Interactions of L-arginine with maltose monohydrate in aqueous solutions at 298.15 K: A volumetric study

Ashwani Kumar and Rajinder Kumar Bamezai

Abstract: Density and ultrasonic speeds of L-arginine in water and in aqueous–D-maltose monohydrate (2%, 4% and 6% of maltose monohydrate, w/w in water) mixed solvents were measured at 298.15 K. From these experimental results, the apparent molar volume, V_ϕ, limiting apparent molar volume, $V°_\phi$, and the slope, S_v, transfer volume, $V°_{\phi,tr}$, apparent molar compressibility, $K_{s,\phi}$, limiting apparent molar compressibility $K°_{s,\phi}$, and the slope S_k, transfer compressibility, $K°_{s,\phi,tr,}$ and hydration number, n_H, were calculated. The results have been discussed in terms of solute-solute and solute–solvent interactions in these systems. It has been observed that there exists strong solute-solvent (hydrophilic–ionic group and hydrophilic–hydrophilic group) interactions in these systems, which increases with increase in maltose concentration. The hydrophilic–ionic and hydrophilic–hydrophilic interactions have been found to be dominating over hydrophobic–hydrophilic interactions in the solutions.

Key words: Density; ultrasonic speed; L-arginine; D-maltose; apparent molar volume.

1. Introduction

Proteins play an important role in the biological processes of nearly all living organisms. In order to understand the role played by the biological molecules in the living organism, it is necessary to study the interactions of proteins with their surrounding environment. These interactions are mainly between the protein molecules and the solvent ions. The stabilization of native conformations of proteins has been related to various non-covalent interactions like hydrogen bonding, electrostatic and hydrophobic interactions [1,2]. The study of these interactions provides important insight into the conformational stability and folding/unfolding of globular proteins [3] and are found implicated in several biochemical and physiological processes of a living cell [4-6]. Saccharides/Carbohydrates are widely distributed in various forms of life as essential moieties of glycoproteins, glycolipids, nucleic acids and polysaccharides. Because of conformational flexibility, saccharides play significant roles in many biological processes such as signaling, cell-cell recognition, molecular and cellular communication [7-9] and stabilizing the native conformations of proteins/enzymes [10-12]. Lee and Timasheff [13] studied the thermal transitions of α-chymotrypsin, chymotrypinogen and ribonuclease in sucrose and argued that the sucrose stabilize proteins against thermal damage. The complex conformational and configurational factors determining the structure of proteins in sugar solution makes the study of protein-sugar interactions difficult. Therefore interactions of the model compounds of proteins, i.e., amino acids in aqueous saccharide solution are investigated [14-19]. Since amino acids are the model compounds of protein molecules, their thermodynamic and transport properties in aqueous solutions provide valuable information on solute-solute and solute-solvent interactions that are useful in studying the stability of proteins. Thus, the thermodynamic properties of amino acids in aqueous-saccharide solutions are important for studying the interactions in biological systems [20, 21]. Maltose a (disaccharide) is a water-soluble sugar used for immediate energy along with glucose, being basic source for all living organisms. It is also used in a number of

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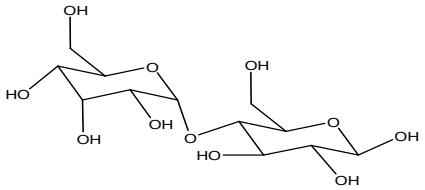
biological reactions as a stabilizing agent or osmolality regulator. Maltose plays an important role in changing the effect by generating a more plasticizing effect than fructose [22]. The structure of α-D-maltose is:



In recent years, there have been extensive studies of thermoacoustic properties of these model components in aqueous-saccharide solutions [15–19,23-28]. But, to the best of our knowledge, very little work has been done on amino acids with positively charged side chain in aqueous-saccharide solutions [16,18,26,28] and no volumetric and ultrasonic studies have been done on L-arginine in aqueous–maltose monohydrate solutions with varying maltose monohydrate concentrations at 298.15 K. These observations led us to undertake the study of L-arginine (with positively charged R group) in aqueous-maltose monohydrate solutions.

In the present article, we report the experimentally measured values of density (ρ) and speed of sound (u) of L-arginine in water and aqueous-maltose monohydrate (2%, 4% and 6% maltose monohydrate, w/w in water) solvents as a function of molal concentrations of L-arginine at 298.15 K and atmospheric pressure. Using the experimentally measured density and ultrasonic data, the apparent molar volume, V_ϕ, limiting apparent molar volume, $V°_\phi$, and the slope, S_v, transfer volume, $V°_{\phi,tr}$, apparent molar compressibility, $K_{s,\phi}$, limiting apparent molar compressibility $K°_{s,\phi}$, and the slope S_k, transfer compressibility, $K°_{s,\phi,tr,}$ and hydration number, n_H, were calculated. The measured and computed parameters have been discussed in terms of ionic–hydrophilic, hydrophilic–hydrophilic and hydrophobic–hydrophilic interactions occurring in the L-arginine in water and aqueous-maltose monohydrate (2%, 4% and 6% maltose monohydrate, w/w in water).

2. Experimental

L-Arginine and D-Maltose monohydrate, herein abbreviated as MM, was used as such (Table 1) without further purification, except drying in an oven for 24 h. The aqueous-saccharide solutions (2%, 4% and 6% of MM, w/w in water) were prepared using triple distilled water with specific conductance less than 1 x 10^{-6} S cm^{-1}. The saccharide solution was used as solvent to prepare L-arginine solution of eight different molal concentrations (ranging from 0.0 m to 0.2 m).

Table 1. Provenance and purity of the chemical samples studied.

Chemical name	Provenance	Purification method	Final mass fraction purity
L-Arginine	Sigma Aldrich, India	Used as received	>0.998
D-Maltose monohydrate	Sigma Aldrich, India	Used as received	>0.998

An electronic single pan five digit analytical balance (Mettler; Model AE-240) with a precision of ±0.00001 g was used for weighing. All the solutions were prepared with care and stored in special airtight bottles to avoid the exposure of solution to air and evaporation. The possible error in the mole fraction is calculated to be less than ±1x10^{-4}. The densities of solutions were measured using a single-capillary pycnometer (made of Borosil glass) having a bulb capacity of ~10 mL. The capillary, with graduated marks had a uniform bore which could be closed by a well-fitted glass cap. The pycnometer was calibrated by measuring the density of triply distilled water at 298.15 K. The uncertainty in density measurements was within ±0.03 kg m^{-3}. The speed of sound in the solutions were measured using a single-crystal variable-path multi-frequency ultrasonic interferometer (Model: M-82S, Mittal Enterprises, India) having stainless steel sample cell (with digital micrometer) operating at a fixed frequency of 2 MHz. The uncertainty in speed measurement was found to be within ±0.5 m s^{-1}. The temperature of the sample solution was maintained to an accuracy of ±0.02 K using an electronic controlled thermostatic water bath (Model: TIC-4000N, Thermotech, India).

3. Results and discussion

The experimental values of density (ρ) and speed of sound (u) of L-arginine in water and aqueous-MM (2%, 4% and 6% MM) as a function of molal concentration of L-arginine at 298.15 K are listed in Tables 2 and 3, respectively.

Table 2. Densities (ρ/kg m^{-3}) of solutions of L-arginine in water, aqueous–MM (2%, 4% and 6%) as function of molality (m/ mol kg^{-1}) of L-arginine at 298.15 K.

Molality (m/ mol kg^{-1})	L-Arginine in water	L-Arginine in 2% MM	L-Arginine in 4% MM	L-Arginine in 6% MM
0.0000	997.07	1004.26	1011.64	1020.59
0.0250	998.35	1005.50	1012.86	1021.78
0.0500	999.63	1006.74	1014.08	1022.97
0.0750	1000.91	1007.98	1015.30	1024.16
0.1000	1002.19	1009.22	1016.52	1025.35
0.1250	1003.47	1010.46	1017.74	1026.54
0.1500	1004.75	1011.70	1018.96	1027.73
0.1750	1006.03	1012.94	1020.18	1028.92
0.2000	1007.31	1014.18	1021.40	1030.11

Table 3. Viscosities (η x 10^3/N s m^{-2}) of solutions of L-arginine in water, aqueous–MM (2%, 4% and 6%) as functions of molality (m/ mol kg^{-1}) of L-arginine at 298.15 K.

Molality (m/ mol kg^{-1})	L-Arginine in water	L-Arginine in 2% MM	L-Arginine in 4% MM	L-Arginine in 6% MM
0.0000	1497.60	1506.33	1512.27	1516.80
0.0250	1499.60	1508.40	1514.38	1518.92
0.0500	1501.58	1510.47	1516.47	1521.02
0.0750	1503.54	1512.51	1518.54	1523.10
0.1000	1505.48	1514.53	1520.59	1525.16
0.1250	1507.40	1516.53	1522.62	1527.20
0.1500	1509.30	1518.51	1524.63	1529.22
0.1750	1511.18	1520.47	1526.62	1531.22
0.2000	1513.04	1522.41	1528.59	1533.20

Apparent molar volume and apparent molar compressibility

The apparent molar volume (V_ϕ) and apparent molar compressibility ($K_{s,\phi}$) of the solutions were calculated using relations 1 and 2.

$$V_\phi = \frac{1000(\rho_o - \rho)}{m\rho\rho_o} + \frac{M}{\rho} \quad \ldots\ldots 1$$

$$K_{s,\phi} = \frac{1000(\kappa_s\rho_o - \kappa^o_s\rho)}{m\rho\rho_o} + \frac{M}{\rho} \quad \ldots\ldots 2$$

where m is the molality of L-arginine in solution, ρ and ρ_o are densities of the solution and the solvent (aqueous-MM), respectively; M is the molar mass of the solute (L-arginine). κ_s and κ^o_s are isentropic compressibilitie of the solution and the solvent, respectively.

The variation of V_ϕ (Fig. 1) and $K_{s,\phi}$ (Fig. 2) as function of molality of L-arginine has been found to be linear in the studied concentration range at 298.15 K for L-arginine in water, and in all the three aqueous-MM solvents.

The isentropic compressibility (κ_s) has been calculated using the relation:

$$\kappa_s = 1/u^2\rho \quad \ldots\ldots 3$$

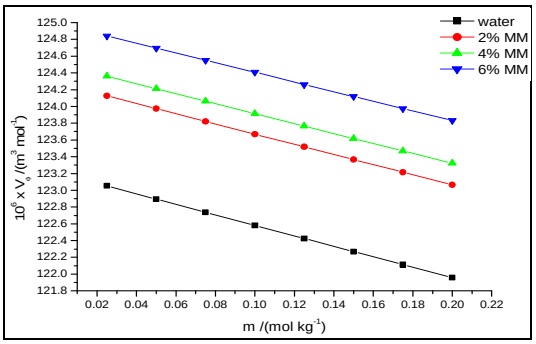


Fig. 1. Variations of apparent molar volume, V_ϕ vs. molality, m of L-arginine in water and MM + water (w/w) solutions at 298.15 K.

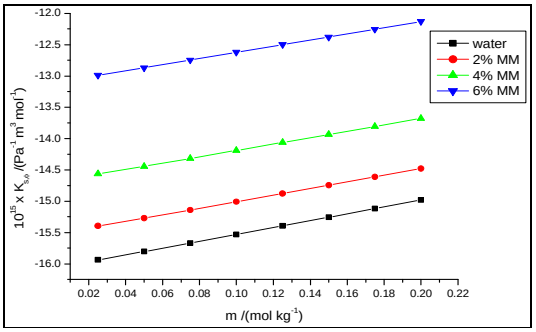


Fig. 2. Variations of apparent molar compressibility, $K_{s,\phi}$ vs. molality, m of L-arginine in water and MM + water (w/w) solutions at 298.15 K.

The isentropic compressibility of L-arginine in water and aqueous-MM plotted in Fig. 3 show a decrease with increase in molal concentration of L-arginine. The decreasing κ_s values in aqueous-MM, on increasing the amount of L-arginine, indicate that the water molecules associated with ionic groups of zwitterion/hydrophilic groups of L-arginine are less compressible than those of the water molecules in the bulk solution [29, 30].

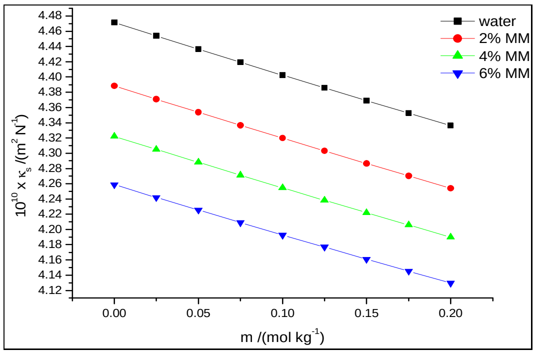


Fig. 3. Variations of isentropic compressibility, κ_s, vs. molality, m of L-arginine in water and MM + water (w/w) solutions at 298.15 K.

Limiting apparent molar volume and apparent molar compressibility

The values of limiting apparent molar volume (V^o_ϕ) and limiting apparent molar compressibility ($K^o_{s,\phi}$) were estimated by the least square fit of the apparent molar volume and apparent molar compressibility values using the following equations [31].

$$V_\phi = V^o_\phi + S_v m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

$$K_{s,\phi} = K^o_{s,\phi} + S_k m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Here, the intercepts, V^o_ϕ and $K^o_{s,\phi}$ are limiting apparent molar volume and limiting apparent molar compressibility at infinite dilution, respectively, whereas S_v or S_k is their corresponding slopes. The values of V^o_ϕ, $K^o_{s,\phi}$, S_v and S_k along with the standard deviation, σ, for L-arginine in aqueous-MM at 298.15 K are summarized in Tables 4 and 5 and shown graphically in the Figs. S1 and S2 as supplementary material.

Table 4. Limiting apparent molar volume ($V°_\phi$), standard deviation of linear regression (σ, using Equation 4), slope (S_v) and transfer volume ($V°_{\phi,tr}$) for L-arginine in aqueous-MM at 298.15 K.

Property	T/K (298.15 K)
L-Arginine in water	
$10^6 \cdot V°_\phi$ /m^3 mol^{-1}	123.208
σ for equation (4)	0.001
$10^6 \cdot S_v$ /m^3 mol^{-1} kg^{-1}	-6.256
L-Arginine in 2% aqueous-MM	
$10^6 \cdot V°_\phi$ /m^3 mol^{-1}	124.278
σ for equation (4)	0.001
$10^6 \cdot S_v$ /m^3 mol^{-1} kg^{-1}	-6.073
$10^6 \cdot V°_{\phi,tr}$ /m^3 mol^{-1}	1.070
L-Arginine in 4% aqueous-MM	
$10^6 \cdot V°_\phi$ /m^3 mol^{-1}	124.509
σ for equation (4)	0.001
$10^6 \cdot S_v$ /m^3 mol^{-1} kg^{-1}	-5.942
$10^6 \cdot V°_{\phi,tr}$ /m^3 mol^{-1}	1.301
L-Arginine in 6% aqueous-MM	
$10^6 \cdot V°_\phi$ /m^3 mol^{-1}	124.984
σ for equation (4)	0.001
$10^6 \cdot S_v$ /m^3 mol^{-1} kg^{-1}	-5.766
$10^6 \cdot V°_{\phi,tr}$ /m^3 mol^{-1}	1.776

The intercept, V^o_ϕ, is free from solute-solute interactions and, therefore, provides a measure of solute-solvent interactions and S_v is the experimental slope; an indicative of solute-solute interactions. An evaluation of Table 4 reveals that the V^o_ϕ values are positive and S_v values are negative for L-arginine in aqueous as well as aqueous-MM indicating the presence of strong solute–solvent interactions and weak solute-solute interactions. This trend of V^o_ϕ values may be due to their hydration behaviour that depends on the nature of solute species which comprises of following interactions [20, 32-34]: (i) the terminal groups of zwitterions of amino acids, NH_3^+ and COO^- are hydrated in an electrostatic manner; whereas hydration of R group depends on its nature, which may be hydrophilic, hydrophobic or amphiphilic; (ii) electrostriction of NH_3^+ end is ten times greater than COO^- end of the zwitterion; and (iii) the overlapping of hydration co-spheres of terminal groups, i.e., NH_3^+ and COO^- groups and of adjacent groups results in volume change. The V^o_ϕ value increases due to reduction in the electrostriction at terminals, whereas it decreases due to disruption of side group hydration by that of the charged end. A similar behaviour with glucose/sucrose concentration

was observed by Zhao et al. [28] for arginine in aqueous-carbohydrate solution and by Nain et al. [16,26] for L-histidine in aqueous-glucose, and aqueous-sucrose solutions.

The $K°_{s,\phi}$ and S_k values (Table 5) are found to be negative and positive, respectively in the studied concentration region. The former values are negative (Fig. S2 of supplementary material), indicating that there occurs strong solute-solvent interactions and weak solute-solute interactions in these systems. This further supports the observation that the hydrophilic-ionic and hydrophilic-hydrophilic groups interaction between OH groups of maltose monohydrate with L-arginine zwitterions dominate in these systems. The negative values of $K°_{s,\phi}$ (loss of compressibility of medium) reindicates that the water molecules surrounding the amino acid molecules provide great resistance to compression than water molecules present in bulk.

Table 5. Limiting apparent molar compressibility ($K°_{s,\phi}$), standard deviation of linear regression (σ, using Equation 5) slope (S_k) and transfer compressibility, ($K°_{s,\phi,tr}$) for L-arginine in aqueous-MM at 298.15 K.

Property	T/K (298.15)
L-Arginine in water	
$10^{15}\cdot K°_{s,\phi}$ /$Pa^{-1}\,m^3\,mol^{-1}$	-16.079
σ for equation (5)	0.002
$10^{15}\cdot S_k$ / $Pa^{-1}\,m^3\,mol^{-1}\,kg^{-1}$	5.490
L-Arginine in 2% aqueous-MM	
$10^{15}\cdot K°_{s,\phi}$ /$Pa^{-1}\,m^3\,mol^{-1}$	-15.532
σ for equation (5)	0.003
$10^{15}\cdot S_k$ / $Pa^{-1}\,m^3\,mol^{-1}\,kg^{-1}$	5.261
$10^{6}\cdot K°_{s,\phi,tr}$ / $Pa^{-1}\,m^3\,mol^{-1}$	0.547
L-Arginine in 4% aqueous-MM	
$10^{15}\cdot K°_{s,\phi}$ /$Pa^{-1}\,m^3\,mol^{-1}$	-14.695
σ for equation (5)	0.003
$10^{15}\cdot S_k$ / $Pa^{-1}\cdot\,m^3\,mol^{-1}\,kg^{-1}$	5.079
$10^{6}\cdot K°_{s,\phi,tr}$ / $Pa^{-1}\,m^3\,mol^{-1}$	1.384
L-Arginine in 6% aqueous-MM	
$10^{15}\cdot K°_{s,\phi}$ /$Pa^{-1}\,m^3\,mol^{-1}$	-13.112
σ for equation (5)	0.001
$10^{15}\cdot S_k$ / $Pa^{-1}\,m^3\,mol^{-1}\,kg^{-1}$	4.906
$10^{6}\cdot K°_{s,\phi,tr}$ / $Pa^{-1}\,m^3\,mol^{-1}$	2.967

Transfer volume

The limiting apparent molar transfer volume ($V°_{\phi,tr}$) of L-arginine from water to aqueous-MM was calculated using the following expression.

$$V^o_{\phi,tr} = V^o_{\phi,aq\text{-}MM} - V^o_{\phi,water} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 6$$

where $V°_{\phi,water}$ is the limiting apparent molar volume of L-arginine in water (Table 4). The $V°_{\phi,tr}$ value for L-arginine from water to aqueous-MM is shown in Table 4. The values of $V°_{\phi}$ of L-arginine in aqueous - MM are more than those in pure water, i.e., $V°_{\phi,tr}$ value of L-arginine is positive and increases with increase in mass % of MM. The different types of interactions occurring between L-arginine and MM may be classified as follows [20,27,33,34].

(a) Hydrophilic-ionic interaction between OH groups of MM and (NH_3^+ and COO^-) zwitterionic centers of L-arginine molecules.

(b) Hydrophilic-hydrophilic interaction between the OH groups of MM and NH_3^+ groups of L-arginine molecules mediated through hydrogen bonding.

(c) Hydrophilic-hydrophobic interaction between the OH groups of MM and non-polar ($-CH_2$) groups of L-arginine molecules.

(d) Hydrophobic-hydrophobic interaction between the non-polar groups of MM molecules and non-polar ($-CH_2$) in side chain of L-arginine molecules.

The interactions occurring between MM and L-arginine molecules can be explained by the co-sphere overlap model, as proposed by Friedman and Krishnan model [35], according to which the effect of overlap of hydration co-sphere is decisive in determining the nature of interaction between the solute species. It has been observed [33] that the overlap of co-spheres of two ionic species produces an increase in volume, whereas the overlap of hydrophobic-hydrophobic groups and ionic-hydrophobic groups results in a decrease in volume. Since amino acids exist predominantly as zwitterions in pure water, there is an overall decrease in volume of the water due to the electrostriction of water near the end group. Interaction of type (a) leads to a positive contribution to the transfer volume owing to the overlap of the hydration co-sphere of the ion (COO^- and NH_3^+) and hydrophilic OH group, which leads to the reduction in electrostriction of the water caused by these ions. The interaction of type (b) also makes a positive contribution to the transfer volume, since the overlap of the hydration co-sphere of NH_2 and OH groups leads to increase in the magnitude

of hydrogen bonding interaction. On the other hand, interaction of type (c) makes a negative contribution to the transfer volume because of their co-sphere overlap. Interaction of type (d) also leads to a negative contribution to the transfer volume due to disruption of side group hydration by that of charged end. The observed positive $V°_{\phi,tr}$ values for these systems suggest that the ionic-hydrophilic and hydrophilic-hydrophilic group interactions dominate in these systems. The $V°_{\phi,tr}$ values increase with increase MM concentration in the solutions (Table 4). This may be due to greater ionic-hydrophilic group and hydrophilic-hydrophilic group interactions with increased concentrations of MM.

Transfer compressibility

The limiting apparent molar transfer compressibility ($K°_{s,\phi,tr}$) of L-arginine from water to aqueous-MM were calculated by using the following relation.

$$K^{o}_{s,\phi,tr} = K^{o}_{s,\phi,aq\text{-}MM} - K^{o}_{s,\phi,water} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 7$$

$K°_{s,\phi,water}$ is the limiting apparent molar compressibility of L-arginine in water (Table 5). The $K°_{s,\phi,tr}$ value for L-arginine from water to aqueous-MM is given in Table 5. The $K°_{s,\phi}$ values of L-arginine in aqueous-MM are more than that in pure water, i.e., $K°_{s,\phi,tr}$ values are positive which indicates that the ionic-hydrophilic group and hydrophilic-hydrophilic group interactions dominate in the system. The increase of $K°_{s,\phi,tr}$ values with increase in aqueous - MM concentration may be due to greater ionic-hydrophilic group and hydrophilic-hydrophilic group interactions. The observed trends in $K°_{s,\phi}$ and $K°_{s,\phi,tr}$ further support the conclusions obtained from $V°_{\phi}$ and $V°_{\phi,tr}$.

Hydration number

The hydration number is evaluated using electrostriction partial molar volume, ($V°_{\phi}$ (elect.)), of L-arginine which can be explained using a simple model [36].

$$V°_{\phi}\,(elect.) = V°_{\phi} - V°_{\phi}\,(int.) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 8$$

$V°_{\phi}$ (elect.) is the electrostriction partial molar volume due to the hydration of L-arginine and $V°_{\phi}$ (int.) is the intrinsic partial molar volume of L-arginine. The term $V°_{\phi}$ (int.) comprises of the van der Waals volume and the volume due to packing effects. The values $V°_{\phi}$ (int.) for L-arginine has been calculated from equation [36]

$$V°_{\phi}\,(int.) = (0.7/0.634)V°_{\phi}\,(cryst.) \quad \ldots\ldots\ldots\ldots \quad 9$$

where 0.7 is the packing density for molecules in organic crystals, 0.634 is the packing density for random packing spheres and $V°_{\phi}$ (cryst.) is the crystal molar volume [36], which can be evaluated by the following equation

$$V°_{\phi}\,(cryst.) = /\rho(cryst.) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 10$$

where ρ(cryst.) is the crystal density of L-arginine and its value can be taken from the work of Berlin and Pallansch [37]. The decrease in volume due to electrostriction can be related to the number of water molecules hydrated to L-arginine [38], i.e., hydration number, n_H, can be given as:

$$n_H = V°_{\phi}\,(elect.)/(V°_{E} - V°_{B}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 11$$

where $V°_E$ is the molar volume of electrostricted water and $V°_B$ is the molar volume of bulk water at T = 298.15 K. According to Millero et al. [38].

$$V°_{E} - V°_{B} = -3.3\ cm^{3}\ .\ mol^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 12$$

Therefore, hydration number, n_H can be obtained as

$$n_H = V°_{\phi}\,(elect.)/(-3.3) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 13$$

The n_H value (volumetric method) for L-arginine in aqueous - MM is presented in Table 6 and Fig. S3. The n_H values for L-arginine decrease with increase in the concentration of D-maltose in the solution. This indicates the increase in solute-co-solute interactions. The hydration numbers mainly come from the electrostriction effect of the charged end/polar groups of amino acids on water.

Table 6. Hydration number (n_H) for L-arginine in water and aqueous-MM at T = 298.15 K

System	Volumetric method	Compressibility method
L-Arginine + water	6.65	1.99
L-Arginine + 2% aqueous-MM	6.33	1.92
L-Arginine + 4% aqueous-MM	6.26	1.81
L-Arginine + 6% aqueous-MM	6.11	1.62

This shows that D-maltose have a dehydration effect on the L-arginine, i.e., water

molecules are replaced by maltose molecules with increasing concentration of maltose in solution. Similar trends in n_H values were also observed by Nain et. al. [18, 39] for L-arginine in water + xylose/arabinose and L-phenylalanine in water + arabinose/glucose/ sucrose solutions.

Further, the number of water molecules hydrated to the amino acids, n_H was estimated by from the electrostriction partial molar compressibility $K°_{s,\phi}$(elect.) using the method given by Millero et al. [36],

$$n_H = - K°_{\phi}(\text{elect.})/ (V°_{\phi,b} . K°_{s,\phi,b}) \ldots\ldots\ldots 14$$

where $K°_{s,\phi,b}$ is the isothermal compressibility of bulk water. Value of ($V°_{\phi,b}$· $K°_{s,\phi,b}$) is 8.1 x 10^{-15} m^5· N^{-1}· mol^{-1} . The electrostriction partial molar compressibility $K°_{s,\phi}$(elect.) can be calculated from the experimentally measured values of $K°_{s,\phi}$ using the following relation:

$$K^o_{s,\phi}(\text{elect.}) = K^o_{s,\phi} - K^o_{s,\phi}(\text{int.}) \ldots\ldots\ldots\ldots 15$$

where $K°_{s,\phi}$ (int.) is $K°_{s,\phi}$ (isomer) for L-arginine. $K°_{s,\phi}$ (int.) is less than 5 x 10^{-15} m^5· N^{-1}· mol^{-1} for ionic crystals and many organic solutes in water. So, we can assume $K°_{s,\phi}$ (int.) = 0. Therefore, for $K°_{s,\phi}$ (int.) = 0, equation (15) becomes

$$K^o_{s,\phi}(\text{elect.}) = K^o_{s,\phi} \ldots\ldots\ldots\ldots\ldots\ldots 16$$

The value of n_H (compressibility method) for L-arginine in aqueous-MM is given in Table 6 and shown in Fig. S3.

4. Conclusions

The densities, ρ and ultrasonic speeds, u of solutions of L-arginine in aqueous-maltose monohydrate solvents 2%, 4% and 6% of maltose monohydrate, w/w in water, were measured at 298.15 K. From the experimental results, various parameters, viz., V_ϕ, $V°_\phi$, $V°_{\phi,tr}$, $K_{s,\phi}$, $K°_{s,\phi}$, $K°_{s,\phi,tr}$ and hydration number, n_H, were calculated. The results indicate that there exist strong solute–solvent (ionic–hydrophilic group and hydrophilic–hydrophilic group) interactions in these systems, which increase with increase in maltose concentration. The ionic–hydrophilic and hydrophilic–hydrophilic interactions have been found to be dominating over hydrophobic–hydrophilic interactions in the solutions.

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Supplementary material:

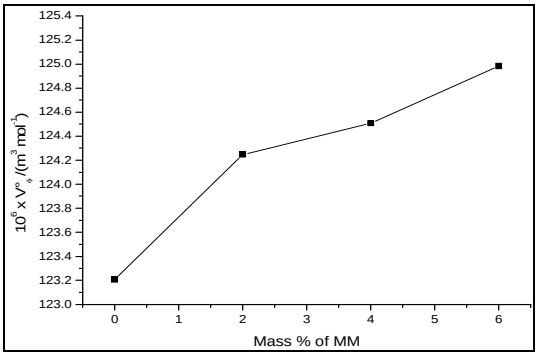

Fig. S1. Variations of limiting apparent molar volume, $V°_{\phi}$ vs. mass % of MM for L-arginine in water + MM solutions at 298.15 K.

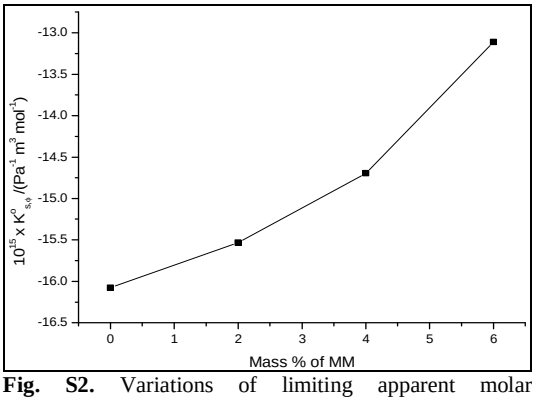

Fig. S2. Variations of limiting apparent molar compressibility, $K°_{s,\phi}$ vs. mass % of MM for L-arginine in water + MM solutions at 298.15 K.

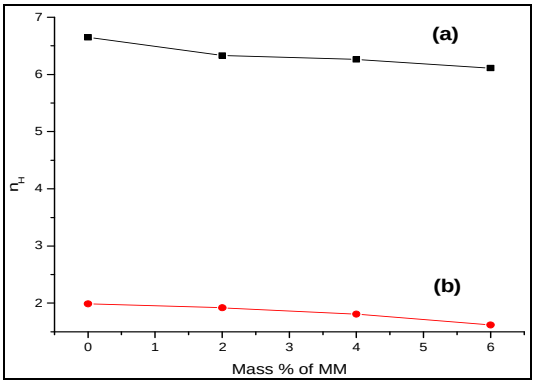

Fig. S3. Variation of hydration number, n_H with mass % of MM for L-arginine in aqueous -MM by (a) volumetric method, (b) compressibility method, at 298.15 K.