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Ultrasonic Studies and Intermolecular/Interionic Interactions Of L-Isoleucine, L-Proline and L-Glutamine in Aqueous K2SO4, KNO3 and KCI Solutions

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1. Introduction

Proteins, large molecules with high molecular weights are composed of varying amount of essentially the same about twenty amino acids well known for this purpose. Proteins play a vital role in nearly all the biological processes. Every protein has a unique three-dimensional structure that may reflect its envisaged function. Its structure is known to be stabilized by the presence of multiple weak interactions. Hydrophobic interactions provide the major contribution to stabilizing the globular form of most soluble proteins; hydrogen bonds and ionic interactions are optimized in the specific structure that is thermodynamically most stable. The thermodynamic stability of the native structure of protein has provided one of the great challenges in Biophysical Chemistry and Biophysics; and still currently remains the subject of extensive investigations (1-14).

The knowledge of stability of proteins in aqueous and mixed aqueous solutions is essential for understanding their structures and functions. The stability of a globular protein in aqueous solutions can be determined by studying the disruption of its native structure, i.e., the process of denaturation. The denaturation of globular proteins in aqueous solutions is a fundamental biological process. During this process, the native folded conformation of protein is converted predominantly into an extended unfolded form and during this process various changes occur in protein hydration. Protein hydration that is the interaction of water with various functional groups of proteins is an important factor in determining the conformational stability of proteins (8-10). Thus, the thermodynamic studies of native and denatured states of proteins are necessary to understand the role of hydration in protein folding / unfolding processes (15-17). The structural details revealed by the high-resolution x-ray crystallography, neutron diffraction, spectroscopy and thermodynamic methods have contributed a great deal towards our understanding of protein functions (18).

The amino acids, the alphabet of protein structure, can be arranged in an almost infinite number of sequences to make an almost infinite number of different proteins. Amino acids are characterized by the presence of a carboxyl group (-COOH) and an amino group (-NH2) attached to the same carbon at the end of the compound. Every amino acid except glycine can occur as either of the optically active stereoisomers, D or L; the more common isomer in nature is the L-form. When the carboxyl carbon

atom of one amino acid covalently binds to the amino nitrogen atom of another amino acid with the release of water molecule, a peptide bond is formed. Asparagine was the first amino acid to be discovered in proteins in 1806.

The direct interpretation of thermodynamic studies on complex configurational and conformational structure of proteins in various solvents is rather tedious and difficult. Therefore, investigations of the behaviour of protein model compounds: amino acids and peptides are of importance. Amino acids and peptides, the basic molecular building blocks of proteins, have been often used as the most conventional substances to estimate the individual contribution of monomeric units in proteins (19). Thermodynamic studies of amino acids and peptides are also helpful in understanding the phase equilibria and separation behaviour of these compounds (20). The thermodynamic properties of amino acids and peptides in aqueous medium provide information about the solute-solvent and solute-solute interactions which, in turn, may be employed to understand several biochemical processes such as protein hydration, denaturation, aggregation, etc. (4,14,18,19,21-103).

The interaction of electrolytes with biochemical compounds have been the subject of numerous studies (104), but little attention has been paid to the properties of aqueous amino acid – electrolyte solution (20,27,92,105-118) despite their physiological importance. A quantitative analysis of the effect of electrolytes on amino acids and peptides is desirable in view of both, theoretical as well as practical applications. The addition of amino acid to electrolytes brings about a sharp change in the solvation of ions. Amino acids form hydrogen bonds with water but in presence of electrolytes it has been observed that there is a complete loss of structure due to bonding between water and the added electrolyte. The change in the structure of solvent or solution around the solute molecule /ion as a result of hydrogen bond formation or disruption leads to decrease or increase in intermolecular free length. It is useful to extend the study of amino acids to a mixed solvent system not only because of the fact that the mixed aqueous solvents are used extensively in chemistry and other related fields to control the factors, which affect some of the properties of significance such as solubility, reactivity and stability of systems but also because biological fluids are ultimately not pure water.

A number of physical techniques have so far been employed to study the intermolecular / interionic interactions in aqueous and non-aqueous systems, but no method alone provide a complete understanding of the nature of these interactions. The density, viscosity and ultrasonic velocity studies of solutions have been employed for studying the behaviour of biological macromolecules. These studies enable one to investigate and understand the inherent concept of the intermolecular interactions and to correlate their behaviour with thermodynamic properties.

Ultrasonic velocity technique has been used to study the thermodynamic properties of aqueous and non-aqueous systems (39,57,64,111,112,116,119-138). The velocity data along with those of density can be employed for the computation of various thermodynamic parameters, namely, isentropic compressibility, change and relative change in isentropic compressibility, specific acoustic impedance and relative association to provide a better source of understanding of interionic / intermolecular interactions in solutions. Nomoto in 1958 (139) and Bhimsenachar et al. in 1962 (140) proposed the relations to evaluate theoretically the sound velocity in liquid mixtures. The ideal mixing relation for ultrasound velocity has been applied by Van Dael and Vangeel (141). Schaffs (142) and Nikan et al. (143) have shown that the sound velocity in the liquid mixture is proportional to the space-filling factor.

In addition, the Flory-Patterson theory has also been attempted to evaluate theoretically the ultrasonic velocity of liquid mixtures using the reduced and characteristic parameters of pure liquids (144,145).

Isothermal compressibility, a thermodynamic parameter, provides a better understanding of the interactions in solutions. Various attempts have been made to evaluate the isothermal compressibility of binary liquid mixtures as well as of aqueous electrolyte solutions (146-157). Chaturvedi and Pratap (158) employed the Carnahan and Starling (151); and Thiele (150) equations to obtain the isothermal compressibility and related properties of a number of liquids at room temperature. Some hard sphere models have also been used to obtain the isothermal compressibility and related thermodynamic parameters of liquids (159-162). McGown (163) and Pandey et al. (164) proposed direct methods for the calculation of isothermal compressibility using the ultrasonic velocity and density data.

The role of internal pressure in liquid thermodynamics was recognized many years ago by Hildebrand (165) following earlier work of Van Laar (166). Pioneer attempts have been made by Barton (167,168), Cagle (169), Rosseinsky (170), Berkowitz et al. (171), Hildebrand et al. (172-174) and Liberman (175) to show the significance of internal pressure as a fundamental property of liquid state and its correlation with other properties. Dunlop et al. (176) determined the internal pressure of different liquid mixtures and compared it with their cohesive energy density values. Suryanarayana (177) suggested an indirect method of evaluating internal pressure from the data of viscosity, density and ultrasonic velocity. This approach has been extensively used for studying the internal pressure of pure liquids, binary liquid mixtures, and solutions of electrolytes and non-electrolytes (178). In addition, properties of liquids such as solubility (179), surface tension (179), energy of activation of viscous flow, dipole moments (180), the glass transition in polymers (181,182) and viscosity properties of polymers (183,184) have been discussed widely in terms of internal pressure, cohesive energy density and solubility parameter values.

The square root of the cohesive energy density is referred to as solubility parameter. This property has been extensively discussed in a review presented by Barton (168). The “universality” of the solubility parameter into parts representing dispersion, dipole-dipole and hydrogen bonding cohesion energies permits a wide use of this parameter (185-187). Pseudo-Gruneisen parameter, a dimensionless constant is governed by the molecular order and structure. Lattice order of liquids can be revealed in the light of this parameter.

Volumetric properties such as apparent / partial molal volumes of solutes in solution can provide better information about the various types of ionic/molecular interactions, viz. hydrogen bonding (188,189), electrostriction (190,191), ionization (192,193), hydrophobic/ hydrophilic interactions (190), and zwitterions formation (74). A number of researchers have determined the partial molal volume of a variety of solutes in different solvents in order to study the solute-solvent interactions in solutions (32-34,36,41,42,45-48,60,62,72,92,105-110,113,115,117,194-202). In addition, partial molal volume measurements are important for obtaining information about the hydration phenomena of solute in a solution (23).

Partial molal isentropic compressibility of solution is an essential physical characteristic reflecting intermolecular/interionic interactions. Studies of compressibility of aqueous solutions of proteins have started a long time ago (203,204). During the last decade a new approach has been developed for investigation of protein volume and compressibility based on x-ray analysis (205-207). In

1964, Goto and Isemura measured the apparent isentropic compressibility of fourteen amino acids over a temperature range from 15 to 45°C (63). Millero et al. (64) have studied fifteen amino acids in aqueous solutions at 25°C. The partial molal isentropic compressibility of a protein in aqueous solution can be considered to be made up of essentially two terms (208,209). One contribution is from the intrinsic compressibility of a protein, which arises from the void volume that exists within the molecule due to imperfect packing of protein chain. The second contribution is due to the hydration of the various amino acid residues that are exposed to the solvent.

Viscometric studies are important for studying transport properties of pure and mixed solutions. Viscosity has been found to be a measure of the resistance of a fluid to flow. The increase in viscosity due to the presence of particles arises from the fact that they lie across the fluid streamlines and are subject to torsional forces. They tend to rotate and then absorb energy. This energy absorption leads to an increased viscosity of the solution (56). It has been observed that viscous forces appear only when adjacent parts of a fluid are moving with different velocities.

The viscosity derived parameters, such as specific, reduced and intrinsic viscosities provide a better understanding of intermolecular / interionic interactions in solutions (54,210-219). The solute-solvent interactions can also be studied in terms of B-coefficient of Jones-Dole equation (220). The partitioning of the B-coefficient into their ionic components was first proposed by Cox and Wolfenden (221) and it was re-examined by Gurney (222) and Kaminsky (223) in 1965. Martin and Tsangaris (55) in 1965 studied the structure making / breaking effects of amino acids on water in terms of B-coefficient and its temperature derivative, dB/dT, values. They found that the magnitude of dB/dT values

is more important than the B-coefficient for explaining the structure making / breaking effects of amino acids on water.

It appears, however, from the exhaustive literature survey that a number of thermodynamic properties of amino acids have been studied in aqueous medium (52,61,83,224-226) but few authors have attempted to investigate amino acids in aqueous electrolyte solutions as functions of concentration and temperature (35,82,227-229). Consequently, with a view to understanding the intermolecular / interionic interactions of amino acids, namely L-isoleucine, L-proline and L-glutamine in 0.5M potassium sulphate, 1M potassium nitrate and 1.5M potassium chloride aqueous solutions, the densities, ultrasonic velocities and viscosities have been measured as functions of temperature and concentration.

Experimental

Material And Sample Preparation

The amino acids: L-isoleucine, L-proline and L-glutamine of high purity (≥99%) used in the studies were obtained from Sisco Research Laboratories, India. All the three amino acids were used without further purification. The amino acids were dried at ~110°C and stored in a vacuum desiccator for several hours before use. The electrolytes KNO3 and KCl were obtained from E. Merck, India; and K2SO4 from S.D. Fine, India. These salts were of high purity (≥99%). The salts were recrystallized in triple distilled water and were dried at 110°C and then kept in vacuum desiccator for several hours. Stock Solutions of 0.5 M K2SO4, 1 M KNO3 and 1.5 M KCl were prepared in triple distilled water and used as solvents for the preparation of solutions. Water used in the experiments was deionized, triple-

distilled, and was degassed prior to making solutions. The degree of degassing was sufficiently high to prevent formation of bubbles in the measuring cell. All the solutions were made by weight on the molality concentration scale within an accuracy of $\pm 1\times10^{-4}$ mol Kg^{-1}.

Temperature Control

A thermostated paraffin bath was used to maintain the desired temperature during the measurements of density and viscosity. The bath was made up of an immersion heater (1.5 KW), a stirrer, a check thermometer (Germany), a contact thermometer and a relay [Jumo type, NT 15.0, 220 V ≅ 10A (Germany)]. Thermal stability of the thermostat was found to be within ± 0.1°.

Density Measurement

Pyknometer consisting of a small bulb with flat bottom of approximately 3.5 ml capacity and a graduated stem was used for the density measurements. The volume at each mark of the pyknometer was calibrated with triple distilled water. The densities of pure water at various required temperatures were taken from literature for calibration purpose (230). In order to check the reproducibility of calibration, the same process was repeated a number of times with different amounts of water. The reproducibility of density values was found to be within ± 0.0003 gm/cm^3. The test solution was introduced into the calibrated pyknometer, weighed and then it was immersed in the paraffin bath. By recording the volume changes as a function of temperature, the densities of solutions were determined at required temperatures.

Viscosity Measurement

Canon-Fenske viscometer was used for the viscosity measurement of various solutions under study. The viscometer consists of three parallel arms with a common base. The viscometer was calibrated with the triple distilled water. The viscosity coefficient values of water at different temperatures were taken from literature (231). The clean and dry viscometer was filled with test solution and was clamped in the thermostated bath in a vertical position. In order to avoid the absorption of moisture by solution, the open ends of the three arms of viscometer were fitted with the anhydrous calcium chloride glass tubes through rubber tubes. The solution was sucked into the measuring bulb and was allowed to stand there for about two minutes by closing the calcium chloride tubes with rubber corks and then the corks were removed for recording the time of fall of solution from the upper to lower end of the bulb. After taking several readings at the desired temperature the average of the very close values of time of fall was taken.

The viscosity coefficient was calculated employing the following Poiseuille's equation,

$$\eta = \pi gh\ \rho tr^4/8vl \qquad [1]$$

where g, h, ρ, 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. The above equation can also be written as

$$\eta = \rho\beta t \qquad [2]$$

where $\beta = \pi g h r^4 / 8vl$ is constant for a given viscometer. The viscosity value of the test solution was calculated using the reported viscosity values of pure water at various temperatures. Equation [3] was employed for the calculation of viscosity of solutions.

$$\eta_1 = (\rho_1 t_1 / \rho_2 t_2) \times \eta_2 \qquad [3]$$

where η, ρ and t are the viscosity coefficient, the density and the time of fall of the solution, respectively. The reproducibility in viscosity measurements was found to be within $\pm 0.003 \times 10^{-4}$ N m^{-2} s.

Ultrasonic Velocity Measurement

An ultrasonic interferometer (Mittal's model: M-77) was used for the measurement of ultrasound velocity at a frequency of 4 MHz in the temperature range: 298.15 – 323.15 K. Water from ultra-thermostat (Type U-10) was circulated through the brass jacket surrounding the cell and the quartz crystal. The jacket was well insulated and the temperature of the solution under study was maintained to an accuracy of ± 0.1°. The instrument was calibrated with the triple distilled water. The ultrasonic velocity values of water at different temperatures were taken from literature (232) for calibration purpose.

Working Principle

An ultrasonic interferometer is a simple and direct device to determine the ultrasonic velocity in liquids with a high degree of accuracy. The principle used in the measurement of velocity (u) is based on the accurate determination of the wavelength (λ) in the medium. Ultrasonic waves of known frequency (f) are produced by a quartz plate fixed at the bottom of the cell. A movable metallic plate kept parallel to the quartz plate reflects these waves. If the separation between these two plates is exactly a whole multiple of the ultrasound wavelength, standing waves are formed in the medium. This acoustic resonance gives rise to an electrical reaction on the generator driving the quartz plate and the anode current of the generator becomes maximum. If the distance is now increased or decreased and the variation is exactly one half wavelength ($\lambda/2$) or multiple of it, anode current again becomes maximum. The velocity can be obtained by using the relation,

$$u = \lambda \times f \qquad [4]$$

Description

The ultrasonic interferometer consists of two parts (i) the high frequency generator and (ii) the measuring cell. The “high frequency generator” is designed to excite the quartz plate fixed at the bottom of the measuring cell and its resonant frequency to generate ultrasonic waves in the liquid filled in the “measuring cell”. A micrometer to observe the change in current and two controls for the purpose of sensitivity regulation and initial adjustments of micrometer are provided on the panel of the high frequency generator. The “measuring cell” is a specially designed double walled cell for maintaining a constant temperature of the liquid during experiment. A fine micrometer screw has been provided at the top, which can lower or raise the reflector plate in the liquid in the cell through a known distance. It has quartz plate fixed at its bottom.

Instrument was adjusted in the following manner:

1. The cell was inserted in the square base socket and clamped to it with the help of a screw provided on one of its sides.
2. The curled cap of the cell was unscrewed and removed from the double walled construction of the cell. In the middle portion of it the experimental liquid was poured and screwed the curled cap.
3. Water was circulated through the two chutes in the double wall construction in order to maintain the desired temperature.
4. The cell was connected with the high frequency generator by a co-axial cable provided with the instrument.

For the initial adjustment, two knobs are provided on high frequency generator, one is marked with 'Adj' and the other with 'Gain'. With knob marked 'Adj' the position of needle on the ammeter was adjusted and the knob marked 'Gain' was used to increase the sensitivity of the instrument for greater deflection. The ammeter was used to record the maximum deflections by adjusting the micrometer.

Measurements

The measuring cell was connected to the output terminal of the high frequency generator through a shielded cable. The cell was filled with the liquid before switching on the generator. The ultrasonic waves of 4 MHz frequency produced by a gold plated quartz crystal fixed at the bottom of a cell are passed through the medium. A movable plate reflects the waves and the standing waves are formed in the liquid in between the reflector plate and the quartz crystal. Acoustic resonance due to these standing waves gives rise to an electrical reaction to the generator driving the quartz plate and the anode current of the generator becomes maximum. The micrometer screw was raised slowly to record the maximum anode current. The wavelength was determined with the help of a total distance moved by the micrometer for twenty maximum readings of the anode current. The total distance (d) gives the value of wavelength with the help of the relation, $d = n \times \lambda/2$, where n is the maximum number of readings. Using the wavelength, the ultrasound velocity in the liquid was obtained with the help of Equation [4]. The reproducibility in velocity measurement was within $\pm$ 0.5 ms^{-1}.

Precautions

1. The generator was switched on after filling the cell by the experimental liquid.
2. The experimental liquid was removed from the cell after use.
3. The micrometer was kept open at 25 mm after use.
4. The sudden rise or fall in the temperature of circulated liquid was avoided to prevent thermal shock to the quartz crystal.
5. While cleaning the cell, care was taken not to spoil or scratch the gold plating on the quartz crystal.
6. The generator was given 15 minutes warming up time before observation.

A number of researchers have employed the ultrasonic technique to evaluate the thermodynamic properties of amino acids (39,57, 64,111,112,119-121), peptides (18,19,116) and proteins (122,129) in aqueous and mixed aqueous solutions. Ultrasonic velocity data as such provide limited information about the nature and the relative strengths of various types of intermolecular / interionic interactions but their derived parameters, viz., isentropic compressibility (KS), change in isentropic compressibility (AKJ), relative change in isentropic compressibility (AKS/KO), specific acoustic impedance (Z) and relative association (RA) provide an information about the extent of various types of interactions responsible for the behaviour of pure liquids and of solutions. The velocity of sound in a liquid usually refers to a longitudinal type of wave mode. The rate of propagation depends upon the type of wave, the elastic properties of the medium, the density of the medium and the frequency. The propagation velocity of ultrasound wave in normal liquids decreases with an increase in temperature but in water the velocity attains a maximum value of 1557 ms'" at 74°C and above this temperature the ultrasound velocity diminishes (233). This abnormal property of water may be attributed to its peculiar liquid structure. When a salt is added to water, tlic velocity of solution increases or decreases with an increase in temperature depending upon its ionic concentration and the type of ion - water interactions. The isentropic compressibility of water attains a minimum value at 64T. This behaviour of water is also apparently due to its peculiar structure (233). ^\^^

Nandi and Robinson (234) studied the salting in /salting out effects of several salts on biological macromolecules and concluded that the salts interact directly with the peptide group. Salt-induced electrostatic forces are known to play a vital role in modifying the protein structure by affecting properties like, solubility, denaturation and activity of enzymes (235-237). The trend of variation of ultrasonic velocity with concentration and temperature depends on the equilibrium properties of amino acids in aqueous electrolyte solution. Their equilibrium properties in solution are determined by the relative magnitude of electrostriction caused by the polar end groups, the structure-enforcing influence of the hydrophobic alkyl groups and the extent of interaction between ions and hydrophilic groups. In the present work, the ultrasonic velocity and density of amino acids, viz. L-isoleucine, L-proline and L-glutamine as functions of concentration and temperature in three aqueous electrolyte solutions, namely 0.5M K2SO4, IM KNO3 and 1.5M KCl have been measured to examine the solute-solute and solute-solvent interactions in solutions. RESULTS AND DISCUSSION The density data of all the three amin(^ acids in aqueous solutions of K2SO4, KNO3 and KCl measured as functions of concentration and temperature are listed in Table 1.1. The plots of density versus concentration are shown in Figs. 1.1-1.9. All the systems seem to exhibit almost linear behaviour in their variation with concentration as well as

Table 1.1: Experimental values of density (p xlO' , kg m') as functions of concentration and temperature

(i) L-isoleucine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0000	1.0606	1.0593	1.0579	1.0561	1.0542	1.0519
0.0284	1.0611	1.0597	1.0582	1.0564	1.0544	1.0521
0.0474	1.0615	1.0600	1.0684	1.0565	1.0545	1.0522
0.0665	1.0618	1.0603	1.0586	1.0567	1.0546	1.0523

0.0857	1.0622	1.0605	1.0588	1.0569	1.0547	1.0524
0.1049	1.0626	1.0608	1.0590	1.0570	1.0548	1.0525
0.1243	1.0629	1.0611	1.0592	1.0571	1.0549	1.0526
0.1437	1.0633	1.0613	1.0593	1.0573	1.0551	1.0527
0.1633	1.0636	1.0617	1.0596	1.0575	1.0552	1.0528

(ii) L-isoleucine in aqueous KNO3 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0544	1.0529	1.0511	1.0490	1.0467	1.0442
0.0285	1.0550	1.0534	1.0515	1.0493	1.0470	1.0445
0.0477	1.0553	1.0536	1.0517	1.0496	1.0472	1.0447
0.0669	1.0557	1.0540	1.0520	1.0497	1.0474	1.0448
0.0862	1.0560	1.0542	1.0523	1.0500	1.0476	1.0450
0.1056	1.0564	1.0546	1.0524	1.0502	1.0477	1.0451
0.1250	1.0567	1.0548	1.0527	1.0504	1.0479	1.0454
0.1446	1.0571	1.0552	1.0529	1.0506	1.0482	1.0456
0.1642	1.0575	1.0555	1.0532	1.0508	1.0483	1.0457

(iii) L-isoleucine in aqueous KCI solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0629	1.0614	1.0597	1.0578	1.0556	1.0533
0.0285	1.0634	1.0618	1.0600	1.0580	1.0558	1.0535
0.0474	1.0638	1.0622	1.0603	1.0583	1.0560	1.0537
0.0665	1.0641	1.0624	1.0606	1.0585	1.0562	1.0539
0.0856	1.0645	1.0628	1.0607	1.0586	1.0563	1.0540
0.1049	1.0648	1.0631	1.0610	1.0589	1.0565	1.0542
0.1243	1.0652	1.0633	1.0612	1.0590	1.0567	1.0544
0.1437	1.0656	1.0637	1.0615	1.0592	1.0569	1.0546
0.1632	1.0659	1.0639	1.0616	1.0595	1.0571	1.0548

(iv) L-proline in aqueous K2SO4 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0606	1.0593	1.0579	1.0561	1.0542	1.0519
0.0953	1.0617	1.0606	1.0592	1.0576	1.0557	1.0534
0.2909	1.0669	1.0658	1.0643	1.0626	1.0606	1.0584
0.4934	1.0721	1.0709	1.0694	1.0677	1.0656	1.0633
0.7032	1.0773	1.0760	1.0745	1.0727	1.0706	1.0683
0.9206	1.0825	1.0812	1.0796	1.0777	1.0756	1.0733
1.1462	1.0877	1.0863	1.0847	1.0827	1.0806	1.0782

(v) L-proline in aqueous KNO3 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0544	1.0529	1.0511	1.0490	1.0467	1.0442
0.0958	1.0571	1.0554	1.0535	1.0514	1.0491	1.0466
0.1932	1.0598	1.0580	1.0561	1.0539	1.0516	1.0492
0.2923	1.0626	1.0608	1.0588	1.0566	1.0542	1.0516
0.3932	1.0653	1.0634	1.0614	1.0592	1.0568	1.0542
0.4958	1.0681	1.0661	1.0640	1.0618	1.0593	1.0568
0.6002	1.0708	1.0688	1.0667	1.0645	1.0619	1.0592
0.7065	1.0736	1.0714	1.0692	1.0670	1.0645	1.0618
0.8146	1.0763	1.0742	1.0719	1.0697	1.0670	1.0643
0.9248	1.0791	1.0768	1.0744	1.0724	1.0696	1.0669
1.0371	1.0818	1.0794	1.0771	1.0749	1.0721	1.0694

(vi) L-proIine in aqueous KCl solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0629	1.0614	1.0597	1.0578	1.0556	1.0533
0.0950	1.0644	1.0630	1.0614	1.0595	1.0573	1.0549
0.2900	1.0691	1.0677	1.0660	1.0641	1.0618	1.0594
0.4920	1.0738	1.0724	1.0706	1.0686	1.0664	1.0639
0.7015	1.0785	1.0770	1.0752	1.0732	1.0709	1.0684
0.9189	1.0831	1.0817	1.0799	1.0778	1.0755	1.0729
1.1445	1.0878	1.0863	1.0845	1.0824	1.0800	1.0774

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0606	1.0593	1.0579	1.0561	1.0542	1.0519
0.0379	1.0618	1.0604	1.0590	1.0573	1.0554	1.0532
0.0762	1.0637	1.0622	1.0607	1.0590	1.0570	1.0548
0.1147	1.0656	1.0640	1.0625	1.0607	1.0587	1.0565
0.1535	1.0675	1.0659	1.0643	1.0624	1.0604	1.0581
0.1926	1.0694	1.0677	1.0660	1.0641	1.0620	1.0597
0.2320	1.0714	1.0695	1.0678	1.0658	1.0637	1.0614
0.2717	1.0733	1.0714	1.0695	1.0675	1.0654	1.0630

(viii) L-glutamine in aqueous KNO3 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0544	1.0529	1.0511	1.0490	1.0467	1.0442
0.0381	1.0558	1.0545	1.0530	1.0509	1.0487	1.0463
0.0766	1.0580	1.0567	1.0551	1.0530	1.0507	1.0483
0.1152	1.0602	1.0588	1.0572	1.0550	1.0528	1.0503
0.1542	1.0623	1.0610	1.0593	1.0571	1.0549	1.0523
0.1934	1.0645	1.0631	1.0614	1.0592	1.0570	1.0543
0.2330	1.0667	1.0652	1.0636	1.0612	1.0591	1.0563
0.2728	1.0689	1.0674	1.0657	1.0633	1.0611	1.0583

(ix) L-glutamine in aqueous KCl solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1.0629	1.0614	1.0597	1.0578	1.0556	1.0533
0.0379	1.0636	1.0621	1.0605	1.0587	1.0567	1.0545
0.0760	1.0652	1.0637	1.0621	1.0603	1.0583	1.0561
0.1145	1.0668	1.0652	1.0636	1.0619	1.0599	1.0577
0.1534	1.0684	1.0667	1.0652	1.0634	1.0614	1.0593
0.1925	1.0699	1.0682	1.0667	1.0650	1.0630	1.0609
0.2320	1.0715	1.0697	1.0683	1.0666	1.0646	1.0625
0.2718	1.0731	1.0712	1.0698	1.0682	1.0662	1.0641

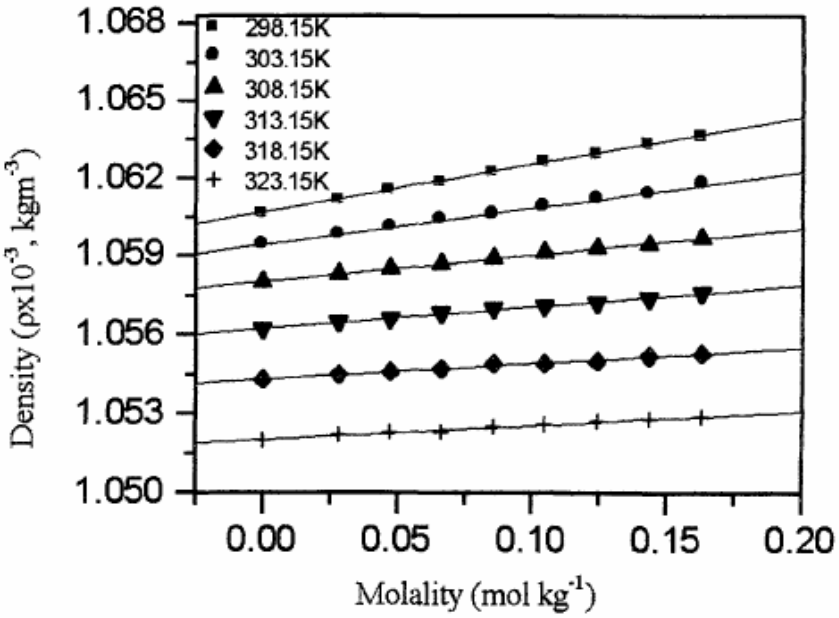


Fig 1.1: Plot of density versus concentration of L-isoleucine in aqueous K_2SO_4 solution.

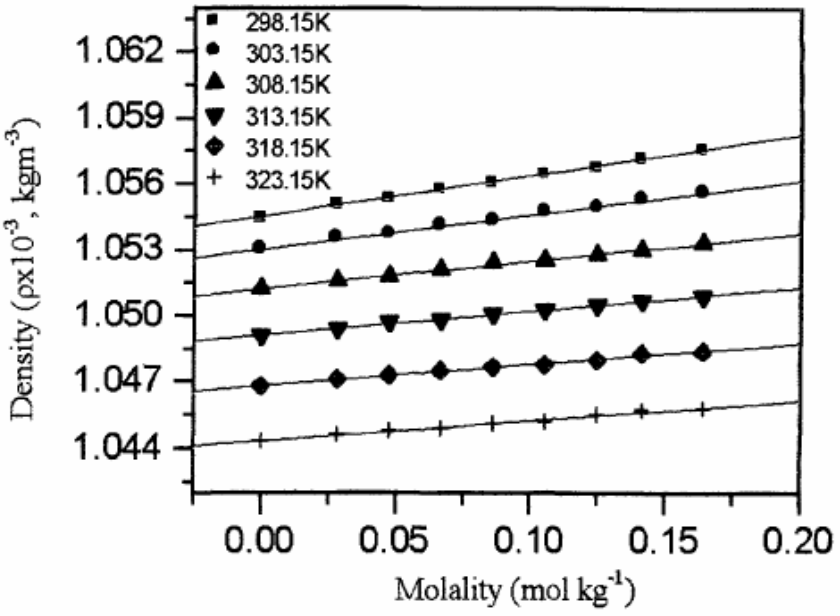


Fig 1.2: Plot of density versus concentration of L-isoleucine in aqueous KNO_3 solution.

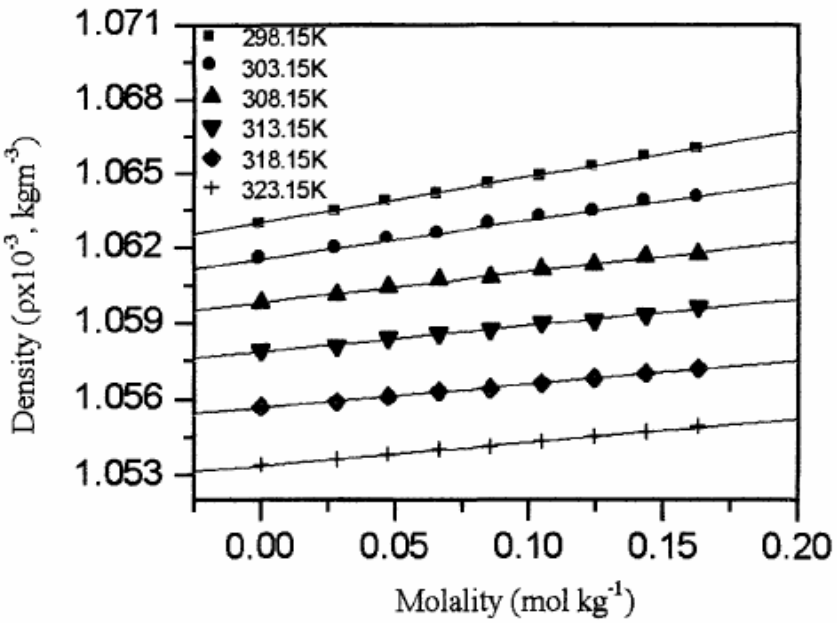


Fig 1.3: Plot of density versus concentration of L-isoleucine in aqueous KCl solution.

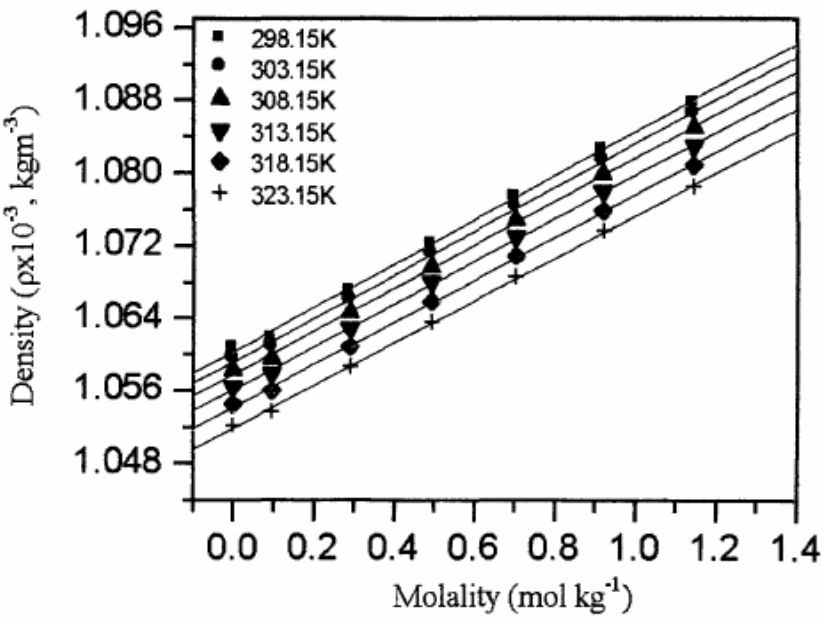


Fig 1.4: Plot of density versus concentration of L-proline in aqueous K_2SO_4 solution.

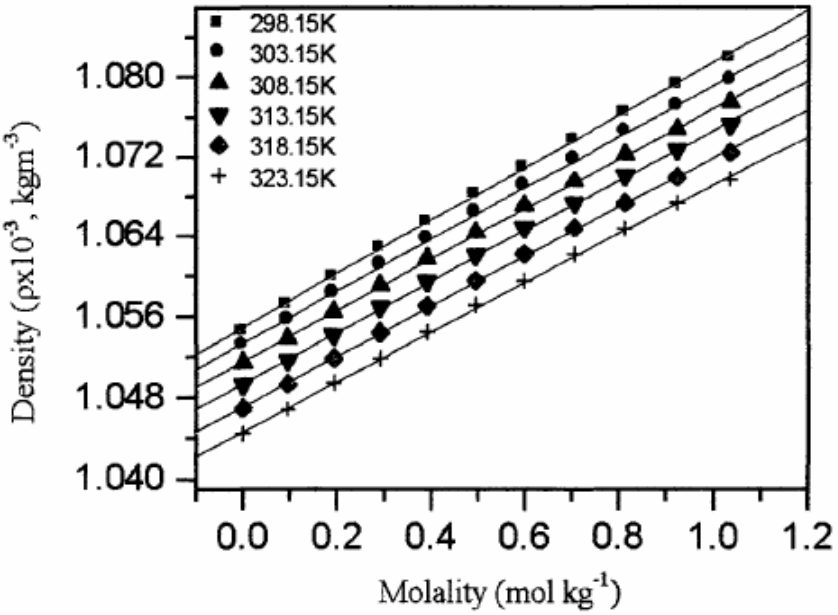


Fig 1.5: Plot of density versus concentration of L-proline in aqueous $KN0_3$ solution.

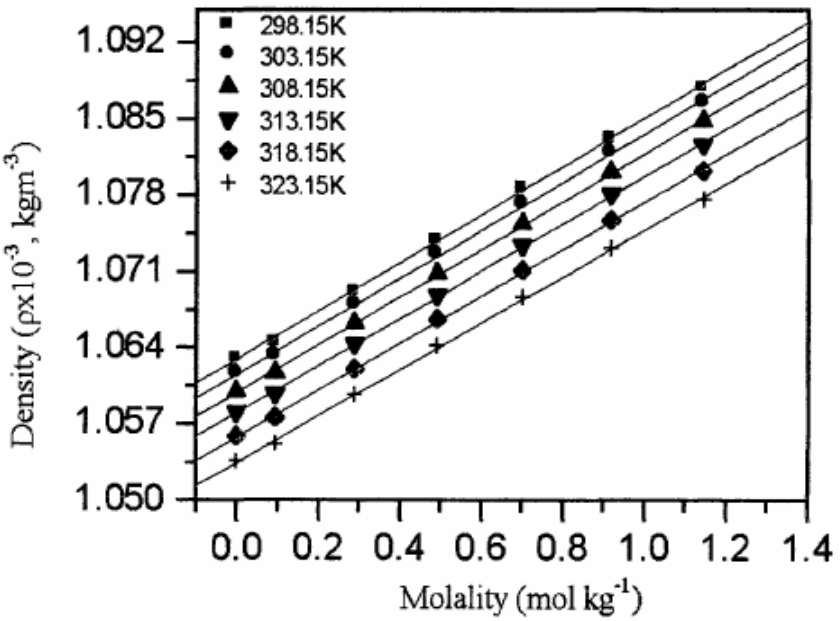


Fig 1.6: Plot of density versus concentration of L-proline in aqueous KCl solution.

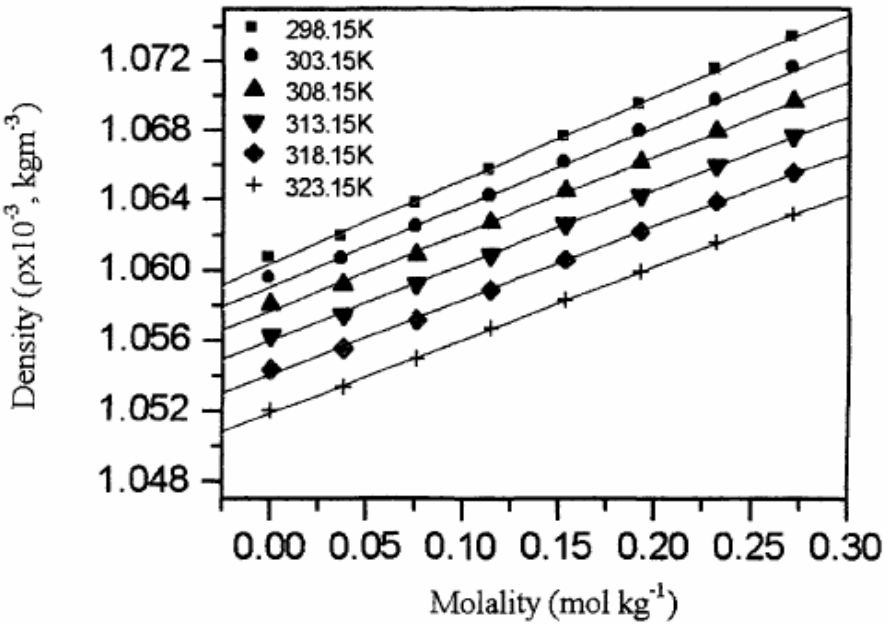


Fig 1.7: Plot of density versus concentration of L-glutamine in aqueous K_2SO_4 solution.

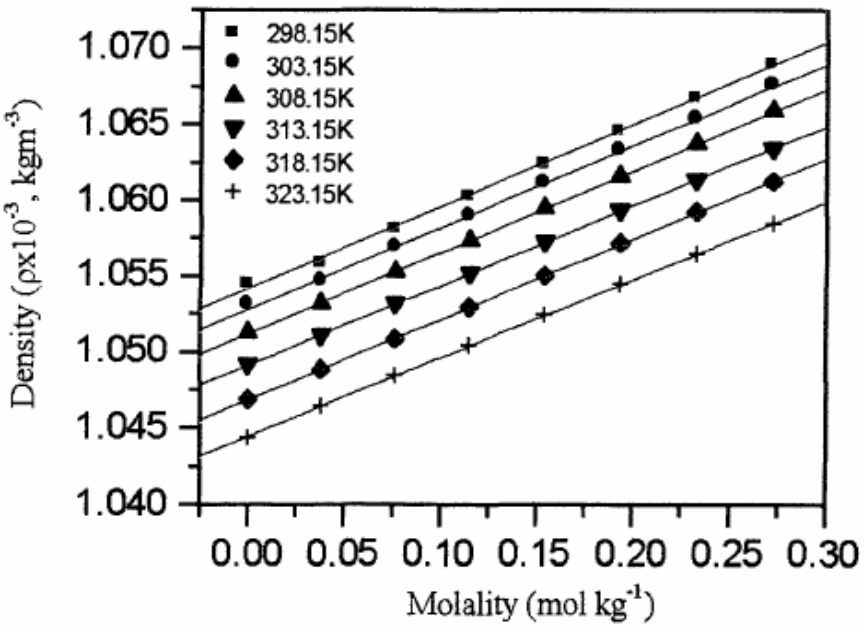


Fig 1.8: Plot of density versus concentration of L-glutamine in aqueous KNO_3 solution.

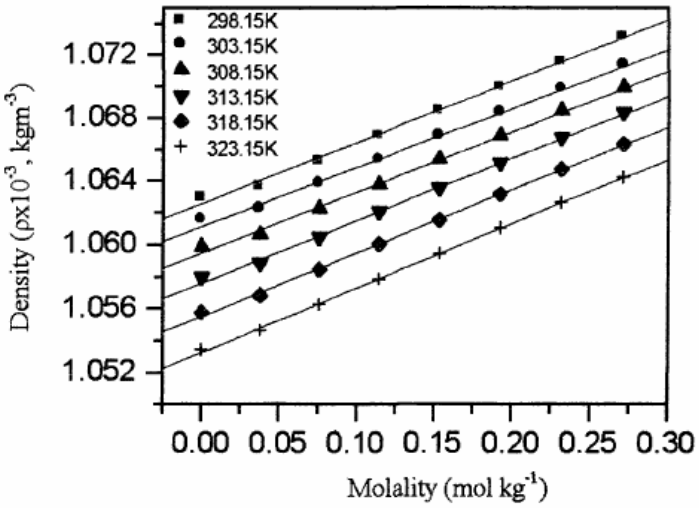


Fig 1.9: Plot of density versus concentration of L-glutamine in aqueous KCl solution.

with temperature. The measured densities of solutions have been least squares fitted to non-linear equations, p = po + Pim + p2m^ [1.1] P-PO + P,T + P2T' [1.2] where po, Pi, pi ; m and T are the fitted coefficients, molality and temperature, respectively. The least-squares fitted coefficients of the above polynomials along with the standard deviations are listed in Tables 1.2 and 1.3, respectively. The standard deviations of these best-fitted values support the tendency to exhibit non-linear behaviour with concentration as well as with temperature. The density values of all the studied systems increase with increase in concentration of solute and have been found to be higher than those of water at all temperatures as envisaged (230). These values show a usual decreasing trend of variation with increase in temperature. The trend of variation of density values of an amino acid in electrolyte solutions has been found to be in the order: KCl > K2SO4 > KNO3. This trend is in consonance with the trend of variation of densities of aqueous electrolyte solvents, i.e., 1.5M KCl > 0.5MK2SO4> IMKNO3 The measured ultrasonic velocities for the three amino acids in aqueous electrolytic solutions of 0.5M K2SO4, IM KNO3 and 1.5M KCl for several concentration and temperature are listed in Table 1.4. The relevant plots (Figs. 1.10-1.18) are either linear or show a tendency for a non-linear behaviour with concentration of solute. In the case of L- isoleucine in aqueous K2SO4 solution the plots are linear unlike those in KNO3 and KCl in which a second order regression equation seem to be

Table 1.2: Least squares fit coefficients of the density equation,

p = Po + Pim + p2m as a function of temperature

(i) L-isoleucine in aqueous K2SO4 solution

Temperature (K)	**p_0**	**p_1**	**p_2**	**σ(p)**
298.15	1.06058	1.91607	-3.18936	0.3
303.15	1.05931	1.40857	1.63169	0.4
308.15	1.05790	1.06911	-3.18992	0.3
313.15	1.05612	0.88267	-3.54311	0.4
318.15	1.05421	0.60182	-0.31228	0.4
323.15	1.05191	0.54827	-0.12469	0.4

(ii) L-isoleucine in aqueous KNO3 solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	1.05443	1.84748	1.18063	0.4
303.15	105292	1.51200	4.10195	0.6
318.15	1.04671	1.02549	-2.54797	0.5
323.15	1.04422	0.89658	1.68234	0.6

(iii) L-isoleucine in aqueous KCl solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	1.06290	1.84108	0.86488	0.3
303.15	1.06138	1.68337	-7.33154	0.6
308.15	1.05968	1.34491	-8.68011	0.6
313.15	1.05779	0.97674	2.82198	0.6
318.15	1.05560	0.78678	8.18078	0.3
323.15	1.05330	0.78678	8.18078	0.3

(iv) L-proline in aqueous K2SO4 solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	1.06002	2.43405	-0.05245	4.6
303.15	0588	2.45523	-0.40314	3.9
308.15	05742	2.43195	-0.35668	3.9
318.15	1.05382	2.39998	-0.47144	3.1
323.15	1.05152	2.41921	-0.71365	3.0

(v) L-proIine in aqueous KNO3 solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	05438	2.86795	-2.13962	0.3
303.15	1.05281	2.78094	-2.03506	0.7
308.15	1.05100	2.72113	1.98208	0.7
313.15	1.04889	2.68451	1.63293	0.8
318.15	04662	2.65584	1.87546	0.5
323.15	04416	2.62153	-1.79743	0.5

(vi) L-proIine in aqueous KCl solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	1.06257	2.31758	-0.93767	2.6
303.15	1.061	2.33547	-1.12145	2.3
308.15	05947	2.30219	-0.95528	1.8
313.15	1.0575	1	8	517
-0.98407	1.7			
318.15	1.05537	2.28307	1.09699	1.8
323.15	1.05305	2.24581	-0.98738	2.0

(vii) L-glutamine in aqueous K2SO4 solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	1.06040	4.30250	17.69281	1.7
303.15	1.05909	4.08380	17.50069	1.8
308.15	1.05769	4.02243	13.31115	1.7
313.15	1.05595	4.01392	9.54809	1.2
318.15	1.05406	3.89646	10.82739	1.2
323.15	1.05180	3.99490	5.38043	0.9

(viii) L-glutamine in aqueous KNO3 solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	1.05418	4.97134	16.69593	1.8
303.15	1.05274	5.16657	8.16942	1.4
308.15	1.05105	5.28555	3.56946	0.5
313.15	1.04895	5.28055	-0.62751	0.5
318.15	1.04667	5.35999	-1.86389	0.5
323.15	1.04423	5.35745	-7.49919	0.2

(ix) L-glutamine in aqueous KCI solution

Temperature (K)	p_0	p_1	p_2	σ(p)
298.15	1.06264	3.38319	18.40476	2.2
303.15	1.06115	3.33176	14.64291	2.0
308.15	1.05947	3.43144	14.92514	1.9
313.15	1.05761	3.51821	14.89063	1.6
318.15	1.05547	3.71026	9.38461	1.1
323.15	1.05318	3.85787	6.53839	1.0

Table 1.3: Least squares fit coefficients of the density equation, p = Po + piT + P2T as a function of concentration

(i) L-isoleucine in aqueous K2SO4 solution

Concentration (mol kg^{-1})	p_0	p_1	p_2	σ(p)
0.0000	0.68209	2.76021	-5.00000	0.5
0.0284	0.72057	2.52632	-4.64286	0.4
0.0474	0.78667	2.11434	-4.00000	0.3
0.0665	0.75614	2.32424	-4.35714	0.2
0.0857	0.82703	1.87474	-3.64286	0.7
0.1049	0.90053	1.41666	-2.92857	0.4
0.1243	0.93128	1.22944	-2.64286	0.2
0.1437	0.99596	0.82203	-2.00000	0.7
0.1633	0.96530	1.03250	-2.35714	0.3

(ii) L-isoleucin(; in aqueous KNO3 solution

Concentration (mol kg^{-1})	p_0	p_1	p_2	σ(p)
0.0000	0.69484	2.69679	-5.00000	0.4
0.0285	0.76114	2.28481	-4.35714	0.5
0.0477	0.76897	2.23814	-4.28571	0.3
0.0669	0.79397	2.09186	-4.07143	0.6
0.0862	0.77444	2.22214	-4.28571	0.5
0.1056	0.83384	1.85397	-3.71429	0.6
0.1250	0.87560	1.58713	-3.28571	0.5
0.1446	0.92640	1.26905	-2.78571	0.6
0.1642	0.93743	1.21210	-2.71429	0.5

(iii) L-isoleucine in aqueous KCI solution

Concentration (mol kg^{-1})	p_0	p_1	p_2	σ(p)
0.0000	0.76464	2.27814	-4.28571	0.3
0.0284	0.83084	1.86616	-3.64286	0.2
0.0474	0.83398	1.85702	-3.64286	0.5
0.0665	0.84216	1.80921	-3.57143	0.6
0.0856	0.92928	1.26296	-2.71429	0.7
0.1049	0.90342	1.43590	-3.00000	0.9
0.1243	1.00202	0.80831	-2.00000	0.4
0.1437	1.03287	0.62109	-1.71429	0.8
0.1632	1.06806	0.39748	-1.35714	0.7

(iv) L-proIine in aqueous K2SO4 solution

Concentration (mol kg^{-1})	p_0	p_1	p_2	σ(p)
0.0000	0.68209	2.76021	-5.00000	0.5
0.0953	0.60961	3.22000	-5.71429	0.4
0.2909	0.65266	2.98668	-5.35714	0.4
0.4934	0.63337	3.15391	-5.64286	0.3
0.7032	0.67536	2.92401	-5.28571	0.2
0.9206	0.71102	2.73679	-5.00000	0.4
1.1462	0.71944	2.72593	-5.00000	0.4

(v) L-proIine in aqueous KNO3 solution

Concentration (mol kg^{-1})	p_0	p_1	p_2	σ(p)
0.0000	0.69484	2.69679	-5.00000	0.4
0.0958	0.79693	2.06520	-4.00000	0.0

0.1932	0.86999	1.61627	-3.28571	0.4
0.2923	0.80840	2.04520	-4.00000	0.0
0.3932	0.84634	1.82045	-3.64286	0.2
0.4958	0.92069	1.36752	-2.92857	0.4
0.6002	0.83009	1.97854	-3.92857	0.6
0.7065	0.95845	1.17401	-2.64285	0.9
0.8146	0.90248	1.56256	-3.28571	0.8
0.9248	0.97541	1.11420	-2.57143	1.8
1.0371	0.98755	1.06125	-2.50000	1.4

(vi) L-proIine in aqueous KCl solution

Concentration (mol kg^{-1})	**p_0**	**p_1**	**p_2**	**σ(p)**
0.0000	0.76464	2.27814	-4.28571	0.3
0.0950	0.66843	2.90401	-5.28571	0.2
0.2900	0.67587	2.89487	-5.28571	04
0.4920	0.70362	2.75374	-5.07143	0.4
0.7015	0.71739	2.70193	-5.00000	0.2
0.9189	0.65473	3.14057	-5.71429	0.4
1.1445	0.66851	3.08876	-5.64286	0.2

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg^{-1})	**p_0**	**p_1**	**p_2**	**σ(p)**
0.0000	0.68209	2.76021	-5.00000	0.5
0.0379	0.75055	2.32157	-4.28571	0.6
0.0762	0.79044	2.08768	-3.92857	0.6
0.1147	0.82913	1.85779	-3.57143	0.7
0.1535	0.82791	1.88959	-3.64286	0.5
0.1926	0.86780	1.65570	-3.28571	0.5
0.2320	0.94183	1.20106	-2.57143	0.8
0.2717	0.96797	1.05592	-2.35714	0.7

(viii) L-glutamine in aqueous KNO3 solution

Concentration (mol kg^{-1})	**p_0**	**p_1**	**p_2**	**σ(p)**
0.0000	0.69484	2.69679	-5.00000	0.4
0.0381	0.59877	3.30056	-5.92857	0.9
0.0766	0.60371	3.29142	-5.92857	0.9
0.1152	0.63530	3.10762	-5.64286	0.9
0.1542	0.59749	3.36932	-6.07143	0.9
0.1934	0.60137	3.36361	-6.07143	0.7

0.2330	0.60560	3.35675	-6.07143	1.5
0.2728	0.61054	3.34761	-6.07143	1.2

(ix) L-glutamine in aqueous KCl solution

Concentration (mol kg^{-1})	p_0	p_1	p_2	σ(p)
0.0000	0.76464	2.27814	-4.28571	0.3
0.0379	0.82079	1.90045	-3.64286	0.2
0.0760	0.82239	1.90045	-3.64286	0.2
0.1145	0.85769	1.68084	-3.28571	0.7
0.1534	0.90074	1.41400	-2.85714	0.9
0.1925	0.90069	1.41914	-2.85714	1.0
0.2320	0.90863	1.37648	-2.78571	1.5
0.2718	0.94393	1.15687	-2.42857	1.9

Table 1.4: Experimental values of ultrasonic velocity (u, ms') as functions of concentration and temperature

(i) L-isoIeucine in aqueous K2SO4 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1563.8	1571.2	1578.8	1587.6	1592.6	1597.6
0.0284	1564.6	1573.8	1580.4	1589.2	1595.2	1599.4
0.0474	1568.4	1575.6	1582.0	1590.6	1596.4	1600.4
0.0665	1568.8	1578.0	1584.8	1592.2	1598.4	1602.8
0.0857	1572.4	1579.6	1587.7	1594.4	1596.2	1601.2
0.1049	1572.7	1581.8	1590.7	1593.4	1600.4	1605.0
0.1243	1573.1	1582.1	1591.7	1595.8	1604.4	1608.4
0.1437	1575.8	1585.0	1592.0	1598.8		
0.1633	1577.6	1586.0	1593.8	1600.8	1605.7	1609.4

(ii) L-isoleucine in aqueous KNO3 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1531.8	1541.8	1550.2	1557.4	1563.6	1568.4
0.0285	1532.8	1542.6	1551.2	1558.2	1564.4	1568.8
0.0477	1533.2	1543.8	1552.4	1559.2	1564.8	1569.2
0.0669	1536.0	1545.2	1553.4	1560.0	1565.6	1569.8
0.0862	1539.6	1549.3	1556.8	1561.0	1566.0	1571.0
0.1056	1541.4	1551.6	1558.8	1563.2	1569.7	1573.8
0.1250	1544.0	1553.2	1559.4	1564.8	1573.2	1576.4
0.1446	1545.6	1554.0	1560.2	1567.8	1574.4	1578.0
0.1642	1547.0	1556.4	1563.4	1568.8	1575.8	1579.0

(iii) L-isoieucine in aqueous KCl solution

Concentration (mol kg^{-1})	303.15	308.15	313.15	318.15	323.15
0.0000	1584.0	1590.4	1595.8	1601.6	1606.2
0.0284	1585.9	1591.5	1596.0	1602.4	1607.0
0.0474	1586.2	1592.0	1596.4	1603.0	1607.8
0.0665	1587.2	1593.2	1597.4	1604.4	1608.4
0.0856	1588.8	1595.2	1599.4	1605.2	1609.2
0.1049	1592.1	1598.5	1602.6	1606.0	1610.4
0.1243	1593.3	1600.0	1604.6	1608.0	1613.5
0.1437	1596.0	1600.8	1606.8	1612.0	1615.8
0.1632	1598.4	1603.2	1608.2	1614.0	1618.0

(iv) L-proline in aqueous K2SO4 solution

Concentration (mol kg^{-1})	303.15	308.15	313.15	318.15	323.15
0.0000	1571.2	1578.8	1587.6	1592.6	1597.6
0.0953	1577.2	1585.2	1592.4	1597.2	1601.6
0.2909	1589.2	1596.4	1604.4	1608.6	1612.8
0.4934	1604.2	1611.4	1618.0	1622.4	1625.6
0.7032	1616.0	1621.4	1625.8	1630.4	1635.8
0.9206	1627.2	1631.2	1634.8	1640.2	1644.9
1.1462	1640.4	1644.4	1648.2	1651.8	1656.8

(v) L-proline in aqueous KNO3 solution

Concentration (mol kg^{-1})	303.15	308.15	313.15	318.15	323.15
0.0000	1541.8	1550.2	1557.4	1563.6	1568.4
0.0958	1549.0	1552.4	1559.2	1564.8	1569.8
0.1932	1553.6	1558.1	1563.2	1568.6	1573.4
0.2923	1558.8	1563.9	1570.6	1575.2	1580.4
0.3922	1561.8	1567.2	1573.8	1581.4	1584.8
0.4958	1568.2	1575.4	1580.2	1585.6	1589.8
0.6002	1577.2	1581.2	1588.0	1594.4	1597.0
0.7065	1581.6	1585.6	1593.8	1599.0	1602.2
0.8146	1584.8	1591.2	1597.8	1602.4	1608.0
0.9248	1593.6	1600.8	1605.6	1609.6	1613.8
1.0371	1598.4	1604.4	1609.0	1612.0	1615.2

(vi) L-proIine in aqueous KCl solution

Concentration (mol kg⁻¹)	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1577.2	1584.0	1590.4	1595.8	1601.6	1606.2
0.0950	1579.0	1586.6	1593.6	1600.8	1607.0	1611.0
0.2900	1589.6	1598.8	1606.8	1612.4	1617.2	1621.8
0.4920	1603.2	1612.6	1617.8	1624.0	1627.6	1631.4
0.7015	1617.2	1623.6	1630.8	1635.2	1638.8	1642.0
0.9189	1629.2	1637.4	1641.3	1645.4	1649.2	1652.2
1.1445	1643.2	1649.2	1654.4	1658.0	1660.7	1663.0

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	1571.2	1578.8	1587.6	1592.6	1597.6
0.0379	1574.0	1581.6	1588.6	1594.2	1598.8
0.0762	1576.4	1585.6	1591.2	1596.2	1601.4
0.1147	1581.0	1588.4	1594.8	1600.6	1605.6
0.1535	1583.2	1590.8	1598.4	1603.2	1607.4
0.1926	1585.4	1592.8	1600.0	1606.0	1610.0
0.2320	1588.6	1596.5	1604.4	1608.4	1613.6
0.2717	1592.2	1598.8	1605.0	1610.4	1614.0

(viii) L-glutaml ine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	1541.8	1550.2	1557.4	1563.6	1568.4
0.0381	1546.8	1552.4	1558.0	1563.8	1568.8
0.0766	1549.2	1556.4	1560.4	1564.2	1569.2
0.1152	1551.8	1557.6	1562.8	1566.8	1570.8
0.1542	1554.6	1560.0	1566.2	1568.8	1573.2
0.1934	1555.8	1564.0	1568.8	1572.8	1575.4
0.2330	1558.0	1565.6	1569.8	1574.0	1578.4
0.2728	1562.4	1570.0	1574.4	1579.0	1583.4

(ix) L-glutamine in aqueous KCi solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	1584.0	1590.4	1595.8	1601.6	1606.2
0.0379	1585.4	1593.0	1597.6	1604.4	1608.8
0.0760	1588.0	1596.2	1600.6	1607.8	1610.8
0.1145	1590.6	1597.4	1603.4	1608.6	1614.4

0.1534	1593.0	1599.2	1604.8	1610.6	1616.0
0.1925	1597.2	1603.2	1608.6	1613.0	1617.4
0.2320	1599.8	1606.6	1611.0	1614.6	1619.8
0.2718	1603.6	1609.2	1614.9	1619.4	1622.2

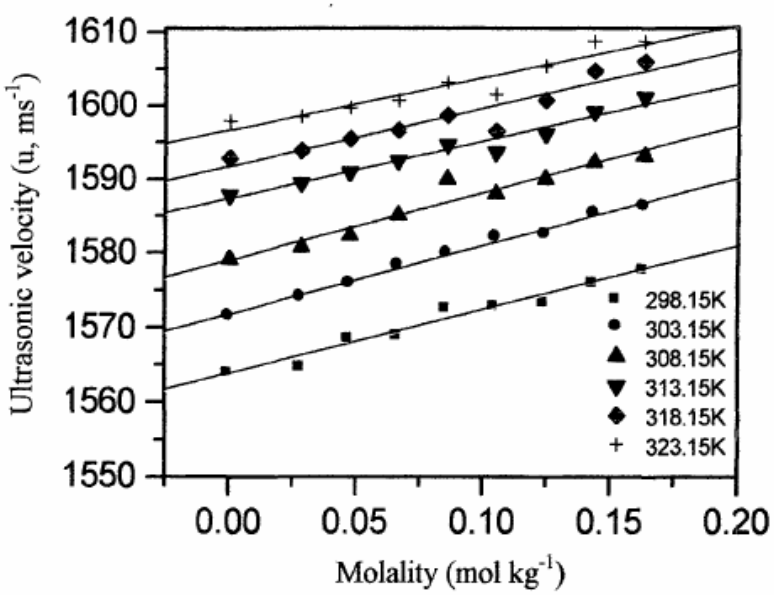


Fig.1.10: Plot of ultrasonic velocity versus concentration of L-isoleucine in aqueous K_2SO_4 solution.

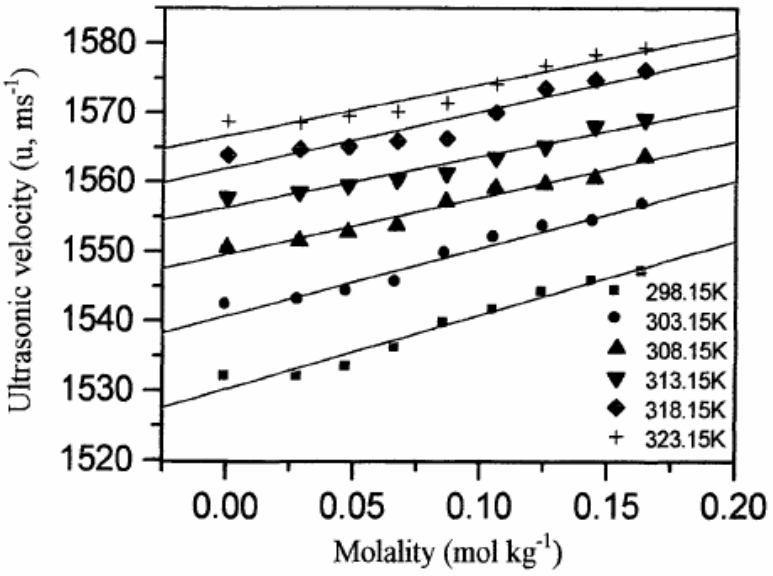


Fig.1.11: Plot of ultrasonic velocity versus concentration of L-isoleucine in aqueous KNO_3 solution.

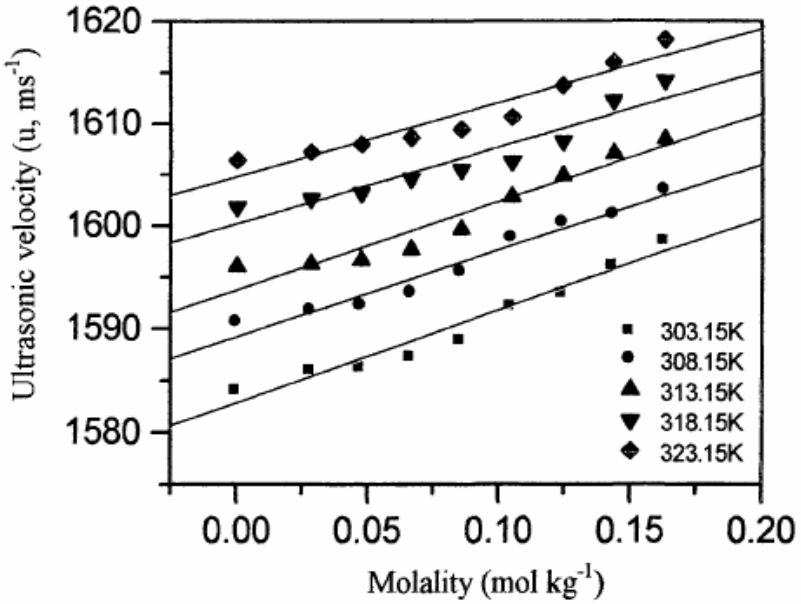


Fig.1.12: Plot of ultrasonic velocity versus concentration of L-isoleucine in aqueous KCl solution.

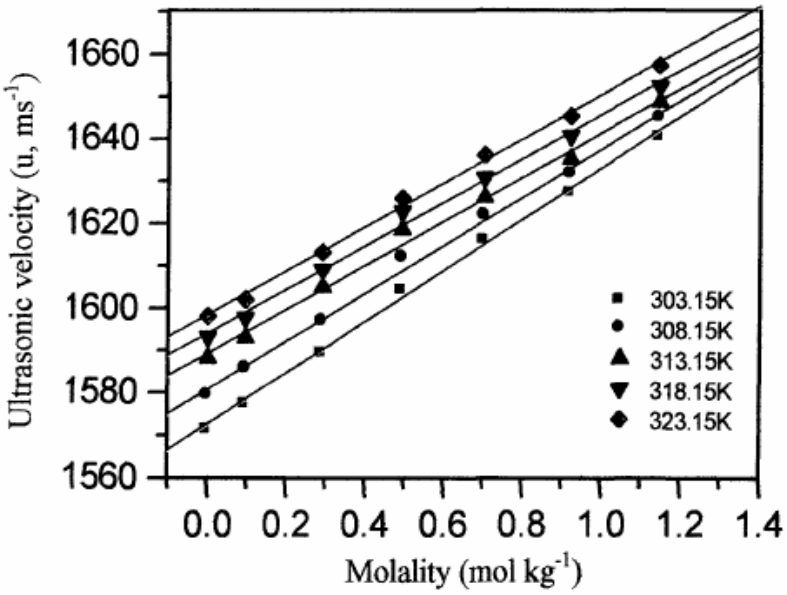


Fig.1.13: Plot of ultrasonic velocity versus concentration of L-proline in aqueous K_2SO_4 solution.

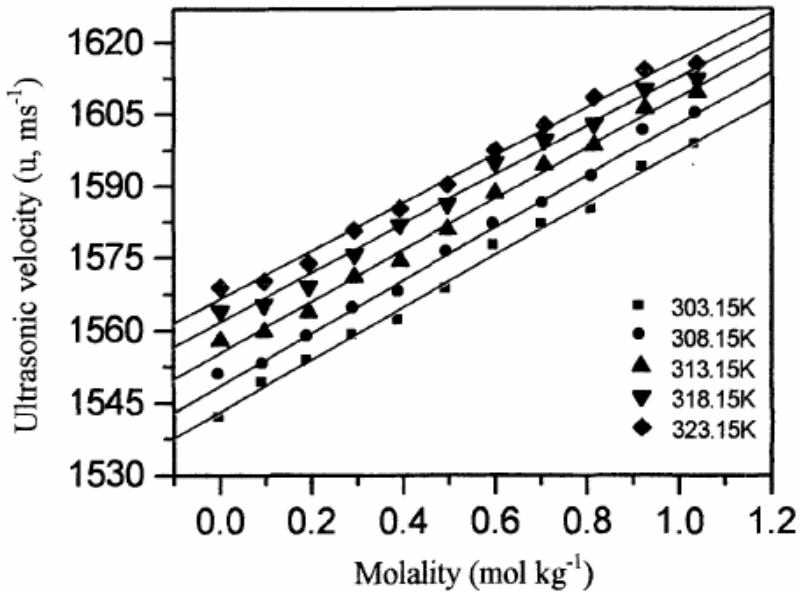


Fig.1.14: Plot of ultrasonic velocity versus concentration of L-proline in aqueous KNO_3 solution.

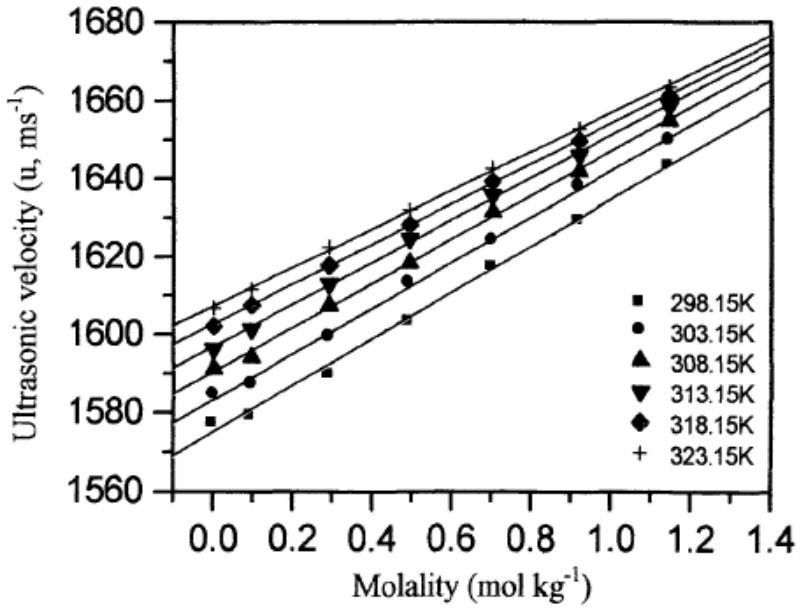


Fig.1.15: Plot of ultrasonic velocity versus concentration of L-proline in aqueous KCl solution.

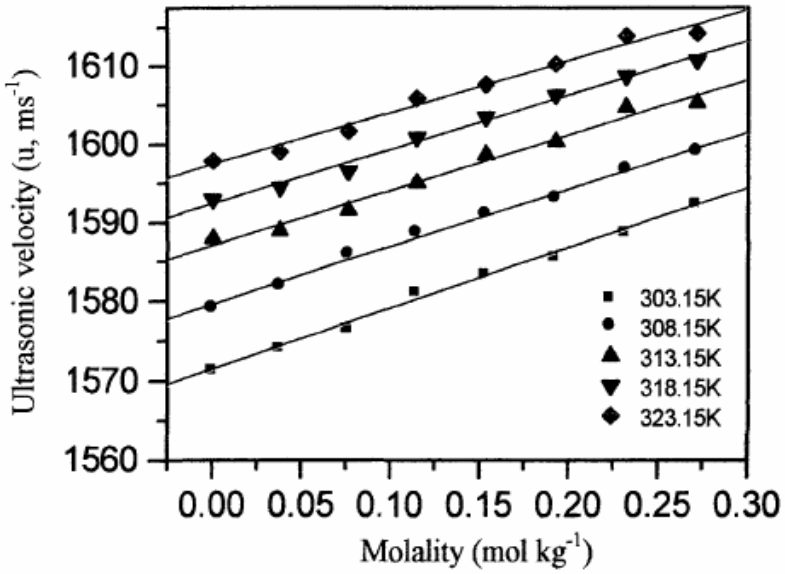


Fig.1.16: Plot of ultrasonic velocity versus concentration of L-glutamine in aqueous K_2SO_4 solution.

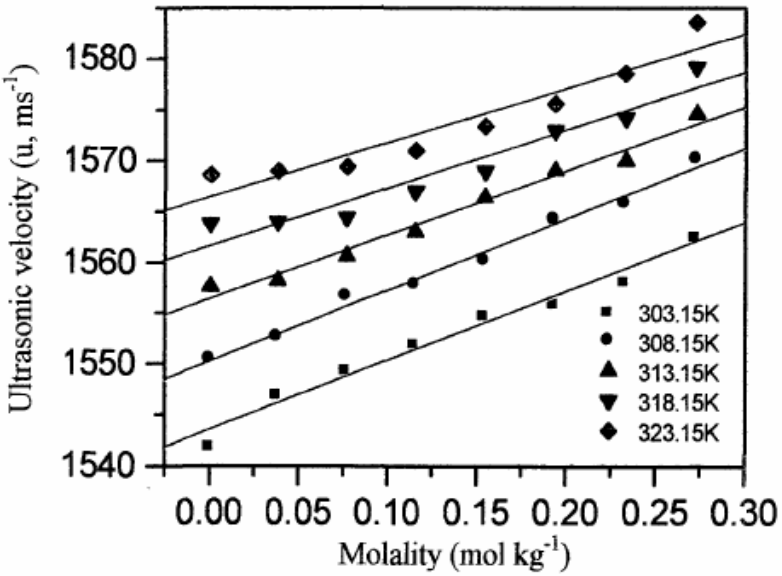


Fig.1.17: Plot of ultrasonic velocity versus concentration of L-glutamine in aqueous KNO_3 solution.

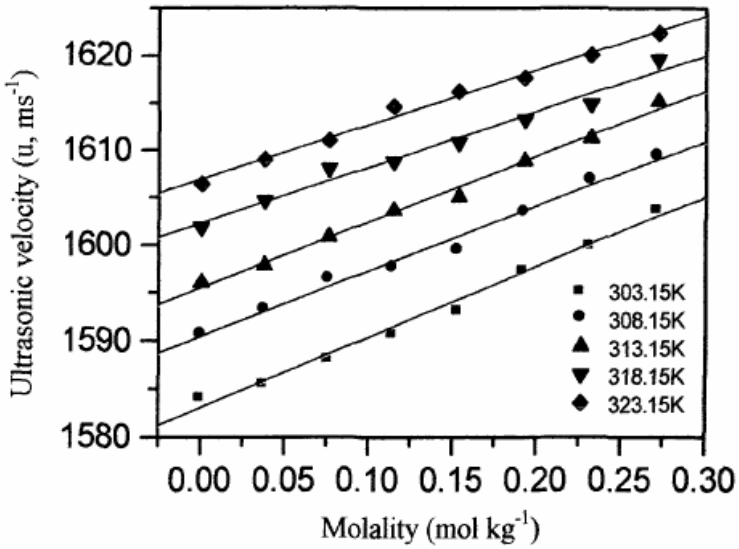


Fig.1.18: Plot of ultrasonic velocity versus concentration of L-glutamine in aqueous KCl solution.

better suited for the purpose. In the cases of L-proline as well as in L- glutamine in aqueous K2SO4 and KCl these plots are either linear or close to linear unlike those in KNO3 which exhibit a tendency for a second- order non-linear fit of the data. These values have been least-squares fitted to the equation, u = Uo + U|m + U2m^ [1.3] where UQ, U], U2; and m are the fitted coefficients and molality of solufion, respectively. The fitted coefficient values along with the standard deviation have been given in Table 1.5. The ultrasonic velocity values show an increasing trend of variation with increase in solute concentration as well as with temperature. The increase in ultrasonic velocity values with increasing concentration in test solutions may be attributed to an overall cohesion brought about by the various interactions operative in solutions (50). As is well known, the amino acid molecules are essentially zwitterions in aqueous solutions. The K'*' is the common ion in all the three electrolytes, i.e., K2SO4, KNO3 and KCl. K"^ ion will have affinity with COO' ion of zwitterions of L-isoleucine, L-proline and L-glutamine. The SO^^" NO: and cr ions of electrolytes may interact with -NH3 group of zwitterions of the said amino acids. The cations and the anions also interact with polar water molecules. The increase in concentration of solute decreases the thermal motion in solution due to the presence of more number of hydrated structures of zwitterions in solution. The ion-hydrophilic, ion-dipole, and ion-ion interactions intensify the overall cohesion in solutions, which in turn, lead to increase the ultrasonic velocity values. The increase in ultrasonic velocity with

Table 1.5: Least squares fit coefficients of the equation, u = Uo + U|m + U2m as a function of temperature

(i) L-isoIeucine in aqueous K2SO4 solution

Temperature (K)	**u_0**	**u_1**	**u_2**	**σ(u)**
298.15	1563.33	93.50	-47.78	10.2
303.15	1571.04	106.93	-89.73	4.8
308.15	1578.02	116.83	-152.95	14.0

313.15	1587.81	46.85	188.29	8.6
318.15	1592.97	16.55	378.88	13.8
323.15	1597.54	22.95	293.37	11.6

(ii) L-isoleucine in aqueous KNO3 solution

Temperature (K)	u_0	u_1	u_2	σ(u)
298.15	1530.48	80.18	161.06	12.1
303.15	1540.87	75.75	131.82	11.2
308.15	1549.69	61.91	122.82	9.0
313.15	1557.37	19.34	325.60	4.5
318.15	1563.45	9.08	440.39	10.8
323.15	1567.90	11.28	379.29	8.1

(iii) L-isoIeucine in aqueous KCI solution

Temperature (K)	u_0	u_1	u_2	σ(u)
303.15	1584.13	29.47	361.59	5.5
308.15	1589.99	44.24	238.64	8.0
313.15	1595.26	16.56	420.05	8.3
318.15	1601.93	-3.72	475.24	6.4
323.15	1606.49	-3.69	459.89	4.7

(iv) L-proIine in aqueous K2SO4 solution

Temperature (K)	u_0	u_1	u_2	σ(u)
303.15	1570.84	69.04	-7.50	9.3
308.15	1578.81	66.83	-8.94	13.6
313.15	1587.44	61.07	-7.94	17.8
318.15	1592.16	61.30	-8.57	13.8
323.15	1596.86	59.11	-6.24	10.6

(v) L-proline in aqueous KNO3 solution

Temperature (K)	u_0	u_1	u_2	σ(u)
303.15	1542.65	53.80	0.23	9.9
308.15	1548.94	48.14	6.21	13.7
313.15	1555.31	49.75	3.50	16.3
318.15	1560.80	53.42	-2.22	19.5
323.15	1565.92	50.11	-0.14	18.1

(vi) L-proiine in aqueous KCl solution

Temperature (K)	u_0	u_1	u_2	σ(u)
298.15	1575.32	53.63	5.38	17.0
303.15	1582.49	59.57	0.74	13.6
308.15	1589.54	58.99	2.11	11.1
313.15	1595.62	58.94	4.18	5.7
318.15	1601.72	54.02	2.25	2.4
323.15	1606.19	53.23	3.23	2.9

(vii) L-glutamine in aqueous K2SO4 solution

Temperature (K)	u_0	u_1	u_2	σ(u)
303.15	1571.12	78.37	-7.16	6.3
308.15	1578.82	85.56	-45.82	5.1
313.15	1586.69	71.29	-1.83	10.5
318.15	1591.88	74.04	-15.64	7.7
323.15	1596.79	74.40	-29.64	9.5

(viii) L-glutamine in aqueous KNO3 solution

Temperature (K)	u_0	u_1	u_2	σ(u)
303.15	1542.75	83.03	-55.04	10.5
308.15	1550.38	60.98	33.92	7.9
313.15	1556.85	45.85	63.48	8.4
318.15	1563.28	8.47	178.45	7.9
323.15	1568.51	-5.25	214.75	3.6

(ix) L-glutamine in aqueous KCI solution

Temperature (K)	u_0	u_1	u_2	σ(u)
303.15	1583.75	49.06	89.63	4.1
308.15	1590.78	53.39	54.64	7.3
313.15	1595.78	55.34	51.63	5.2
318.15	1602.28	52.43	25.13	10.1
323.15	1606.22	69.22	-42.29	5.2

temperature may be due to the formation of more associated clusters of water. The rise in temperature breaks the hydrogen bonding in water and forms smaller aggregates. These aggregates may have numerous cavities in which other species (non-hydrogen bonded water molecules (238) / solute molecules) may be accommodated forming compact clusters. Such clusters seem to be quite stable and, consequently, do not exhibit any perceptible change with thermal variations up to a reasonably high temperature. The solute-solvent interaction may be explained in terms of scaled particle theory (239-242) and the Kirkwood model (243). According to the scaled particle theory the dissolution of a solute molecule may be considered to be a two-step process: 1. Creation of a cavity in the solvent large enough to enclose the solute molecules. 2. Placement of the solute molecule into the cavity so that it can interact with the solvent. According to the Kirkwood model, the hydration spheres of K"^ and •COO' ions as well as those of CI, SO^" and NO; and NH^ ions will overlap with each other. Using the ultrasonic velocity and density data of solution the iscntropic compressibility, K^ values have been calculated from the Laplace relation, «:. = ^ [1-4] pu

The isentropic compressibility values recorded as functions of concentration and temperature for all the solutions are given in Table 1.6. Compressibility is known to be a powerful thermodynamic parameter for elucidating the behaviour of a solute in a solvent (244). The compressibility behaviour of solutes in solution can provide better information concerning the solute-solvent and solute-solute interactions. An examination of Table 1.6 shows that the isentropic compressibility values decrease with an increase in solute concentration as well as with temperature. The Ks values of aqueous K2SO4, KNO3 and KCl

solutions have been found to be less as compared to that of water at all the temperatures (4.48x10""^ m^N"' at 25°C) (64). The K^ values have been found to decrease with the addition of amino acids to the said aqueous electrolyte solutions. The decrease in isentropic compressibility may be attributed to an increase in the number of incompressible entities with an increase in solute concentration in solution. It may be attributed to an increase in the ion-ion, ion-zwitterions and zwitterions-water dipole interactions. The addition of solute molecules to an aqueous electrolyte solution will enhance the solute-solute and solute-solvent interactions in solution and it will cause a decrease in the isentropic compressibility values. The decrease in isentropic compressibility with increase in temperature may be ascribed lo an overall increase in cohesion forces in the systems under invesligalion. The plots of K\ with solute concentration are linear in all the cases except in those of L-isoleucine in aqueous KNO3 and KCl solutions and L-glutamine in that of aqueous KNO3 as shown in Figs. 1.19-1.27. The change in isentropic compressibility (AKS) values (245) have been obtained using the following equation,

Table 1.6: Isentropic compressibility (KJXIO , m N") as functions of
concentration and temperature

(i) L-isoIeucine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0000	38.56	38.24	37.92	37.57	37.40	37.25
0.0284	38.50	38.10	37.84	37.48	37.35	37.21
0.0474	38.30	38.00	37.75	37.43	37.27	37.15
0.0665	38.27	37.88	37.61	37.33	37.21	37.11
0.0857	38.08	37.79	37.37	37.22	37.11	36.99
0.1049	38.05	37.68	37.46	37.26	37.21	37.06
0.1243	38.02	37.65	37.36	37.15	37.01	36.88
0.1437	37.87	37.51	37.25	37.00	36.82	36.72
0.1633	37.78	37.45	37.20	36.90	36.76	36.62

(ii) L-isoleucine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0000	40.42	39.95	39.5	9	39.30	39.08
38.93						
0.0285	40.36	39.89	39.52	39.25	39.05	38.90
0.0477	40.31	39.82	39.46	39.19	39.00	38.87
0.0669	40.15	39.74	39.39	39.15	38.95	38.84
0.0862	39.95	39.52	39.21	39.09	38.92	38.77
0.1056	39.84	39.39	39.11	38.97	38.74	38.63
0.1250	39.70	39.30	39.06	38.88	38.56	38.49
0.1446	39.60	39.24	39.02	38.72	38.49	38.41
0.1642	39.51	39.11	38.85	38.67	38.42	38.36

(iii) L-isoIeucine'in aqueous KCl solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	37.55	37.31	37.12	36.93	36.80
0.0284	37.45	37.25	37.11	36.89	36.76
0.0474	37.42	37.21	37.08	36.85	36.71
0.0665	37.36	37.15	37.02	36.78	36.68
0.0856	37.27	37.05	36.93	36.74	36.64
0.1049	37.11	36.88	36.77	36.70	36.58
0.1243	37.05	36.81	36.68	36.60	36.43
0.1437	36.91	36.76	36.57	36.41	36.32
0.1632	36.79	36.65	36.49	36.31	36.21

(iv) L-proIine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	38.24	37.92	37.57	37.40	37.25
0.0953	37.90	37.57	37.29	37.13	37.01
0.2909	37.15	36.87	36.56	36.44	36.32
0.4934	36.29	36.01	35.76	35.65	35.59
0.7032	35.59	35.40	35.27	35.14	34.98
0.9206	34.93	34.81	34.72	34.56	34.44
1.1462	34.21	34.09	34.00	33.92	33.79

(v) L-proIine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	Value	Value	Value	Value	Value	Value
303.15	308.1	5	313.15	318.15	323.15	
0.0000	39.95	39.59	39.30	39.08	38.93	
0.0958	39.53	39.39	39.12	38.93	38.77	
0.1932	39.16	39.00	38.83	38.65	38.50	
0.2923	38.80	38.62	38.37	38.23	38.07	
0.3932	38.55	38.36	38.12	37.84	37.77	
0.4958	38.14	37.87	37.72	37.55	37.44	
0.6002	37.61	37.50	37.25	37.04	37.02	
0.7065	37.31	37.20	36.90	36.74	36.69	
0.8146	37.07	36.85	36.62	36.50	36.34	
0.9248	36.57	36.32	36.17	36.09	35.99	
1.0371	36.26	36.07	35.94	35.90	35.84	

(vi) L-proline in aqjie ous KCI solution

Concentration (mol kg⁻¹)	Value	Value	Value	Value	Value	Value
298.15	303.15	3	08.15	313.15	318.15	323.15
0.0000	37.82	37.55	37.31	37.12	36.93	36.80
0.0950	37.68	37.37	37.10	36.83	36.62	36.53
0.2900	37.02	36.64	36.33	36.15	36.01	35.89
0.4920	36.23	35.86	35.69	35.48	35.40	35.32
0.7015	35.45	35.22	34.97	34.85	34.77	34.72
0.9189	34.78	34.48	34.38	34.27	34.19	34.14
1.1445	34.05	33.85	33.69	33.61	33.57	33.56

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	38.24	37.92	37.57	37.40	37.25
0.0379	38.07	37.75	37.48	37.28	37.15
0.0762	37.88	37.50	37.30	37.13	36.97
0.1147	37.60	37.30	37.07	36.87	36.88
0.1535	37.43	37.13	36.84	36.69	36.58
0.1926	37.26	36.98	36.71	36.51	36.41
0.2320	37.05	36.74	36.45	36.34	36.19
0.2717	36.82	36.58	36.37	36.19	36.11

(viii) L-glutamine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	39.95	39.59	39.30	39.08	38.93
0.0381	39.64	39.41	39.20	38.99	38.83
0.0766	39.43	39.13	39.00	38.90	38.74
0.1152	39.22	38.99	38.81	38.69	38.59
0.1542	39.00	38.79	38.57	38.52	38.40
0.1934	38.86	38.52	38.36	38.25	38.22
0.2330	38.68	38.36	38.24	38.11	38.00
0.2728	38.38	38.07	37.94	37.80	37.69

(ix) L-glutamine in aqueous KCl solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	37.55	37.31	37.12	36.93	36.80
0.0379	37.46	37.16	37.01	36.76	36.64
0.0760	37.28	36.95	36.81	36.55	36.49
0.1145	37.11	36.85	36.63	36.46	36.28

0.1534	36.94	36.71	36.51	36.32	36.15
0.1925	36.70	36.47	36.29	36.16	36.03
0.2320	36.53	36.27	36.13	36.03	35.87
0.2718	36.30	36.10	35.90	35.77	35.71

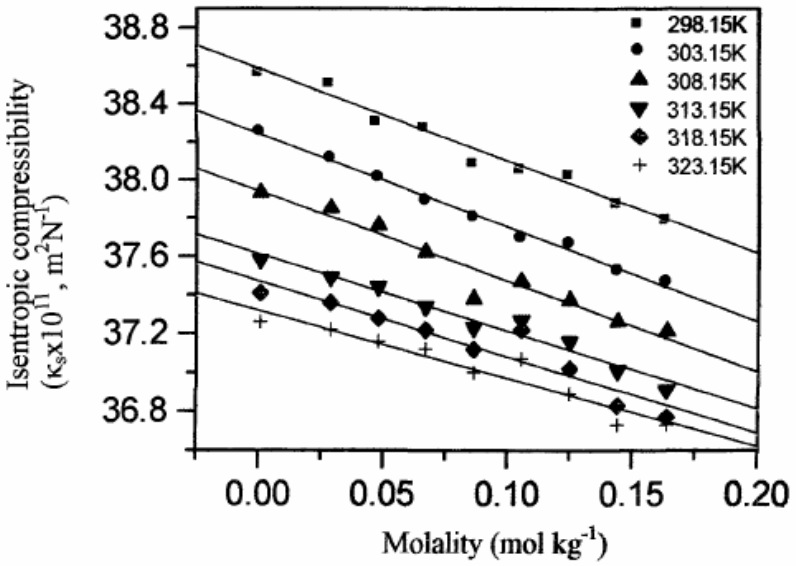


Fig.1.19: Plot of isentropic compressibility versus concentration of L-isoleucine in aqueous K_2SO_4 solution.

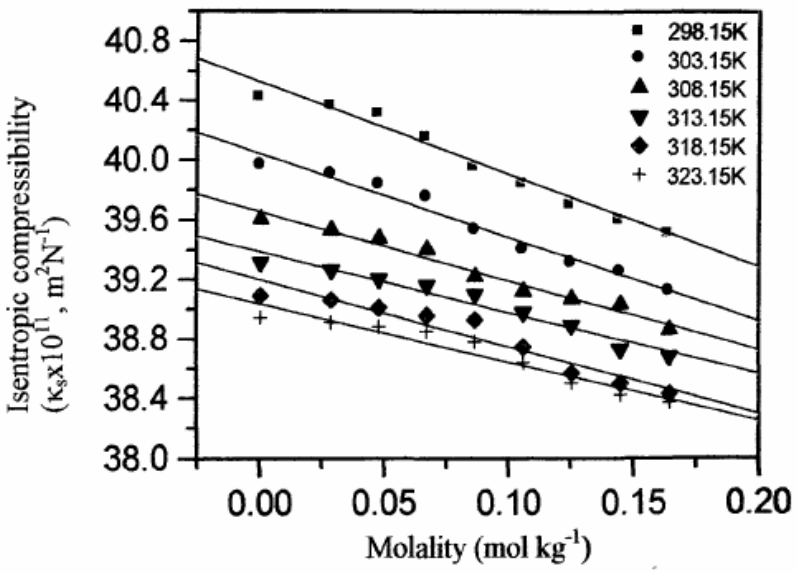


Fig.1.20: Plot of isentropic compressibility versus concentration of L-isoleucine in aqueous KNO_3 solution.

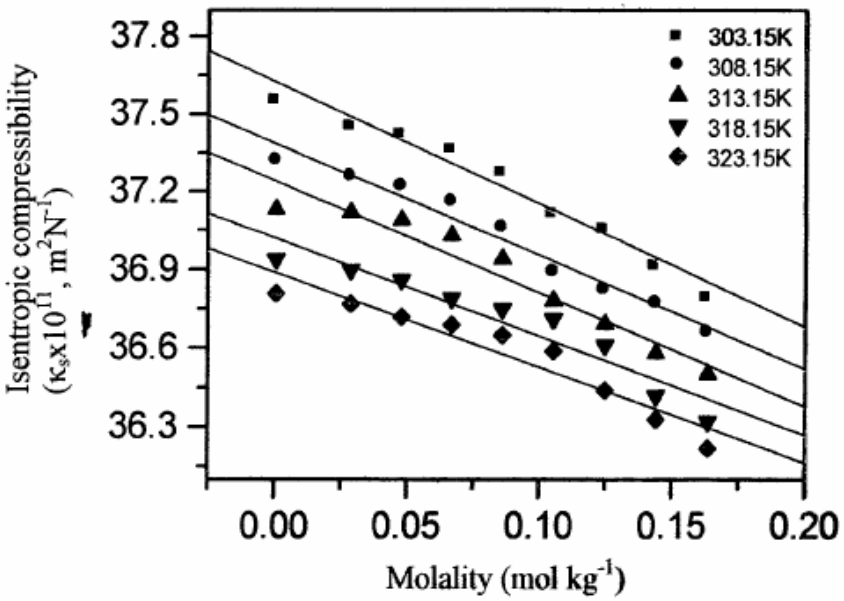


Fig.1.21: Plot of isentropic compressibility versus concentration of L-isoleucine in aqueous KCl solution.

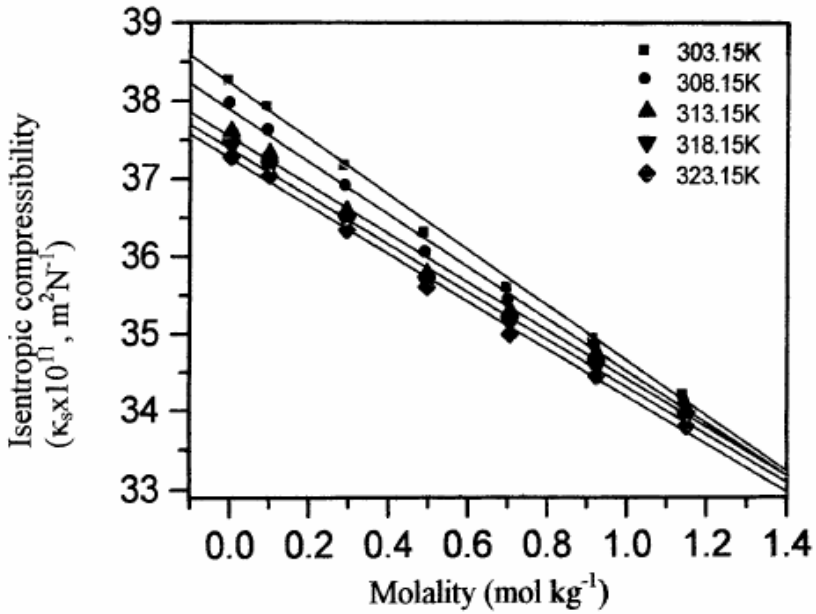


Fig.1.22: Plot of isentropic compressibility versus concentration of L-proline in aqueous K_2S0_4solution.

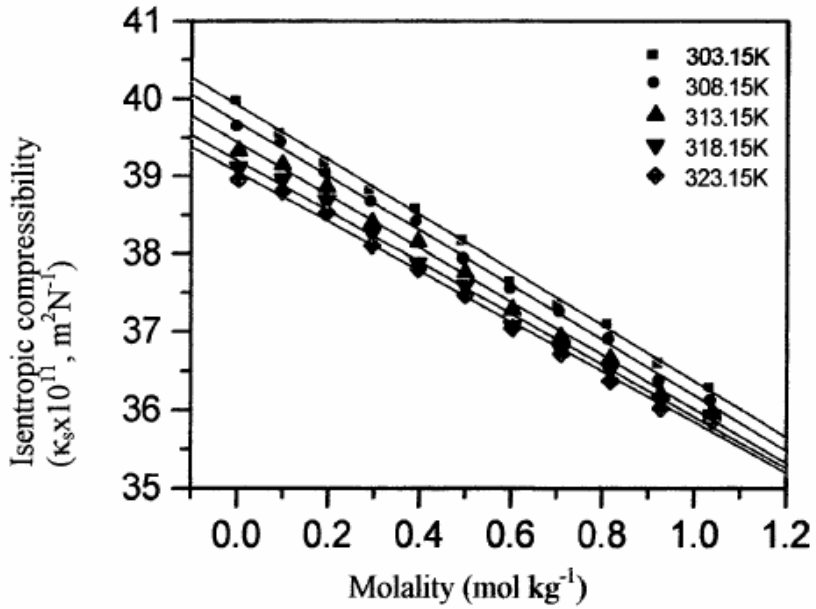


Fig.1.23: Plot of isentropic compressibility versus concentration of L-proline in aqueous KNO_3 solution.

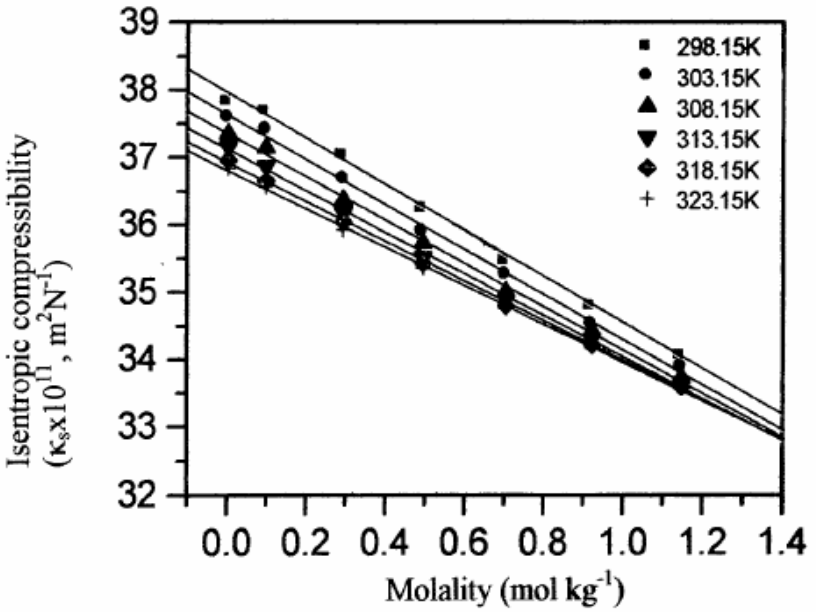


Fig.1.24: Plot of isentropic compressibility versus concentration of L-proline in aqueous KCl solution.

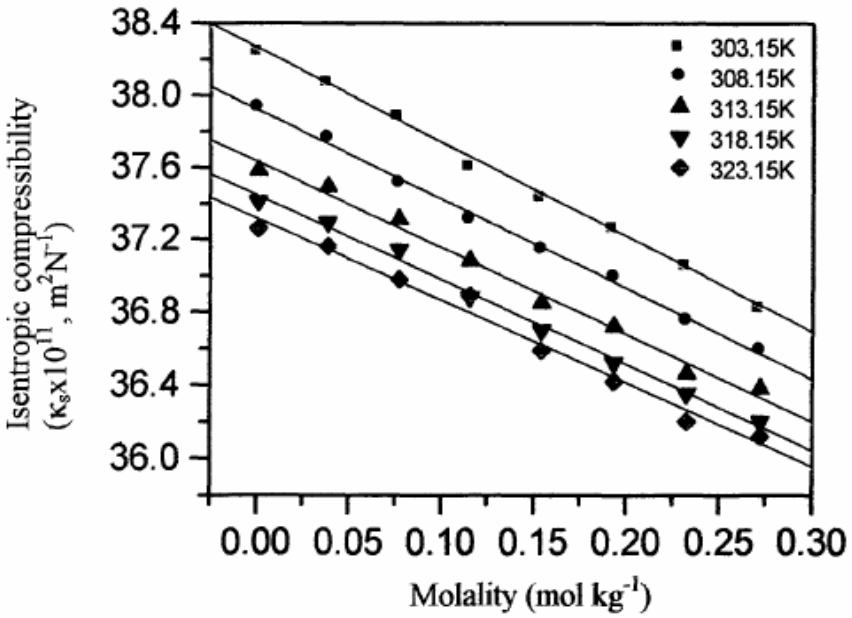


Fig.1.25: Plot of isentropic compressibility versus concentration of L-glutamine in aqueous K_2S0_4 solution.

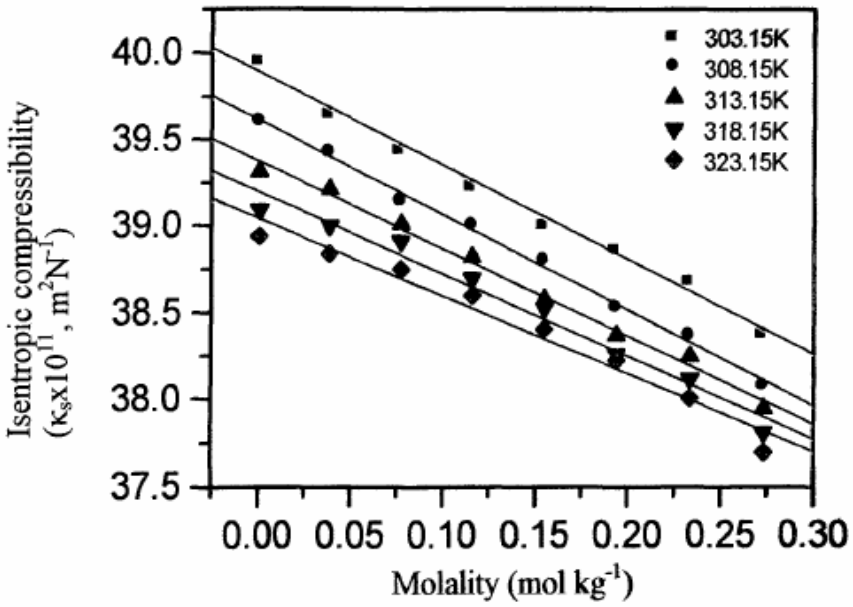


Fig.1.26: Plot of isentropic compressibility versus concentration of L-glutamine in aqueous KNO_3 solution.

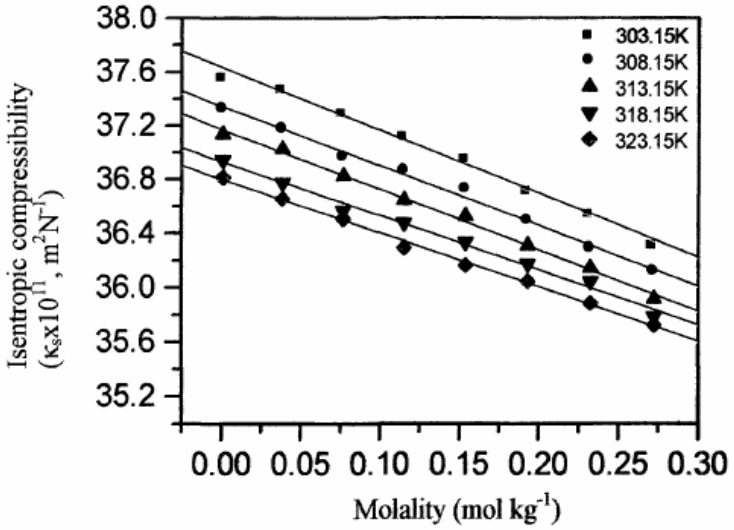


Fig.1.27: Plot of isentropic compressibility versus concentration of L-glutamine in aqueous KCl solution.

AKS= Ko-Ks = A + Bm [1.5] in which A is the intercept while B is the slope value of AKS versus m plotj whereoiKo and KS are the isentropic compressibilities of solvent and solution, respectively. The AKJ values, listed in Table 1.7, show an increase with increase in concentration of amino acids and decrease with increase in temperature in all the three systems under investigation. The plots of AKS versus solute concentration exhibit apparently linear behviour with concentration. However, a close examination of these plots suggests a non-linear fit of second-order in majority of the cases as shown in Figs. 1.28-1.36. It is noteworthy that the intercept values are either close to zero or zero as envisaged in the light of the relevant equation. Using the isentropic compressibility values of solution and solvent, the relative change in isentropic compressibility (246) has been obtained from the relation, Kr = AKS/KO = A' + B'm [1.5] where A' and B' stand for the intercept and the slope values of AKS / KQ versus m plot. The Kr values have been listed in Table 1.8. The plots of Kr with solute concentration exhibit the same pattern of behaviour as those shown in the cases of change in uevrtyopic compressibility plots (Figs. 1.37-1.45). These values represent the incompressible parts of solution. On examining the relative change in isentropic compressibility values it has been found that the values increase with increase in solute concentration and decrease with increase in temperature. Such an increase may be ascribed to an increase in the incompressible entities in the solution. Similarly, the decrease in Kr values with temperature may be interpreted as due to a decrease in the repulsive forces between the incompressible entities in solution.

Table 1.7: Change in isentropic compressibility (AKSXIO , m N") as functions of concentration and temperature

(i) L-isoleucine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0284	0.06	0.14	0.09	0.09	0.05	0.04
0.0474	0.26	0.24	0.17	0.14	0.13	0.09
0.0665	0.29	0.36	0.31	0.24	0.19	0.14

0.0857	0.48	0.45	0.55	0.35	0.29	0.26
0.1049	0.51	0.56	0.46	0.30	0.19	0.19
0.1243	0.54	0.59	0.57	0.42	0.39	0.37
0.1437	0.68	0.73	0.68	0.57	0.58	0.53
0.1633	0.78	0.80	0.72	0.67	0.64	0.53

(ii) L-isoIeucine in ji queous KNO3 solution

Concentration (mol kg⁻¹)	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0285	0.06	0.06	0.07	0.05	0.03	0.03
0.0477	0.11	0.13	0.13	0.11	0.08	0.06
0.0669	0.27	0.22	0.20	0.16	0.13	0.09
0.0862	0.47	0.43	0.38	0.22	0.15	0.16
0.1056	0.58	0.57	0.48	0.34	0.34	0.30
0.1250	0.72	0.66	0.53	0.42	0.52	0.44
0.1446	0.82	0.71	0.57	0.58	0.59	0.52
0.1642	0.91	0.84	0.74	0.64	0.66	0.58

(iii) L-isoleucine in aqueous KCl solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0284	0.11	0.06	0.02	0.04	0.04
0.0474	0.13	0.10	0.05	0.08	0.09
0.0665	0.19	0.16	0.10	0.15	0.12
0.0856	0.28	0.26	0.19	0.19	0.16
0.1049	0.44	0.42	0.35	0.37	0.37
0.1243	0.50	0.50	0.45	0.33	0.37
0.1437	0.64	0.55	0.55	0.52	0.48
0.1632	0.76	0.66	0.63	0.62	0.59

(iv) L-proIine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0953	0.34	0.35	0.28	0.27	0.24
0.2909	1.09	1.05	1.01	0.96	0.92
0.4934	1.95	1.91	1.79	1.75	1.66
0.7032	2.65	2.52	2.30	2.26	2.26
0.9206	3.31	3.11	2.85	2.84	2.8
1.1462	4.03	3.57	3.48	3.46	

(v) L-proline in aqueous KNO3 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0958	0.43	0.20	0.18	0.15	0.16
0.1932	0.79	0.59	0.47	0.43	0.43
0.2923	1.16	0.97	0.94	0.85	0.86
0.3932	1.40	1.23	1.19	1.24	1.16
0.4958	1.81	1.72	1.59	1.53	1.49
0.6002	2.34	2.09	2.05	2.03	1.91
0.7065	2.64	2.39	2.41	2.34	2.24
0.8146	2.89	2.74	2.69	2.58	2.59
0.9248	3.39	3.27	3.13	2.99	2.94
1.0371	3.69	3.52	3.37	3.18	3.03

(vi) L-proline in aqueous KCl solution

Concentration (mol kg⁻¹)	298.15	303.15	308.15	313.15	318.15	323.15
0.0950	0.14	0.18	0.21	0.29	0.31	0.27
0.2900	0.80	0.91	0.97	0.98	0.92	0.91
0.4920	1.59	1.69	1.62	1.64	1.53	1.48
0.7015	2.37	2.33	2.34	2.27	2.16	2.08
0.9189	3.04	3.07	2.93	2.85	2.75	2.66
1.1445	3.77	3.70	3.62	3.51	3.36	3.24

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0379	0.18	0.17	0.09	0.12	0.10
0.0762	0.36	0.42	0.27	0.27	0.28
0.1147	0.64	0.62	0.50	0.53	0.53
0.1535	0.81	0.79	0.73	0.71	0.67
0.1926	0.98	0.95	0.86	0.89	0.84
0.2320	1.19	1.18	1.12	1.06	1.06
0.2717	1.42	1.34	1.20	1.21	1.13

(viii) L-glutamine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0381	0.32	0.18	0.10	0.08	0.10
0.0766	0.52	0.46	0.30	0.18	0.19
0.1152	0.73	0.60	0.49	0.38	0.34
0.1542	0.96	0.80	0.74	0.56	0.54
0.1934	1.09	1.07	0.94	0.83	0.71

0.2330	1.28	1.23	1.06	0.97	0.93
0.2728	1.58	1.52	1.36	1.28	1.24

(ix) L-glutamine in aqueous KCl solution

Concentration (mol kg^{-1})	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0379	0.09	0.15	0.12	0.18	0.16
0.0760	0.27	0.35	0.31	0.38	0.31
0.1145	0.44	0.46	0.49	0.47	0.52
0.1534	0.61	0.60	0.61	0.61	0.65
0.1925	0.85	0.83	0.84	0.77	0.77
0.2320	1.02	1.04	1.00	0.90	0.93
0.2718	1.25	1.21	1.23	1.17	1.09

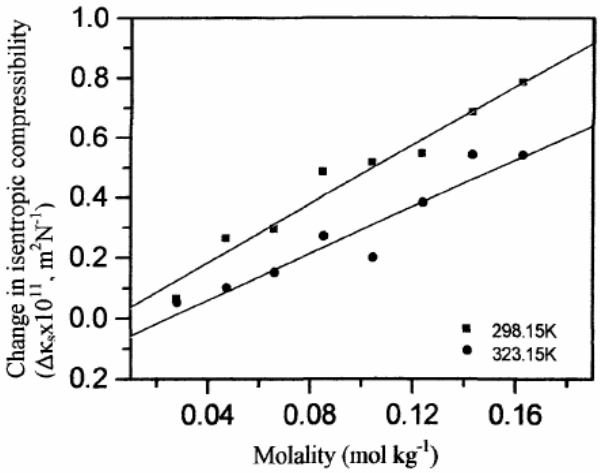


Fig.1.28: Plot of change in isentropic compressibility versus concentration of L-isoleucine in aqueous K_2SO_4 solution.

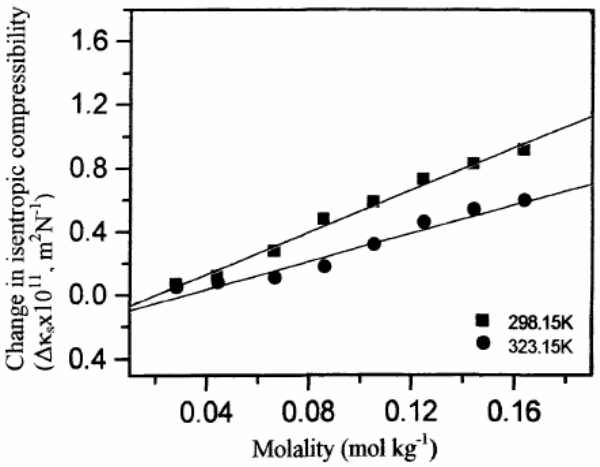


Fig.1.29: Plot of change in isentropic compressibility versus concentration of L-isoleucine in aqueous KNO_3 solution.

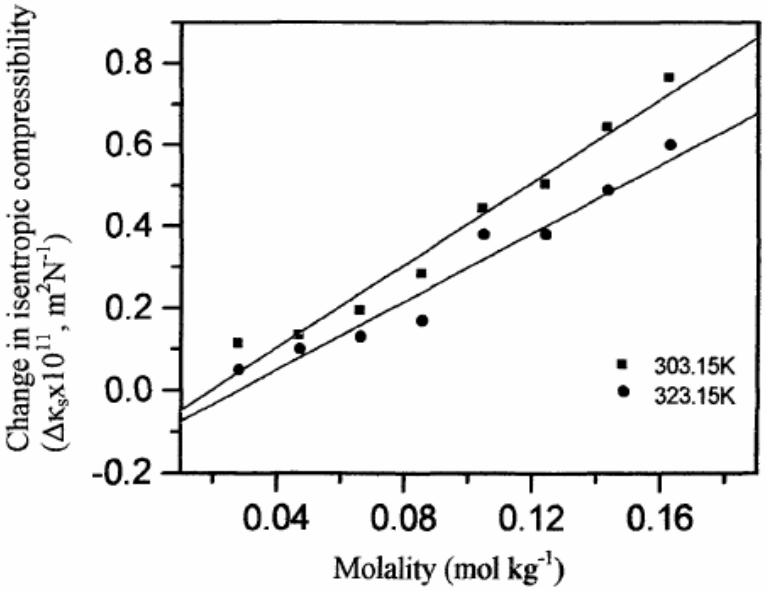


Fig.1.30: Plot of change in isentropic compressibility versus concentration of L-isoleucine in aqueous KCl solution.

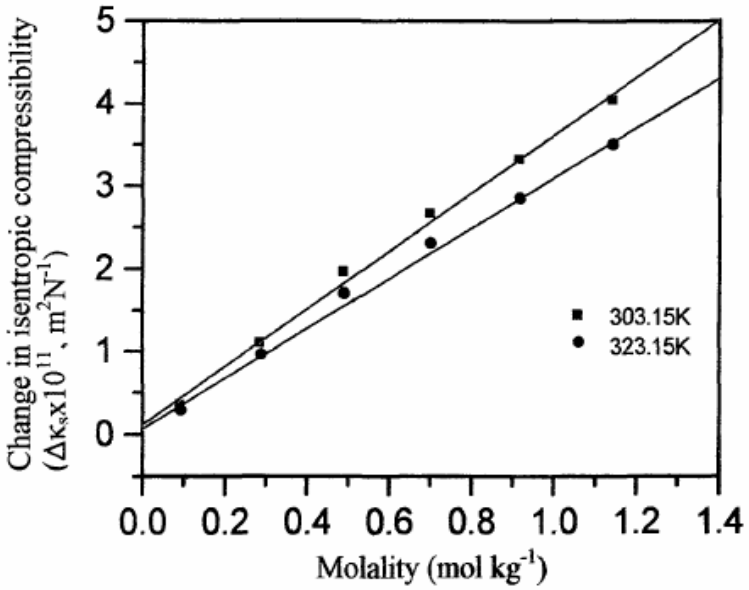


Fig.1.31: Plot of change in isentropic compressibility versus concentration of L-proline in aqueous K_2SO_4 solution.

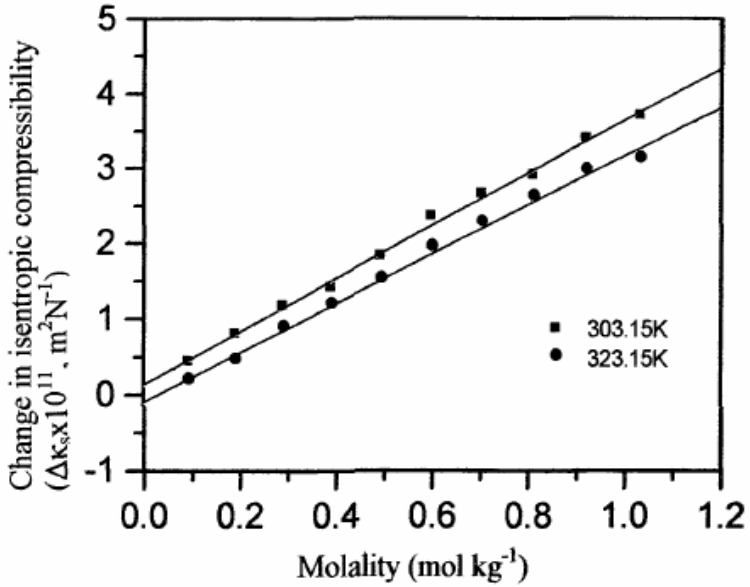


Fig.1.32: Plot of change in isentropic compressibility versus concentration of L-proline in aqueous KNO_3 solution.

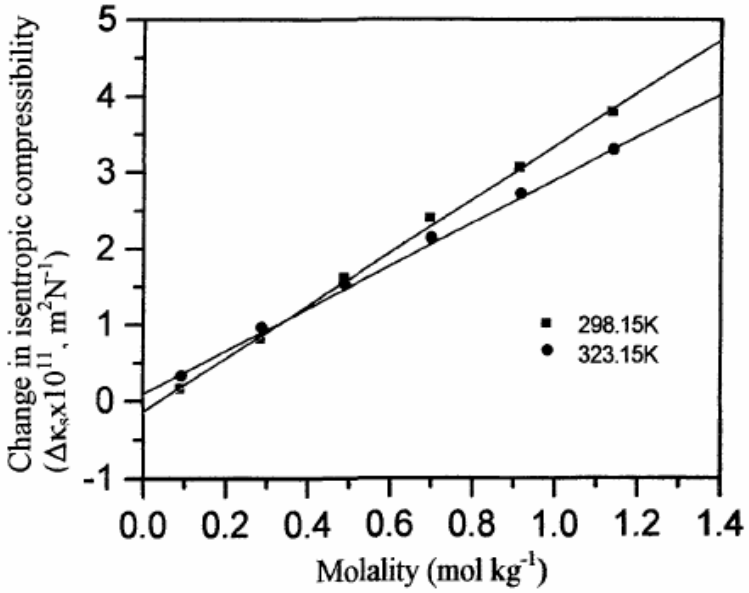


Fig.1.33: Plot of change in isentropic compressibility versus concentration of L-proline in aqueous KCl solution.

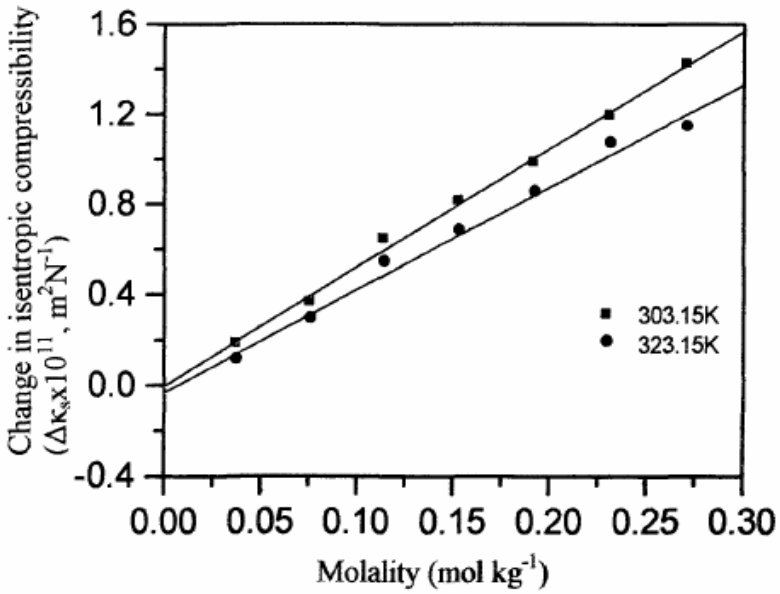


Fig.1.34: Plot of change in isentropic compressibility versus concentration of L-glutamine in aqueous K_2SO_4 solution.

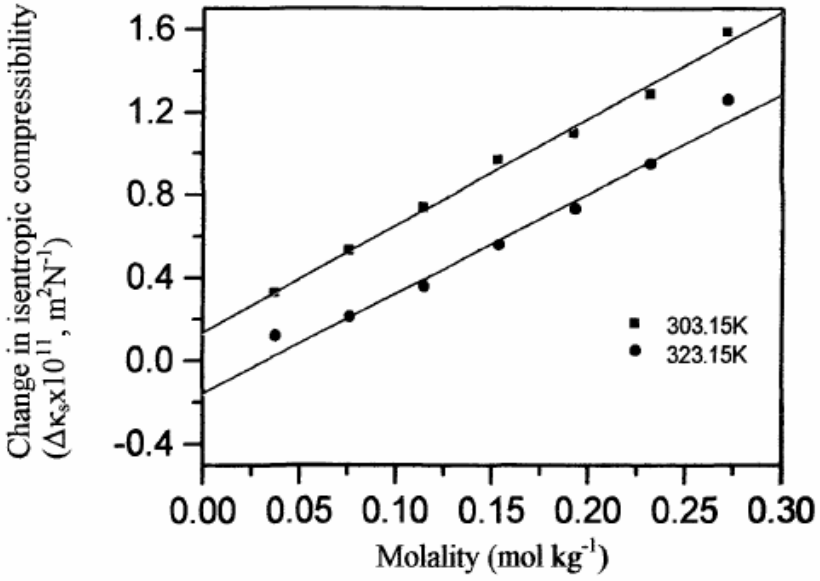


Fig.1.35: Plot of change in isentropic compressibility versus concentration of L-glutamine in aqueous KNO_3 solution.

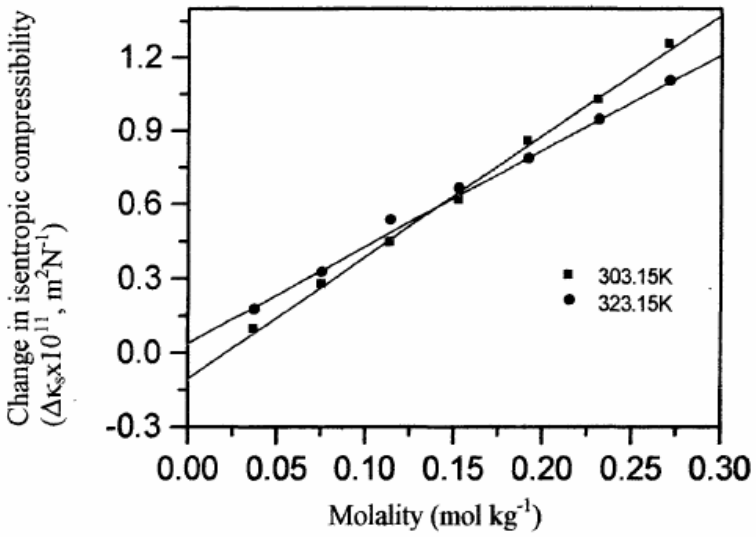


Fig.1.36: Plot of change in isentropic compressibility versus concentration of L-glutamine in aqueous KCl solution.

Table 1.8: Relative change in isentropic compressibility, (AKS/KO) xlO as functions of concentration and temperature

(i) L-isoleucine in aqueous K2SO4 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0284	0.15	0.37	0.23	0.23	0.14	0.09
0.0474	0.67	0.62	0.45	0.36	0.35	0.25
0.0665	0.75	0.95	0.82	0.63	0.51	0.38
0.0857	1.24	1.17	1.45	0.93	0.78	0.70
0.1049	1.31	1.48	1.22	0.81	0.51	0.51
0.1243	1.39	1.54	1.49	1.12	1.04	0.99
0.1437	1.77	1.92	1.78	1.51	1.55	1.41
0.1633	2.02	2.08	1.91	1.77	1.72	1.42

(ii) L-isoleucine in aqueous KNO3 solution

Concentration (mol kg^{-1})	298.15	303.15	308.15	313.15	318.15	323.15
0.0285	0.15	0.15	0.17	0.13	0.08	0.08
0.0477	0.27	0.33	0.34	0.29	0.20	0.15
0.0669	0.67	0.54	0.50	0.40	0.32	0.24
0.0862	1.16	1.09	0.96	0.56	0.39	0.41
0.1056	1.43	1.42	1.22	0.85	0.87	0.77
0.1250	1.79	1.64	1.33	1.08	1.33	1.13
0.1446	2.03	1.78	1.45	1.47	1.51	1.35
0.1642	2.24	2.11	1.88	1.62	1.69	1.48

(iii) L-isoIeucine in aqueous KCl solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0284	0.28	0.17	0.04	0.12	0.12
0.0474	0.35	0.26	0.12	0.21	0.24
0.0665	0.50	0.44	0.27	0.41	0.33
0.0856	0.73	0.69	0.52	0.51	0.44
0.1049	1.17	1.14	0.95	0.63	0.61
0.1243	1.34	1.34	1.21	0.90	1.00
0.1437	1.71	1.46	1.49	1.41	1.31
0.1632	2.02	1.77	1.69	1.67	1.59

(iv) L-proline in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0953	0.88	0.93	0.74	0.72	0.64
0.2909	2.85	2.78	2.68	2.57	2.48
0.4934	5.11	5.04	4.77	4.67	4.45
0.7032	6.93	6.65	6.12	6.04	6.08
0.9206	8.65	8.20	7.58	7.60	7.55
1.1462	10.54	10.10	9.50	9.31	9.29

(v) L-proline in aqueous KNO3 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0958	1.07	0.51	0.46	0.38	0.41
0.1932	1.99	1.48	1.20	1.10	1.11
0.2923	2.90	2.46	2.38	2.17	2.21
0.3932	3.51	3.11	3.02	3.17	2.99
0.4958	4.54	4.35	4.04	3.91	3.83
0.6002	5.86	5.29	5.22	5.20	4.92
0.7065	6.61	6.03	6.13	5.98	5.76
0.8146	7.23	6.93	6.83	6.60	6.66
0.9248	8.47	8.26	7.97	7.65	7.56
1.0371	9.24	8.90	8.57	8.14	7.93

(vi) L-proIine in aqueous KCI solution

Concentration (mol kg⁻¹)	298.15	303.15	308.15	313.15	318.15	323.15
0.0950	0.37	0.48	0.56	0.78	0.83	0.75
0.2900	2.13	2.42	2.61	2.63	2.49	2.48
0.4920	4.20	4.51	4.34	4.42	4.15	4.03
0.7015	6.26	6.20	6.26	6.13	5.85	5.67

0.9189	8.03	8.17	7.86	7.68	7.43	7.22
1.1445	9.98	9.87	9.70	9.47	9.09	8.80

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0379	0.46	0.46	0.24	0.31	0.27
0.0762	0.93	1.12	0.72	0.71	0.75
0.1147	1.67	1.63	1.33	1.42	1.43
0.1535	2.12	2.10	1.93	1.89	1.79
0.1926	2.56	2.50	2.28	2.38	2.26
0.2320	3.11	3.11	2.97	2.83	2.85
0.2717	3.72	3.54	3.20	3.23	3.05

(viii) L-glutamine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0381	0.80	0.46	0.26	0.22	0.25
0.0766	1.31	1.17	0.76	0.46	0.49
0.1152	1.83	1.52	1.25	0.99	0.88
0.1542	2.39	2.02	1.88	1.43	1.37
0.1934	2.73	2.71	2.40	2.13	1.84
0.2330	3.20	3.11	2.71	2.47	2.39
0.2728	3.94	3.84	3.46	3.27	3.19

(ix) L-glutamine in aqueous KCI solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0379	0.24	0.40	0.31	0.48	0.44
0.0760	0.72	0.95	0.83	1.02	0.83
0.1145	1.18	1.24	1.33	1.27	1.43
0.1534	1.62	1.61	1.64	1.65	1.77
0.1925	2.27	2.24	2.25	2.09	2.09
0.2320	2.73	2.80	2.69	2.44	2.52
0.2718	3.32	3.25	3.30	3.16	2.96

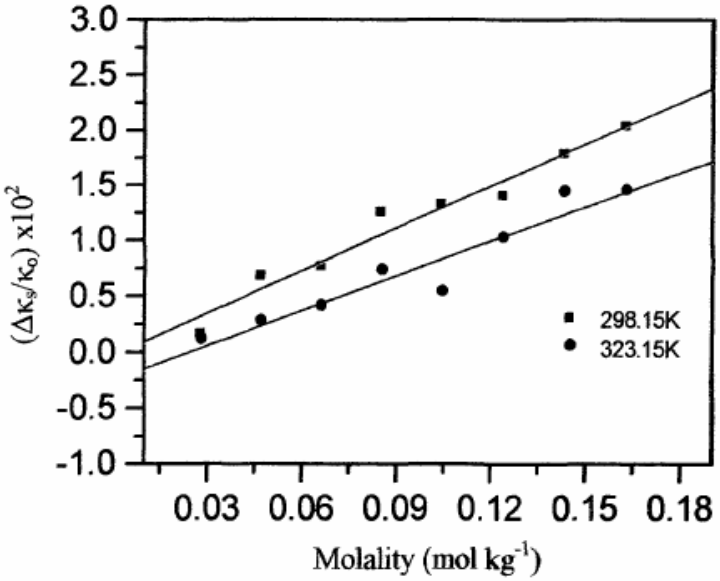


Fig 1.37: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-isoleucine in aqueous K_2SO_4 solution.

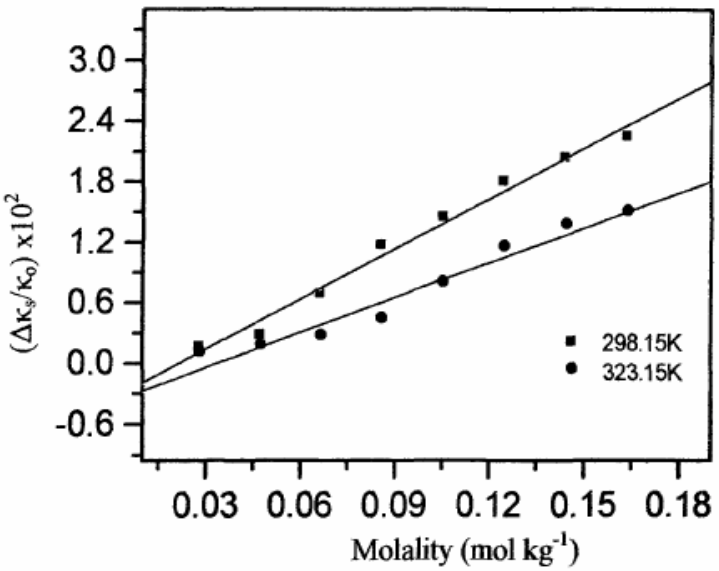


Fig 1.38: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-isoleucine in aqueous KNO_3 solution.

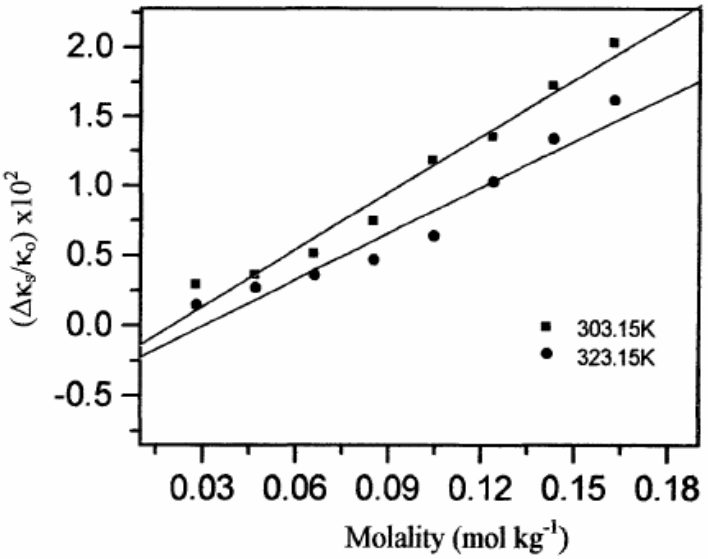


Fig 1.39: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-isoleucine in aqueous KCl solution.

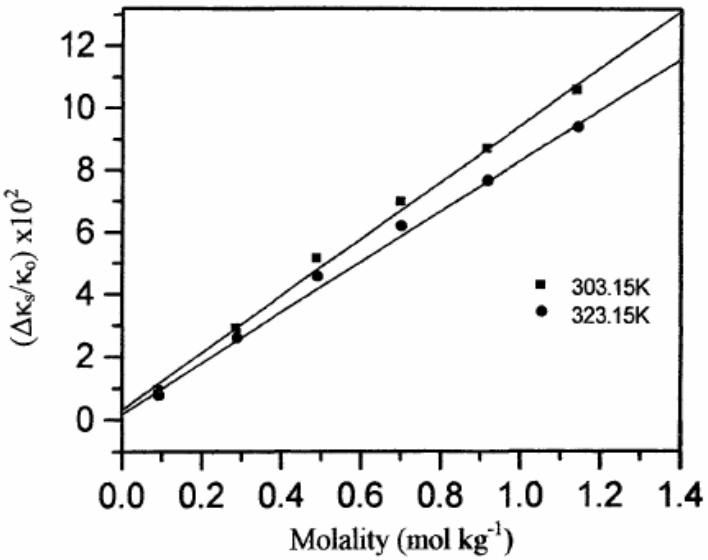


Fig 1.40: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-proline in aqueous K_2SO_4 solution.

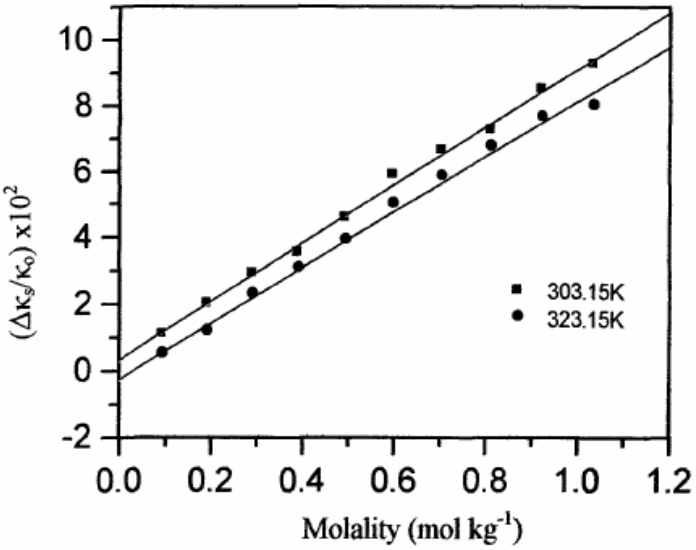


Fig 1.41: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-proline in aqueous KNO_3 solution.

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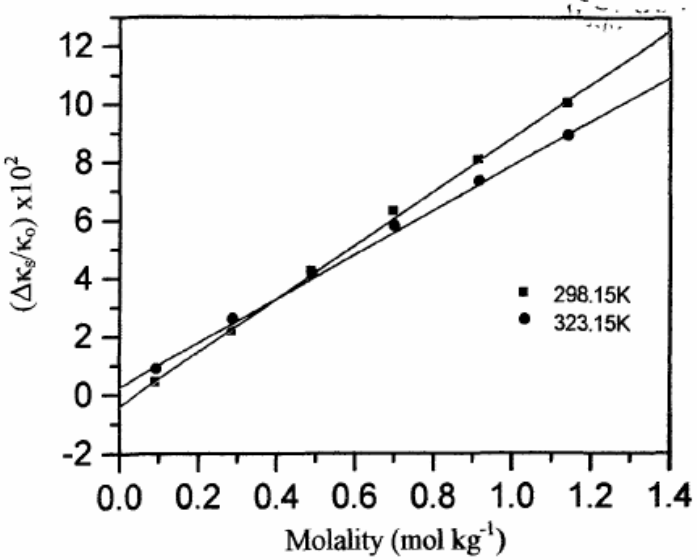


Fig 1.42: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-proline in aqueous KCl solution.

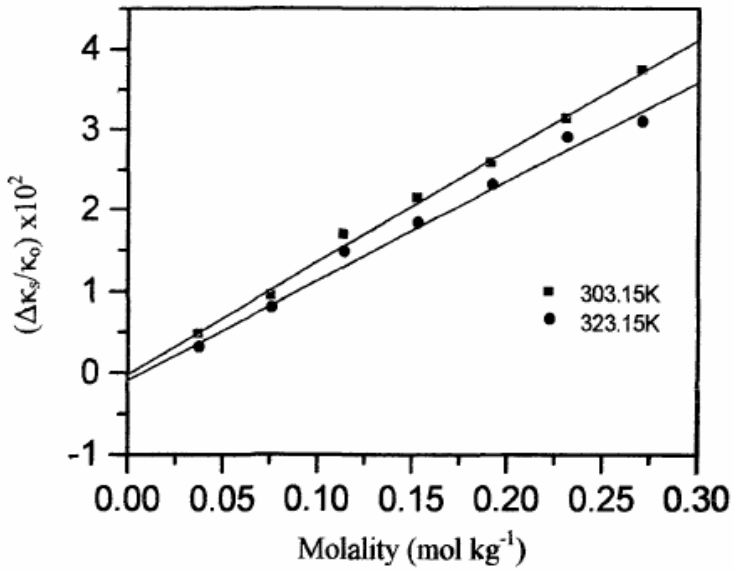


Fig 1.43: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-glutamine in aqueous K_2SO_4 solution.

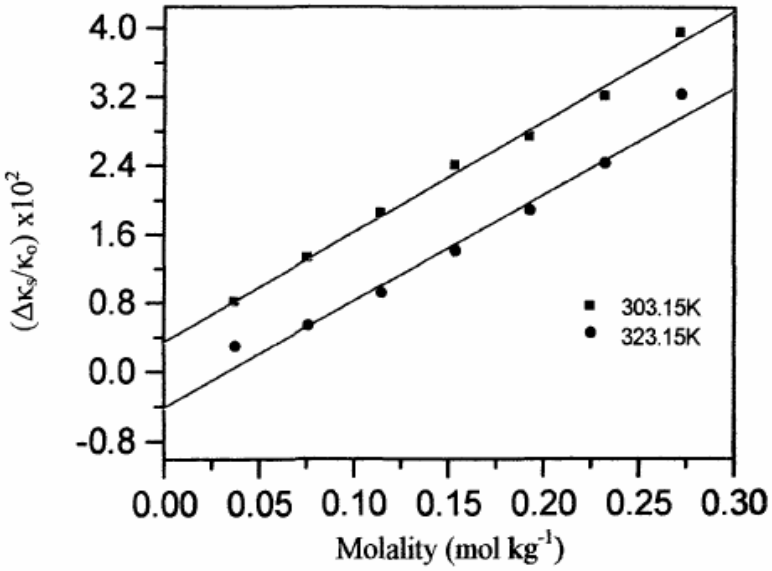


Fig 1.44: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-glutamine in aqueous KNO_3 solution.

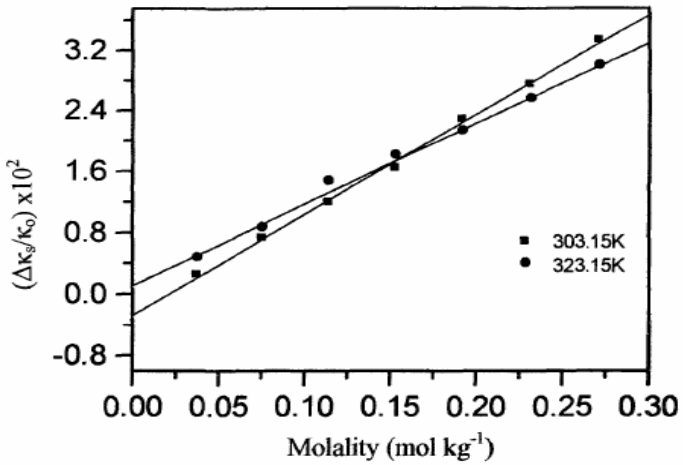


Fig 1.45: Plot of $\Delta\kappa_s/\kappa_o$ versus concentration of L-glutamine in aqueous KCl solution.

The specific acoustic impedance (Z) is also known to be an important thermodynamic parameter, which is employed in understanding the various types of interactions in solutions. The Z values have been obtained by using the following relations (247), Zo = poUo [1.6] Z = pu [1.7] where po and UQ are the density and ultrasonic velocity values of solvents while p and u are the density and ultrasonic velocity of solution, respectively. The calculated values are given in Table 1.9. The Z values have been found to increase with increase in concentration as well as increase in temperature. Such a trend of variation may be ascribed to an overall reduction in the repulsive forces with increases in concentration and temperature. The plots of Z versus solute concentration show a linear behaviour in almost all the systems under investigation (Figs. 1.46-1.54). The values of density and ultrasound velocity have enabled to estimate the magnitude of relative association, RA (248) using the relation, RA = -L(%/-\ [1.8] Po U The values of relative association thus obtained as functions of temperature and concentration are listed in Table 1.10. It may be noted that no pronounced change has been observed for RA values with variations in concentration of solute and temperature. This may be attributed to the presence of essentially weak interactions in solutions.

Table 1.9: Specific acoustic impedance (Z xlO' , kg m" s") as functions of concentration and temperature

(i) L-isoleucine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0000	1658.6	1664.4	1670.4	1676.7	1678.9	1680.5
0.0284	1660.2	1667.8	1672.4	1678.8	1680.3	1681.5
0.0474	1664.9	1670.1	1674.4	1680.1	1682.1	1682.9
0.0665	1665.8	1673.2	1677.7	1682.5	1683.6	1683.9
0.0857	1670.2	1675.2	1683.2	1685.1	1686.0	1686.8
0.1049	1671.1	1678.0	1681.4	1684.2	1683.7	1685.3
0.1243	1672.1	1678.8	1683.8	1686.9	1688.3	1689.4
0.1437	1675.6	1682.2	1686.4	1690.4	1692.8	1693.2
0.1633	1677.9	1683.9	1687.7	1692.9	1694.3	1693.3

(ii) L-isoleucine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	298.15	303.15	308.15	313.15	318.15	323.15
0.0000	1615.1	1623.4	1629.4	1633.7	1636.6	1637.7
0.0285	1616.8	1625.0	1631.1	1635.0	1637.5	1638.6
0.0477	1618.0	1626.6	1632.7	1636.5	1638.7	1639.3
0.0669	1621.6	1628.6	1634.2	1637.5	1639.8	1640.1
0.0862	1625.8	1633.3	1638.2	1639.1	1640.5	1641.7
0.1056	1628.3	1636.3	1640.5	1641.7	1644.6	1644.8
0.1250	1631.6	1638.3	1641.6	1643.7	1648.6	1648.0
0.1446	1633.9	1639.8	1642.7	1647.1	1650.3	1650.0
0.1642	1636.0	1642.8	1646.6	1648.5	1651.9	1651.2

(iii) L-isoleucine in aqueous KCl solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	1681.3	1685.3	1688.0	1690.6	1691.8
0.0284	1683.9	1687.0	1688.6	1691.9	1693.0
0.0474	1684.9	1688.0	1689.5	1692.8	1694.1
0.0665	1686.2	1689.8	1690.9	1694.6	1695.1
0.0856	1688.6	1692.0	1693.1	1695.6	1696.1
0.1049	1692.6	1696.0	1697.0	1696.7	1697.7
0.1243	1694.2	1697.9	1699.3	1699.2	1701.2
0.1437	1697.7	1699.3	1701.9	1703.7	1704.0
0.1632	1700.5	1702.0	1703.9	1706.2	1706.7

(iv) L-proIine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	1664.4	1670.2	1676.7	1678.9	1680.5
0.0953	1672.8	1679.0	1684.1	1686.2	1687.1
0.2909	1693.8	1699.1	1704.8	1706.1	1707.0
0.4934	1717.9	1723.2	1727.5	1728.8	1728.5
0.7032	1738.8	1742.2	1744.0	1745.5	1747.5
0.9206	1759.3	1761.0	1761.8	1764.2	1765.5
1.1462	1782.0	1783.7	1784.5	1784.9	1786.4

(v) L-proline in aqueous KNO3 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0000	1623.4	1629.4	1633.7	1636.6	1637.7
0.0958	1633.3	1635.5	1639.3	1641.6	1643.0
0.1932	1643.7	1645.5	1647.5	1649.5	1650.8

0.2923	1653.6	1655.9	1659.5	1660.6	1662.0
0.3932	1660.8	1663.4	1667.0	1671.2	1670.7
0.4958	1671.9	1676.2	1677.9	1679.6	1680.1
0.6002	1685.7	1686.7	1690.4	1693.1	1691.5
0.7065	1694.5	1695.3	1700.6	1702.1	1701.2
0.8146	1702.4	1705.6	1709.2	1709.8	1711.4
0.9248	1716.0	1719.9	1721.9	1721.6	1721.8
1.0371	1725.3	1728.1	1729.5	1728.2	1727.3

(vi) L-proIine in aqueous KCI solution

Concentration (mol kg⁻¹)	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0000	1676.4	1681.3	1685.3	1688.0	1690.6	1691.8
0.0950	1680.7	1686.6	1691.5	1696.1	1699.1	1699.4
0.2900	1690.4	1707.0	1712.9	1715.8	1717.1	1718.1
0.4920	1721.5	1729.4	1732.0	1735.4	1735.7	1735.7
0.7015	1744.2	1748.6	1753.4	1754.9	1755.0	1754.3
0.9189	1764.6	1771.2	1772.4	1773.4	1773.7	1772.7
1.1445	1787.5	1791.5	1794.2	1794.6	1793.5	1791.7

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0000	1664.4	1670.2	1676.7	1678.9	1680.5
0.0379	1669.1	1674.9	1679.6	1682.5	1683.9
0.0762	1674.5	1681.9	1685.1	1687.2	1689.2
0.1147	1682.2	1687.7	1691.6	1694.6	1696.3
0.1535	1687.5	1693.1	1698.1	1700.0	1700.8
0.1926	1692.7	1697.9	1702.6	1705.6	1706.1
0.2320	1699.0	1704.7	1710.0	1710.9	1712.7
0.2717	1705.9	1709.9	1713.3	1715.7	1715.7

(viii) L-glutamine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0000	1623.4	1629.4	1633.7	1636.6	1637.7
0.0381	1631.1	1634.7	1637.3	1639.9	1641.4
0.0766	1637.0	1642.2	1643.1	1643.5	1645.0
0.1152	1643.1	1646.7	1648.8	1649.5	1649.8
0.1542	1649.4	1652.5	1655.6	1654.9	1655.5
0.1934	1654.0	1660.0	1661.7	1662.5	1660.9
0.2330	1659.6	1665.2	1665.9	1667.0	1667.3
0.2728	1667.7	1673.2	1674.1	1675.5	1675.7

(ix) L-glutamine in aqueous KCl solution

Concentration (mol kg^{-1})	303.15	308.15	313.15	318.15	323.15
0.0000	1681.3	1685.3	1688.0	1690.6	1691.8
0.0379	1683.9	1689.4	1691.4	1695.6	1696.5
0.0760	1689.2	1695.3	1697.1	1701.5	1701.2
0.1145	1694.3	1699.0	1702.7	1705.0	1707.6
0.1534	1699.3	1703.5	1706.5	1709.5	1711.8
0.1925	1706.1	1710.1	1713.2	1714.6	1715.9
0.2320	1711.3	1716.3	1718.3	1718.9	1721.0
0.2718	1717.8	1721.5	1725.1	1726.6	1726.2

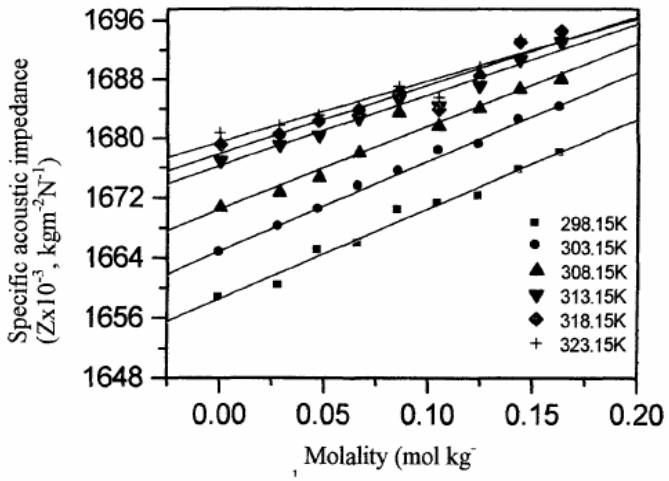


Fig.1.46: Plot of specific acoustic impedance versus concentration of L-isoleucine in aqueous K_2SO_4 solution.

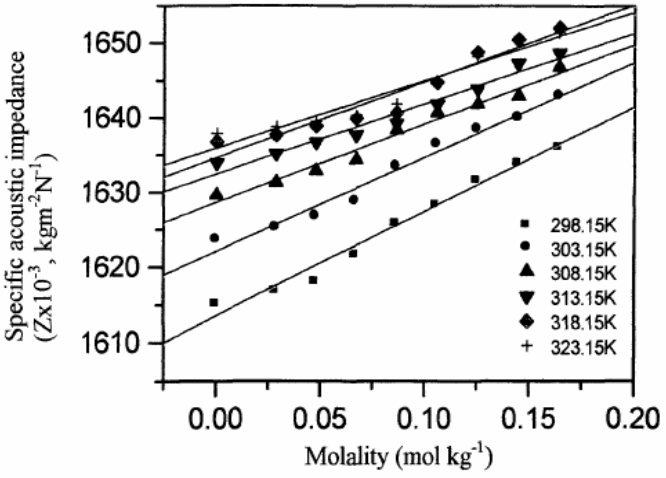


Fig.1.47: Plot of specific acoustic impedance versus concentration of L-isoleucine in aqueous KNO_3 solution.

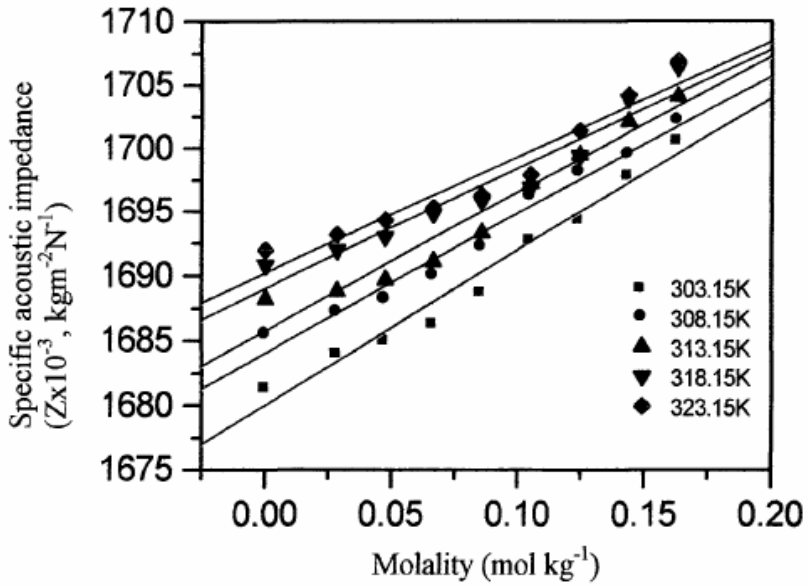


Fig.1.48: Plot of specific acoustic impedance versus concentration of L-isoleucine in aqueous KCl solution.

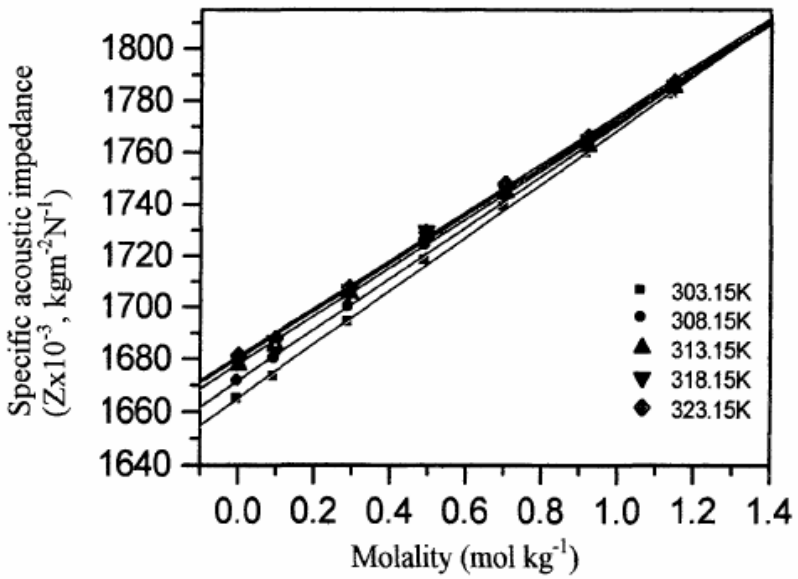


Fig.1.49: Plot of specific acoustic impedance versus concentration of L-proline in aqueous K_2SO_4 solution.

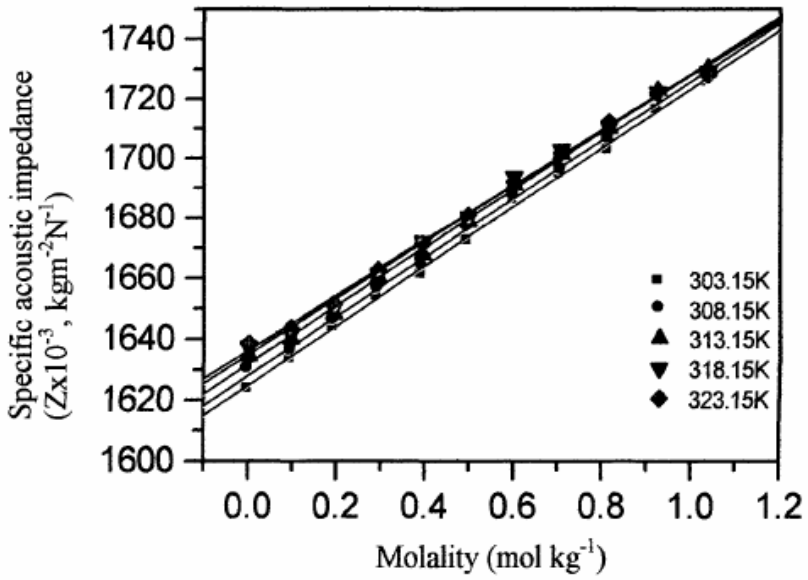


Fig.1.50: Plot of specific acoustic impedance versus concentration of L-proline in aqueous KNO_3 solution.

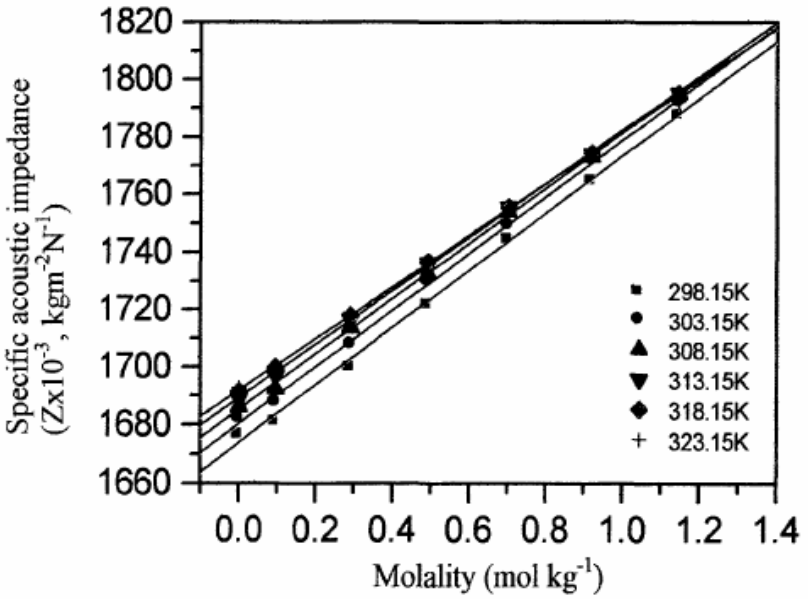


Fig.1.51: Plot of specific acoustic impedance versus concentration of L-proline in aqueous KCl solution.

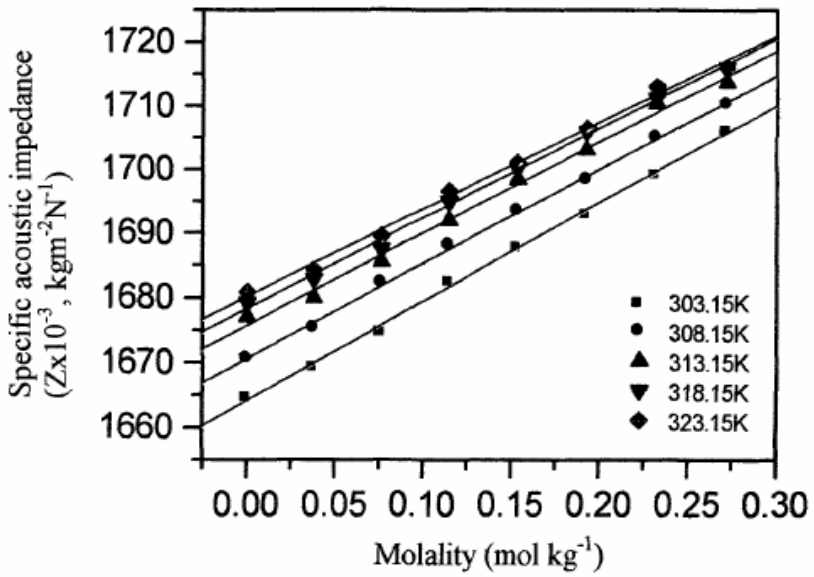


Fig.1.52: Plot of specific acoustic impedance versus concentration of L-glutamine in aqueous K_2SO_4 solution.

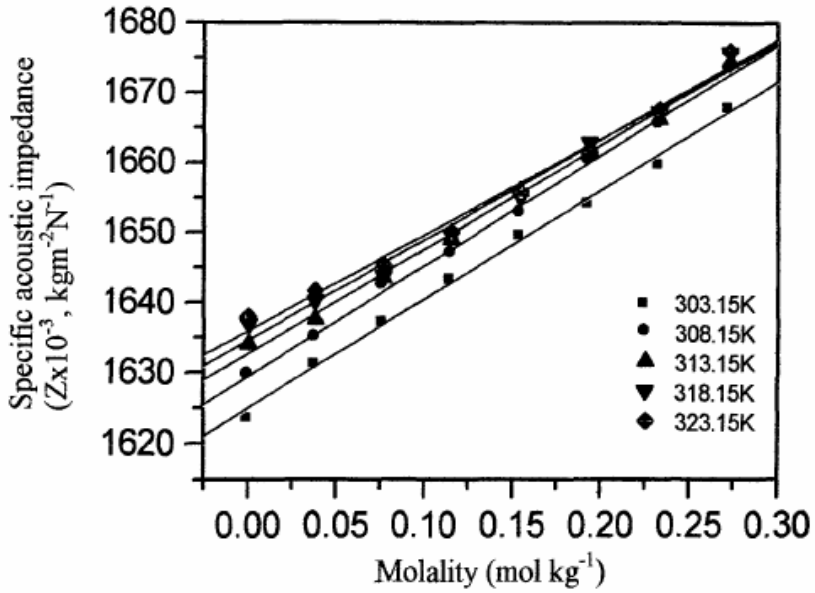


Fig.1.53: Plot of specific acoustic impedance versus concentration of L-glutamine in aqueous KNO_3 solution.

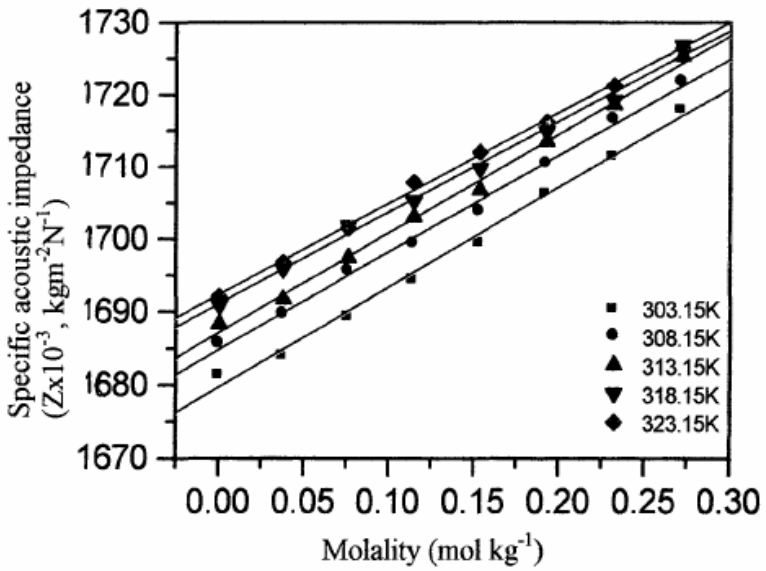


Fig.1.54: Plot of specific acoustic impedance versus concentration of L-glutamine in aqueous KCl solution.

Table 1.10: Relative association (RA) as functions of concentration and temperature

(i) L-isoIeucine in aqueous K2SO4 solution

Concentration (mol kg^{-1})	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0284	1.0003	0.9998	0.9999	0.9999	1.0000	1.0001
0.0474	0.9999	0.9997	0.9998	0.9998	0.9997	0.9999
0.0665	1.0001	0.9995	0.9994	0.9996	0.9996	0.9997
0.0857	0.9997	0.9994	0.9986	0.9993	0.9994	0.9994
0.1049	1.0000	0.9992	0.9992	0.9996	0.9998	0.9998
0.1243	1.0002	0.9994	0.9989	0.9992	0.9990	0.9991
0.1437	1.0000	0.9990	0.9985	0.9988	0.9984	0.9985
0.1633	0.9999	0.9991	0.9987	0.9986	0.9983	0.9986

(ii) L-isoIeucine in aqueous KNO3 solution

Concentration (mol kg^{-1})	**298.15**	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0285	1.0004	1.0003	1.0002	1.0001	1.0002	1.0002
0.0477	1.0005	1.0002	1.0001	1.0002	1.0002	1.0003
0.0669	1.0003	1.0003	1.0002	1.0001	1.0002	1.0003
0.0862	0.9998	0.9996	0.9997	1.0002	1.0003	1.0002
0.1056	0.9998	0.9995	0.9994	0.9999	0.9997	0.9997
0.1250	0.9995	0.9993	0.9995	0.9998	0.9991	0.9995
0.1446	0.9996	0.9996	0.9996	0.9993	0.9991	0.9993
0.1642	0.9996	0.9993	0.9992	0.9993	0.9989	0.9992

(iii) L-isoleucine in aqueous KCI solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0284	1.0000	1.0001	1.0001	1.0000	1.0000
0.0474	1.0003	1.0002	1.0003	1.0001	1.0000
0.0665	1.0003	1.0003	1.0003	1.0000	1.0001
0.0856	1.0003	0.9999	1.0000	0.9999	1.0000
0.1049	0.9999	0.9995	0.9996	0.9999	1.0000
0.1243	0.9998	0.9994	0.9993	0.9997	0.9995
0.1437	0.9996	0.9995	0.9990	0.9991	0.9992
0.1632	0.9993	0.9991	0.9990	0.9988	0.9990

(iv) L-proline in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0953	1.0000	0.9999	1.0004	1.0005	1.0006
0.2909	1.0023	1.0023	1.0026	1.0027	1.0030
0.4934	1.0040	1.0040	1.0046	1.0046	1.0050
0.7032	1.0063	1.0067	1.0077	1.0076	1.0076
0.9206	1.0088	1.0095	1.0105	1.0103	1.0105
1.1462	1.0109	1.0115	1.0125	1.0126	1.0126

(v) L-proline in aqueous KNO3 solution

Concentration (mol kg⁻¹)	303.15	308.15	313.15	318.15	323.15
0.0958	0.9999	1.0018	1.0019	1.0020	1.0020
0.1932	1.0023	1.0031	1.0034	1.0036	1.0037
0.2923	1.0038	1.0044	1.0044	1.0047	1.0045
0.3932	1.0056	1.0061	1.0062	1.0058	1.0061
0.4958	1.0068	1.0068	1.0073	1.0073	1.0075
0.6002	1.0074	1.0082	1.0082	1.0079	1.0082
0.7065	1.0090	1.0096	1.0094	1.0094	1.0097
0.8146	1.0109	1.0110	1.0111	1.0108	
0.9248	1.0115	1.0113	1.0120	1.0120	1.0121
1.0371	1.0129	1.0131	1.0136	0.0139	1.0141

(vi) L-proline in aqueous KCI solution

Concentration (mol kg⁻¹)	298.15	303.15	308.15	313.15	318.15	323.15
0.0950	1.0010	1.0010	1.0009	1.0006	1.0005	1.0005
0.2900	1.0032	1.0028	1.0025	1.0025	1.0026	1.0026
0.4920	1.0048	1.0044	1.0046	1.0043	1.0048	1.0048
0.7015	1.0062	1.0064	1.0062	1.0063	1.0068	1.0069

0.9189	1.0080	1.0079	1.0084	1.0086	1.0090	1.0091
1.1445	1.0095	1.0098	1.0100	1.0103	1.0108	1.0111

(vii) L-glutamine in aqueous K2SO4 solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0379	1.0004	1.0004	1.0009	1.0008	1.0010
0.0762	1.0016	1.0012	1.0020	1.0019	1.0020
0.1147	1.0024	1.0023	1.0028	1.0026	1.0027
0.1535	1.0037	1.0035	1.0037	1.0037	1.0038
0.1926	1.0049	1.0047	1.0050	1.0046	1.0048
0.2320	1.0059	1.0056	1.0057	1.0057	1.0057
0.2717	1.0070	1.0067	1.0071	1.0069	1.0071

(viii) L-glutamine in aqueous KNO3 solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0381	1.0004	1.0013	1.0017	1.0018	1.0019
0.0766	1.0020	1.0025	1.0032	1.0037	1.0038
0.1152	1.0034	1.0042	1.0046	1.0051	1.0053
0.1542	1.0049	1.0057	1.0058	1.0067	1.0067
0.1934	1.0067	1.0068	1.0073	1.0079	1.0082
0.2330	1.0082	1.0086	1.0090	1.0096	1.0094
0.2728	1.0093	1.0096	1.0100	1.0105	1.0103

(ix) L-glutamine in aqueous KCl solution

Concentration (mol kg⁻¹)	**303.15**	**308.15**	**313.15**	**318.15**	**323.15**
0.0379	1.0004	1.0002	1.0005	1.0004	1.0006
0.0760	1.0013	1.0010	1.0014	1.0013	1.0017
0.1145	1.0022	1.0022	1.0023	1.0026	1.0025
0.1534	1.0031	1.0033	1.0034	1.0036	1.0037
0.1925	1.0036	1.0039	1.0041	1.0046	1.0049
0.2320	1.0045	1.0047	1.0051	1.0058	1.0059
0.2718	1.0051	1.0056	1.0058	1.0063	1.0069

References

1. F. Shahidi and P.G. Farrell, J. Chem. Soc. Faraday Soc. I, 74, 858, 1978.
2. R.K. Wadi and R.K. Goyal, /. Solution Chem., 21, 163, 1992.
3. K.P. Prasad and J.C. Ahluwalia, Biopolymers, 19, 263, 1980.
4. S. Cabani, G. Conti and E. Matteoli, Biopolymers, 16, 465, 1977.
5. T.E. Leslie and T.H. Lilley, Biopolymers, 24, 695, 1985.
6. G.M. Blackburn, T.H. Lilley and E. Walmsley, J. Chem. Soc. Faraday Trans. I, 76, 915, 1980.

7. K.P. Murphy and S.J. Gill, J. Chem. Thermodyn., 21, 903, 1989.
8. S. Cabani, G. Conti, E. Matteoli and M.R. Tine, J. Chem. Soc. Faraday Trans. 1,11, 2385, 1981.
9. G. Dipaola and B. Belleau, Can. J. Chem., 56, 1827, 1978.
10. F. Franks, in Biochemical Thermodynamics, M.N. Jones (Ed.), Elsevier: Amsterdam, chap. 2. 1988.
11. R. Bhat, N. Kishore and J.C. Ahluwalia, J. Chem. Faraday Trans.I, 84,2651, 1988.
12. B.S. Lark and K. Bala, Indian J. Chem., 22A, 192, 1983.
13. M.A. Schwitzer and G.R. Hedwig, J. Chem. Eng. Data, 43, 477, 1998.
14. M. Hackel, H.-J. Hinz and G.R. Hedwig, J. Mol. Bio., 291, 197, 1999.
15. E.J. Cohn and J.T. Edsall, Proteins, Amino Acids and Peptides as Ions and Dipolar Ions, Hafner: New York, 1965.
16. J. Wang, Z. Yan, K. Zhuo and J. Lu, Biophys. Chem., 80, 179, 1999.
17. S.K. Singh and N. Kishore, J. Solution Chem., 32, 117, 2003.
18. Z. Yan, J. Wang and J. Lu, J. Chem. Eng. Data, 46, 217, 2001.
19. T. Ogawa, K. Mizutani and M. Yasuda, Bull. Chem. Soc. Jpn., 57, 2064, 1984.
20. D. Kumar, Can. J. Chem., 77, 1288, 1999.
21. T.S. Banipal, D. Kaur and P.K. Banipal, J. Chem. Eng. Data, 49, 1236,2004.
22. H. Rodriguez, A. Soto, A. Arce and M.K. Khoshkbarchi, J. Solution Chem., 32, 56, 2003.
23. P.G. Rohankar and A.S. Aswar, Indian J. Chem., 41A, 312, 2002.
24. B.S. Lark, P. Patyar, T.S. Banipal and N. Kishore, J. Chem. Eng. Data, 49, 553, 2004.
25. Z. Yan, J. Wang, H. Zhang and D. Liu, J. Solution Chem., 27, 473, 1998.
26. M. Natarajan, R.K. Wadi and H.C. Gaur, J. Chem. Eng. Data, 35, 87, 1990.
27. A. Soto, A. Arce, M.K. Khoshkbarchi, J. Solution Chem., 33, 11, 2004.
28. D. Kumar, J. Indian Chem. Soc, 74, 610,1997.
29. A.M. Soto-Campos, M.K. BChoshkbarchi, J.H. Vera, Biophys. Chem., 61,91,1991.
30. U.N. Dash and N.N. Pasupalak, Indian J. Chem., 36A, 834, 1997.
31. D. Ragouramane, Indian J. Chem., 37A, 659, 1998.
32. T.S. Banipal and G. Singh, Indian J. Chem., 43A, 1156, 2004.
33. N. Taulier and T.V. Chalikian, Biochim. et. Biophys. Acta-Protein Structure and Molecular Enzymology, 1595, 48, 2002.
34. R.K.O. Apenten, B. Buttner, B. Mignot, D. Pascal and M.J.W. Povey, FoodHydrocolloids, 14, 83, 2000.
35. A. Almagor, A. Priev, G. Barshtein, B. Gavish and S. Yedgar, Biochim. et Biophys. Acta-Protein Structure and Molecular Enzymology,n^l,\5\,\99%.
36. W.P. Leung, K.C. Cho, Y.M. Lo and C.L. Choy, Biochim. et Biophys. Acta - Protein Structure and Molecular Enzymology, 870, 148, 1986.
37. CM. Bryant and D.J. McClements, Food Hydrocolloids, 13, 439, 1999.
38. N. Taulier and T.V. Chalikian, J. Mol. Biol. 34, 873, 2001.
39. B.N. Waris, U. Hasan and N. Srivastava, Thermochim. Acta, 375, 1,2001.
40. J.A. Evans, C. Barnes and T.J. Lewis, Ultrasound in Medicine and Biology, 14, 299, 1988.
41. J.l. Bhat and H.R. Kumar, Indian J. Pure and Appl Phys., 38, 306, 2000.
42. N. Rohman, N.N. Das and S. Mohiuddin, Aust. J. Chem., 53, 463, 2000.

43. N. Rohman, N.N. Das and S. Mohiuddin, J. Chem. Eng. Data, 44, 465, 1999.
44. R. Pogue and G. Atkinson, J. Chem. Eng Data, 33, 371, 1988.
45. B. Das and D.K. Hazra, Bull. Chem. Soc. Jpn., 65, 3470, 1992.
46. N.P. Rao and R.E. Verrall, Can. J. Chem., 65, 810, 1987.
47. S. Koda, K. Matsumoto, R. Nishimura and H. Nomura, J. Chem. Soc. Faraday Trans., 87, 287, 1991.
48. N. Rohman and S. Mohiuddin, J. Chem. Soc. Faraday Trans., 93, 2053, 1997.
49. R. Delisi, S. Milioto and R.E. Verrall, J. Solution Chem., 19, 639, 1990.
50. O. Nomoto, J. Phys. Soc. Jpn., 13, 1528, 1958.
51. K.C. Reddy, S.V. Subrahmanyam and J. Bhimsenachar, Trans. Faraday Soc. 5S, 2352, 1962.
52. W. Van Dael and E. Vangeel, Proc. 1st. Int. Conf. Cal. Therm. Warsaw, 555, 1969.
53. W. Schaaffs, Acustica, 30, 275, 1974; 33, 272, 1975.
54. P.S. Nikam, M.C. Jadhav and M. Hasan, Indian J. Pure Appl. P/z^^., 33, 398, 1995.
55. S.L. Oswal, Acoust. Lett., 14, 17, 1990.
56. B.R. Chaturvedi, S.K. Verma and N. Pant, Acoust. Lett., 4, 53, 1980.
57. LA. McLure, J.-M.B.-Castillo, J.F. Neville and R.A. Pethrick, Thermochim. Acta, 233, 325, 1994.
58. A. Mulero, C.A. Faundez, M.I. Parra and F. Cuadros, Thermochim. Acta, 334, 1, 1999.
59. S.L. Oswal, P. Oswal, P.S. Modi, J.P. Dave and R.L. Gardas, Thermochim. Acta, 410, 1, 2004.
60. J.L. Labowitz, H.L. Frisch and E. Helfand, J. Chem. Phys., 34, 1037, 1961.
61. E.J. Thiele, J. Chem. Phys., 39, 474, 1963.
62. N.F. Camahan and K.E. Starling, J. Chem. Phys., 51, 635, 1969.
63. E.A. Guggenheim, Mol. Phys. 9, 43, 1965.
64. W.G. Hoover and F.H. Ree, J. Chem. Phys., 49, 3609, 1968.
65. J.D. Pandey and K. Misra, Acoust Lett., 6, 148, 1983.
66. B.B. Owen and P.L. Kronick, J. Phys. Chem., 65, 84, 1961.
67. B.P. Shukla and S.N. Dubey, Acoust. Lett., 9, 71, 1985.
68. M.R. Islam and S.K. Qusidri, Acoust. Lett., 12, 219, 1988.
69. C.V. Chaturvedi and S. Pratap, Acustica, 42, 260, 1979.
70. J.D. Pandey, B.R. Chaturvedi and N. Pant, Acoust. Lett., 4, 92, 1980.
71. N. Pant, C.V. Chaturvedi and G.D. Chaturvedi, Z Phys. Chem. (Leipzig), 264, 513,1983.
72. J.D. Pandey and U. Gupta, Z Phys. Chem. (Leipzig), 268, 477, 1987.
73. D.K. Majumdar and A.R. Purkait, Indian J. Pure Appl. Phys., 19, 273, 1981.
74. J.C. McGown, Nature (London), 210, 1255, 1966.
75. S. Islam and B.N. Waris, Thermochim. Acta, 424, 165, 2004.
76. J.H. Hildebrand and R.L. Scott, The Solubility of Non-Electrolytes, Dover: New York, chap. V, XXIII ,Appendix I, 1964.
77. J.M. Prausnitz, Molecular Thermodynamics of Fluid Phase Equilibria, Prentice-Hall, Englewood Cliffs: N.J., chap. 7, 1969.
78. A.F.M. Barton, J. Chem. Educ, 48, 156, 1971.
79. A.F.M. Barton, Chem. Rev., 75, 731, 1975.
80. F.W. Cagle, J. Chem. Educ, 49, 345, 1972.
81. D.R. Rosseinsky, J. Phys. Chem., 81, 1578, 1977.

82. N. Berkowitz and S.C. Srivastava, Can. J. Chem., 41, 1797, 1963.
83. J.H. Hildebrand and R.L. Scott, Solubility of Non-Electrolytes, Reinhold : New York, 1950.
84. J.H. Hildebrand and R.L. Scott, Regular Solutions, Prentice-Hall, Englewood Cliffs, 1962.
85. J.H. Hildebrand and E.B. Smith, J. Chem. Phys., 31, 145, 1959.
86. D. Liberman, Phys. Fluids, 2, 466, 1959.
87. R.D. Dunlop and R.L. Scott, J. Phys. Chem., 66, 631, 1962.
88. C. V. Suryanarayana, Indian J. Pure Appl. Phys., 27, 751, 1989.
89. L.I. Acevedo, G.C. Pedrosa and M. Katz, J. Solution Chem., 19, 11,1990.
90. J.E. Gordon, /. Am. Chem. Soc, 87,4347, 1965.
91. G.F. Longster and E.E. Walker, Trans. Faraday, Soc, 49, 228, 1953.