water molecules through electrostatic forces, which strengthen the association among the solute and solvent molecules, leading to an increase in cohesion and ultrasonic velocity as the L-Histidine concentration increases [22, 23].

The ultrasonic velocity also shows an increase with rising temperature, a behavior like pure water, were ultrasonic velocity increases with temperature. As the temperature rises, hydrogen bonds between water molecules weaken, resulting in more monomeric water molecules. These molecules fill the gaps in the water's cage-like structure and become "trapped." Consequently, the number of closed-packed water structures increases, facilitating the propagation of ultrasonic waves and leading to an increase in ultrasonic velocity [24].

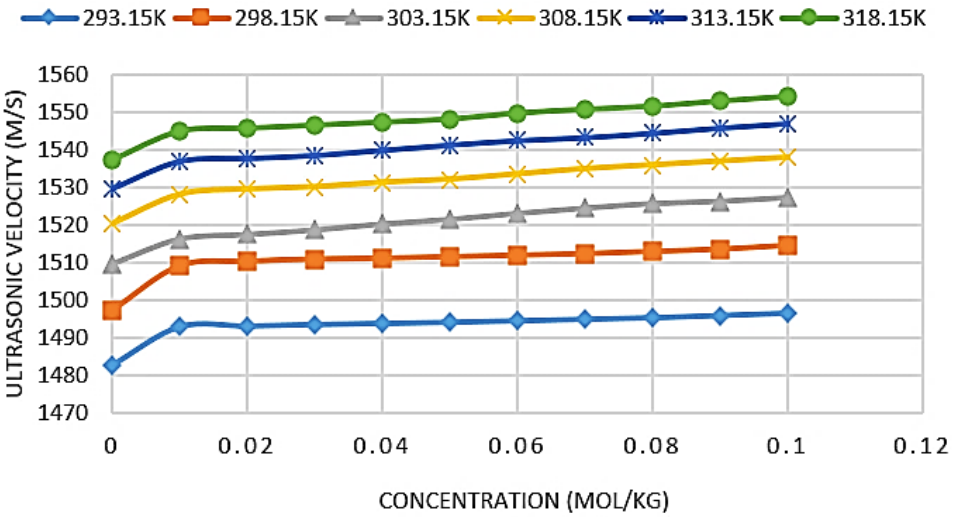

Figure 1. Variation of ultrasonic velocity with concentration of L-histidine at different temperatures.

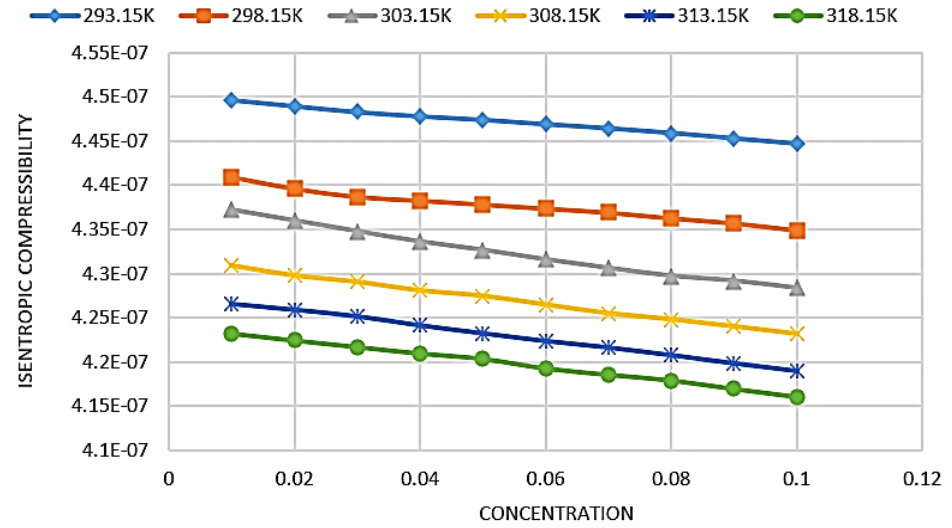

Figure 2. Variation of isentropic compressibility with concentration of L-histidine at different temperatures.

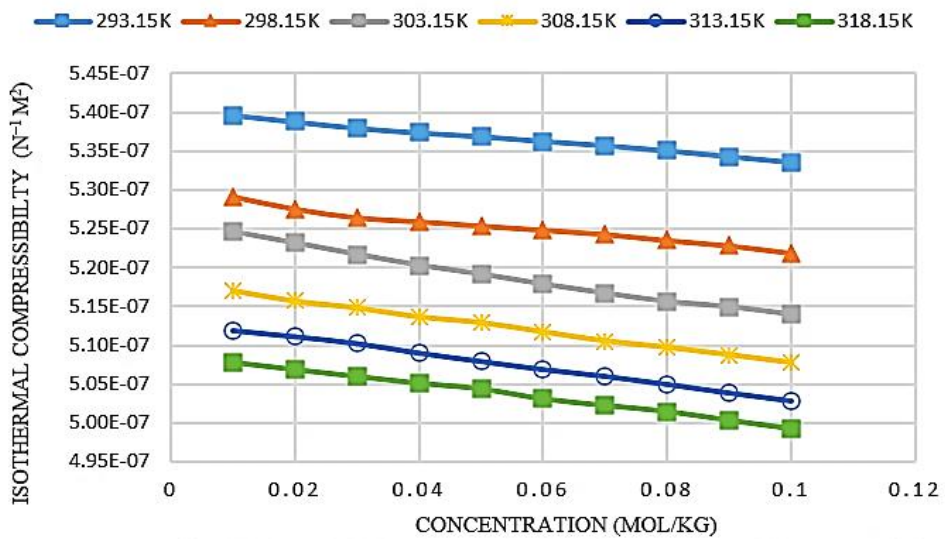

Figure 3. Variation of isothermal compressibility with concentration of L-histidine at different temperatures.

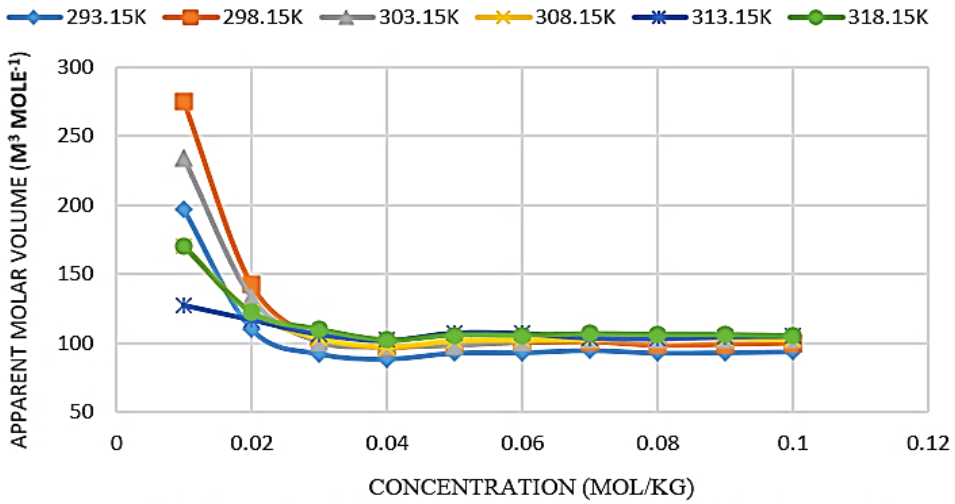

Figure 4. Variation of apparent molar volume with concentration of L-histidine at different temperatures.

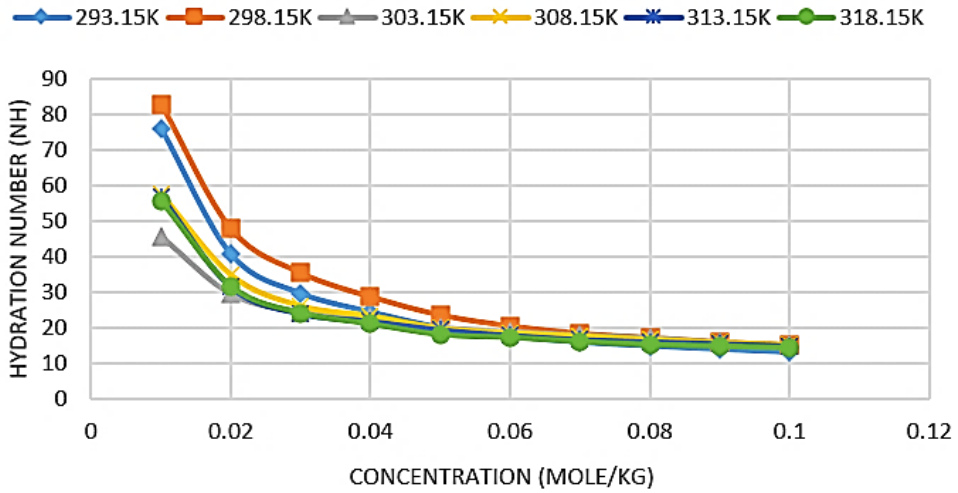

Figure 5. Variation of hydration number with concentration of L-histidine at different temperatures.

The adiabatic compressibility (β_a) was calculated from the ultrasonic velocity and solution density using the equation:

$$\beta_a = 1 / (\mu^2 \rho) \quad (3)$$

The closer packing of molecules, driven by hydrogen bonding between the solute and solvent, further impacts the compressibility of the system. As temperature increases, the reduction in thermal motion results in stronger intermolecular interactions, enhancing the compactness of the solution's structure. This is why the isentropic compressibility decreases with rising temperature [25, 26].

In the aqueous solutions of L-Histidine, Figure 3 shows that the isothermal compressibility decreases with both increasing concentration and temperature. This observation supports the presence of strong solute–solvent interactions, particularly between the $NH_3^+CH_2COO^-$ dipolar ions of L-Histidine and the surrounding water molecules [26, 27].

Hydration number (n_h) was calculated by isothermal coefficients of compressibility of solution and solvent and is given by:

$$n_h = \left(1 - \frac{\beta_i}{\beta_i{}^0}\right) \frac{100 - x}{M_0} \frac{M_2}{x} \quad (4)$$

where, β_i and $\beta_i{}^0$ are isothermal coefficients of compressibility's of solution and solvent, respectively, x is the weight percentage of solute, M_0 and M_2 is the molecular weight of solvent and solute, respectively.

RESULTS FROM VISCOSITY DATA

The variation of relative viscosity for L-Histidine + water mixtures can be represented by Jones–Dole equation [28].

$$\frac{\eta}{\eta_0} = 1 + A + B\sqrt{c} \quad (5)$$

The viscosities of the solvent and solution are denoted as η_0 and η, respectively, with c representing the molal concentration of the solution [28]. The constant A in this equation, known as the Falkenhagen coefficient [29, 30], reflects the contribution from interionic electrostatic forces and remains constant across different solution concentrations. The constant B, known as the Jones–Dole coefficient, measures the degree of order or disorder induced by the solute in the solvent structure [31]. To determine B and A, the values of $(\eta/\eta_0 - 1)/\sqrt{c}$ are plotted against $\sqrt{c}$ for the L-Histidine + water mixtures. The corresponding viscosity values and the constants from the Jones–Dole equation are listed in Table 2.

The A-coefficient is particularly useful when studying ionic solutes, as it pertains to interionic electrostatic interactions. However, in the present study involving non-electrolytes, the A-coefficient takes on very small values, reflecting the weak interionic interactions typical of non-electrolytes. These small values of A might be attributed to hydrogen bonding or Van der Waals forces, which result in weak solute–solute interactions. The A-coefficient quantifies solute–solute interactions that are independent of concentration, whereas the B-coefficient measures the effect of amino acids on the solvent's structural arrangement [28–29]. The lower values of B suggest a hydrophilic interaction between the solute and water, indicating strong hydrogen bonding, as discussed in the case of Φv_0.

Solutes that are strongly hydrated are classified as kosmotropes (structure-makers), while weakly hydrated solutes are considered chaotropes (structure-breakers) [32, 33]. Typically, positive values of B indicate structure-breaking behavior, while negative values suggest structure-making properties of the solute [34]. In the case of L-Histidine + water mixtures, the negative values of *B* suggest that L-Histidine acts as a structure-maker in water, likely due to hydrogen bonding between zwitterions and water molecules.

CONCLUSIONS

A comprehensive study of L-Histidine in water was conducted across a range of concentrations and temperatures using ultrasonic experiments. The ultrasonic velocity data, along with other acoustical

parameters, provided significant insights into the solute–solvent interactions in aqueous solutions. It was observed that as the concentration of L-Histidine increased, the solute–solvent interactions and molecular association within the solution became more pronounced. This enhancement in molecular interactions was reflected in the changes in ultrasonic velocity and other derived parameters. Furthermore, the study revealed that increasing the temperature led to a contraction of molecules, which could be attributed to the weakening of intermolecular cohesive forces between the solute and solvent. This behavior indicates that at higher temperatures, the solution's molecular structure adjusts, likely due to thermal effects that reduce the strength of interactions between L-Histidine molecules and water molecules. These findings emphasize the role of temperature and concentration in modulating the physicochemical properties of amino acid solutions, providing deeper understanding of their behavior in aqueous environments.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

REFERENCES

1. Nain R, Pal R, Sharma J. Chem. Thermodyn. 2011;43:603–612.
2. Banipal TS, Kaur J, Banipal PK, Singh K. J Chem Eng Data. 2008;53:1803–1816.
3. Pal S, Kumar J. Chem. Thermodyn. 2005;37:1085–1092.
4. Zhao P, Ma J, Li J. Chem. Thermodyn. 2005;37:37–4.
5. Ronero CM, Moreno E, Rojas JL. Thermochim Acta. 1999;328:33–38.
6. Hedwig G. J Chem Soc Faraday Trans. 1993;2761–2768.
7. Bhat R, Ahlluwalia J. J Phys Chem. 1985;89:1099–1105.
8. Chalikan T, Sarvazyan A, Breslauer K. J Phys Chem. 1993;97:13017–13026.
9. Kumar D, Sharma S. Z Phys Chem. 2017;1–16.
10. Nain K, Lather M. J Mol Liq. 2015;211:178.
11. Nain K, Pal R, Sharma RK. J Mol Liq. 2012;165:154.
12. Nain K, Pal R, Sharma RK. J Mol Liq. 201;43:603.
13. Hedwig GR, Reading JF. J Chem Soc Faraday Trans. 1991;87:1751–1758.
14. Desnoyers JE. Pure Appl Chem. 1982;54:1469–1478.
15. Badarayani R, Kumar A. J Solution Chem. 2004;33:407–426.
16. Shen J, Li Z, Wang B, Zhang Y. Chem Thermodyn. 2000;32:805–819.
17. Lin G, Lin R, Ma L. Thermochim Acta. 2005;430:31–43.
18. Ramasami P, Kakkar R. J Chem Thermodyn. 2006;38:1385–1395.
19. Riyazuddeen, Altamash T. Thermochim Acta. 2010;501:72–77.
20. Kabiraz DC, Biswas TK, Islam MN, Huque ME. Studies on molecular interactions of some electrolytes in water by volumetric and viscometric measurments at T=(303.15 to 323.15 K). Journal of Scientific Research. 2011 Apr 28;3(2):437-44.
21. Thakur RC, Sharma R, Kumar A, Kumar S, Parmar ML. Partial molar volumes of aluminium chloride, aluminium sulphate and aluminium nitrate in water-rich binary aqueous mixtures of tetrahydrofuran. Orient. J. Chem. 2014;30(4):2037-41.
22. Thirumaran S, Gardliya D. Recent Res Sci Tech. 2011;3(8):56–63.
23. Ragouramane D, Rao AS. Ind J Chem. 1998;37A:659–662.
24. SethuRaman M, Ponnuswamy V, Amrithaganesan G. Ind J Phys. 2004;78(12):1329–1333.
25. Wakulkar M, Lanjewar S, Shah S. Int J Sci Res Sci Tech. 2021;9:1–8.
26. Sethu Raman M, Ponnuswamy V, Kolandaivel P, Perumal K. J Mol Liq. 2008;142:10–16.
27. Sethu Raman M, Ponnuswamy V, Kolandaivel P, Perumal K. J Mol Liq. 2007;135:46–52.
28. Jones G, Dole M. J Am Chem Soc. 1929;51(2):2950–2970.

29. Felkenhagen H, Vernon EL. Z Phys. 1929;30:611–616.
30. Felkenhagen H, Vernon EL. Z Phys. 1932;33:140–145.
31. Iqbal M, Chaudhry M. J Chem Eng Data. 2009;54:1643–1646.
32. Munir M, Ali A. Asian J Biomed Pharm Sci. 2014;4:22.
33. Kaminsky M. Discuss Faraday Soc. 1957;24:171–179.
34. Nain K, Lather M. J Mol Liq. 2015;211:178–186.

