Monatsh Chem (2010) 141:1063–1068
DOI 10.1007/s00706-010-0368-3

ORIGINAL PAPER

Volumetric studies of some electrolytes in water and in aqueous sodium dodecylsulfate solutions at different temperatures

Dulal Chandra Kabiraz · Tapan Kumar Biswas · M. Entazul Huque

Received: 15 September 2009 / Accepted: 2 August 2010 / Published online: 2 September 2010

Abstract The apparent molar volumes (φ_v) of KCl, KNO_3, $MgCl_2$, and $Mg(NO_3)_2$ have been determined in water and in aqueous sodium dodecylsulfate solutions from density measurements at 303.15, 308.15, 313.15, 318.15, and 323.15 K. The limiting apparent molar volumes (φ_v^0) and experimental slopes (S_v) were derived from the Masson equation. The partial molar volume transfer ($\Delta\bar{V}_{tr}$) of the electrolytes were obtained from limiting apparent molar volume data from water to aqueous sodium dodecylsulfate solutions and have been interpreted in terms of ion–ion, hydrophilic–hydrophilic, and hydrophobic–hydrophobic interactions on the basis of a co-sphere overlap model. It is shown that the transfer volumes ($\Delta\bar{V}_{tr}$) are positive and increase with increasing sodium dodecylsulfate concentration for all electrolytes. The structure making or breaking capacities of the electrolytes have been inferred from the sign of $[\partial^2\varphi_v^0/\partial T^2]_p$, i.e., the second derivative of the limiting apparent molar volume with respect to temperature at constant pressure. In water, KCl and KNO_3 exhibit structure breaking and $MgCl_2$ and $Mg(NO_3)_2$ exhibit structure making behavior. All the studied electrolytes were found to act as structure makers in aqueous sodium dodecylsulfate solutions.

Keywords Apparent molar volume · Partial molar volume transfer · Sodium dodecylsulfate · Partial molar volume expansibility

Introduction

Partial molar volumes of electrolytes provide valuable information about ion–ion and ion–solvent interactions in ionic solutions [1–12]. This information is of fundamental importance for understanding reaction rates and equilibria involving dissolved electrolytes. Surfactants are extensively employed in pharmaceutical [13, 14] and biotechnological processes [15, 16]. In protein solution, surfactants are known as protein destabilizers, due to their strong binding with protein molecules [17]. A literature survey showed that, although many studies on thermodynamic properties of various solutes have been carried out in single-component and in mixed solvent systems, little attention has been paid to the behavior of salts in binary aqueous solution of sodium dodecylsulfate (SDS). In the present work we tried to review our knowledge of liquid water, its remarkable physical properties in the presence of some electrolytes and how these give rise to a unique liquid "structure," and its influence on interactions between dissolved solutes. The study deals with the determination of the apparent molar volume, partial molar volume, and the volumes of transfer of several electrolytes at various temperatures. Two types of electrolyte were chosen for the study. In one type, monovalent cations (K^+) were the same but anions were different (Cl^-, NO_3^-); in the other, divalent cations (Mg^{2+}) were the same but anions were different (Cl^-, NO_3^-). Different charge and size of the ions may affect water structure differently, which may be reflected in the partial molar volume measurement data. Sodium dodecylsulfate is a strong water structure maker. The hydrophobic tail of SDS forces water molecules to be compactly structured. With this in view, it was considered interesting to investigate the effect of some electrolytes on aqueous solutions of SDS as a function of temperature. The structure making and breaking effects of

---

D. C. Kabiraz · T. K. Biswas · M. E. Huque (✉)
Department of Chemistry, University of Rajshahi,
Rajshahi 6205, Bangladesh
e-mail: tapankb@ru.ac.bd

electrolytes will probably be more pronounced in this highly structured SDS solution in comparison with in pure water. The effects may mainly be due to the formation and breaking of the spherical micelles formed by SDS. In this study, densities and viscosities of some electrolytes in water and in water–SDS solution were measured. The experimentally measured data were then used to determine the limiting apparent molar volume. The results are discussed on the basis of the change in solute–solvent interaction induced by the solutes. Emphasis is given to the change of solvent structure making and structure breaking behavior of the solute in the solution.

Results and Discussion

Apparent molar volumes (φ_{v}) were calculated using density data and the following equation:

$$\varphi_v = \frac{M_2}{\rho_0} + \frac{1,000}{C}\left[\frac{\rho - \rho_0}{\rho_0}\right], \tag{1}$$

where ρ and ρ_0 are the densities of the solution and pure water in g cm^{-3}, C is the molar concentration of the solution in mol dm^{-3}, and M is the molar mass of the solute. The apparent molar volume at infinite dilution (φ_v^0) was calculated using least-squares fit to linear plots of experimental values of φ_{v} versus the square root of molar concentration ($\sqrt{C}$) using the following Masson equation [18]:

$$\varphi_v = \varphi_v^0 + S_v C^{1/2}, \tag{2}$$

where φ_v^0 is the partial molar volume at infinite dilution (limiting apparent molar volume) and S_{v} is the experimental slope. The values of φ_v^0 and S_{v} along with standard errors are given in Tables 1 and 2. It is evident from the data that S_{v} is positive for the entire electrolyte in water as well as in aqueous SDS solutions at different temperatures, which shows the presence of specific ion–ion interactions in both systems. It is noted that the value of S_{v} for all electrolytes increases in magnitude with increasing SDS content in water, thereby suggesting that ion–ion interactions further strengthen with increasing SDS content. The interactions decrease with increasing temperature. This is caused by more violent thermal agitation at higher temperatures, resulting in diminishing force of the ion–ion interaction [19]. This tendency is supported by the densities, viscosities, and adiabatic compressibility studies on some mineral salts in water at different temperatures [20]. It is reported that the solute–solute interactions decrease with increasing temperature for lithium nitrate, sodium nitrate, potassium nitrate, magnesium nitrate, and calcium nitrate.

In case of metal chlorides (KCl, $MgCl_2$) and metal nitrates [KNO_3, $Mg(NO_3)_2$], the anions are the same but the cations are of different nature. The cations are K^+ and

Table 1 Limiting apparent molar volumes (φ_{v}^0), experimental slopes (S_{v}), and limiting apparent molar volume expansibilities (φ_{E}^0) for some electrolytes in water at different temperatures

Electrolyte	Temperature (K)	φ_{v}^0 (cm^3 mol^{-1})	S_{v} (cm^3 l$^{1/2}$ mol^{-3})	φ_{E}^0 (cm^3 mol^{-1} K^{-1})	$[\partial^2\varphi_{\mathrm{v}}^0/\partial T^2]_{\mathrm{p}}$
KCl	303.15	27.85 (±0.08)	26.8341 (±1.04)	0.218	−0.0030
	308.15	28.88 (±0.04)	25.2195 (±0.48)	0.203	
	313.15	29.90 (±0.04)	23.3535 (±0.56)	0.188	
	318.15	31.09 (±0.04)	22.6327 (±0.55)	0.173	
	323.15	31.93 (±0.04)	20.7287 (±0.52)	0.158	
KNO_3	303.15	38.21 (±0.03)	24.1963 (±1.09)	0.352	−0.0078
	308.15	38.76 (±0.06)	21.5065 (±0.87)	0.313	
	313.15	39.65 (±0.03)	16.6555 (±0.50)	0.274	
	318.15	40.97 (±0.03)	16.5712 (±0.47)	0.235	
	323.15	41.10 (±0.02)	14.9825 (±1.11)	0.196	
$MgCl_2$	303.15	104.27 (±0.07)	34.7897 (±0.95)	0.193	+0.0050
	308.15	105.63 (±0.06)	32.7980 (±0.89)	0.218	
	313.15	106.77 (±0.04)	25.0850 (±0.59)	0.243	
	318.15	108.08 (±0.02)	17.8906 (±0.25)	0.268	
	323.15	109.40 (±0.03)	13.1422 (±0.41)	0.293	
$Mg(NO_3)_2$	303.15	159.07 (±0.06)	40.4747 (±0.85)	0.424	+0.0014
	308.15	160.84 (±0.04)	28.3628 (±0.53)	0.431	
	313.15	162.50 (±0.03)	22.3341 (±0.44)	0.438	
	318.15	164.29 (±0.05)	21.0474 (±0.71)	0.445	
	323.15	166.00 (±0.05)	17.3143 (±0.61)	0.452	

Standard errors are given in parentheses

Table 2 Limiting apparent molar volumes (φ_{v}^{0}), experimental slopes (S_{v}), limiting apparent molar volume expansibilities (φ_{E}^{0}), and partial molar volumes of transfer ($\Delta\bar{V}_{\mathrm{tr}}$) for some electrolytes in aqueous SDS solutions at different temperatures

Temperature (K)	φ_{v}^{0} (cm^3 mol^{-1})	S_{v} (cm^3 l$^{1/2}$ mol^{-3})	φ_{E}^{0} (cm^3 mol^{-1} K^{-1})	$[\partial^2\varphi_{\mathrm{v}}^{0}/\partial T^2]_{\mathrm{p}}$	$\Delta\overline{V}_{\mathrm{tr}}^{0}$ (cm^3 mol^{-1})
0.007 m SDS					
KCl					
303.15	28.80 (±0.04)	15.4604 (±0.53)	0.405		0.95
308.15	29.97 (±0.03)	16.1616 (±0.48)	0.412		0.95
313.15	30.89 (±0.03)	10.1818 (±0.43)	0.419	+0.0014	0.99
318.15	32.24 (±0.05)	20.0075 (±0.67)	0.426		1.15
323.15	33.20 (±0.02)	20.6071 (±0.30)	0.433		1.27
KNO_3					
303.15	29.00 (±0.03)	16.9381 (±0.31)	0.139		0.79
308.15	39.76 (±0.06)	15.2856 (±0.67)	0.188		1.00
313.15	40.78 (±0.03)	12.1626 (±0.35)	0.236	+0.0097	1.13
318.15	42.22 (±0.03)	8.8468 (±0.35)	0.285		1.25
323.15	43.56 (±0.02)	7.1200 (±0.28)	0.334		1.76
$MgCl_2$					
303.15	105.38 (±0.07)	15.6617 (±0.12)	0.277		1.11
308.15	106.95 (±0.07)	14.8038 (±0.13)	0.306		1.32
313.15	108.29 (±0.04)	14.2205 (±0.23)	0.335	+0.0058	1.52
318.15	109.67 (±0.02)	14.0413 (±0.30)	0.364		1.59
323.15	111.72 (±0.03)	13.8207 (±0.40)	0.393		1.68
$Mg(NO_3)_2$					
303.15	159.07 (±0.09)	42.3304 (±0.36)	0.424		1.110
308.15	160.84 (±0.03)	26.1392 (±0.42)	0.431		1.560
313.15	162.65 (±0.09)	26.0688 (±1.16)	0.438	+0.0014	1.600
318.15	164.29 (±0.03)	25.2288 (±0.45)	0.445		1.850
323.15	165.68 (±0.05)	18.2689 (±0.70)	0.452		2.000
0.01 m SDS					
KCl					
303.15	29.56 (±0.07)	44.8653 (±0.88)	0.078		0.80
308.15	30.40 (±0.04)	12.1563 (±0.54)	0.165		1.71
313.15	30.88 (±0.06)	19.2159 (±0.85)	0.252	+0.0174	1.51
318.15	32.80 (±0.05)	29.7511 (±0.61)	0.339		0.98
323.15	34.47 (±0.06)	21.5118 (±0.80)	0.426		1.71
KNO_3					
303.15	39.20 (±0.15)	28.0838 (±1.81)	0.102		0.99
308.15	39.91 (±0.08)	29.4016 (±0.91)	0.166		1.15
313.15	41.17 (±0.08)	21.5595 (±0.93)	0.230	+0.0129	1.52
318.15	42.23 (±0.05)	17.3873 (±0.54)	0.295		1.26
323.15	43.16 (±0.55)	9.3223 (±0.65)	0.358		2.06
$MgCl_2$					
303.15	105.48 (±0.06)	22.2100 (±0.82)	0.217		1.21
308.15	106.92 (±0.02)	19.9347 (±0.32)	0.280		1.29
313.15	108.19 (±0.03)	16.7013 (±0.44)	0.345	+0.0128	1.42
318.15	110.27 (±0.03)	17.8407 (±0.34)	0.408		2.19
323.15	111.67 (±0.02)	12.3433 (±0.20)	0.473		2.27
$Mg(NO_3)_2$					
303.15	159.92 (±0.12)	44.4647 (±0.16)	0.328		1.96
308.15	161.36 (±0.03)	27.1540 (±0.46)	0.343		2.08
313.15	163.28 (±0.07)	33.2207 (±0.91)	0.358	+0.0030	2.23
318.15	165.04 (±0.08)	29.6398 (±1.13)	0.373		2.60
323.15	166.82 (±0.06)	23.3773 (±0.86)	0.388		3.14

Standard errors are given in parentheses

Mg^{2+} and the anions are Cl^- and NO_3^-, respectively. Owing to the large size of Cl^- and NO_3^-, they occupy a large space in the hydration sheath, but NO_3^-, being more polar than Cl^- due to its higher oxygen content, occupies more space. Nitrate has three oxygen atoms, which may enhance the formation of hydrogen bonds in aqueous solution [21, 22]. For this reason φ_v^0 values of nitrate-containing electrolyte are greater than those of Cl^-. Desnoyers and Jolicoeur [23] have reported that the strength of ion–solution interactions decreases with increasing charge of the ions. The value of partial molar volumes for magnesium salts is higher than that of potassium salts owing to the higher charge and small size of Mg^{2+} ions.

The measured partial molar volume can be considered to be a sum of the geometric volume of the solute and the change. This simple approach has been widely used in many models [24–30] to interpret partial molar volume for a broad range of solutes. When two charged centers are not separated by a distance of 3–4 Å, their hydration co-spheres overlap, which results in a decrease in the electrostriction [31]. The overlap of two co-spheres of two ionic species shows an increase in volume, whereas the overlap of hydrophobic–hydrophobic species results in an increase in volume and the overlap of hydrophobic groups and ion–hydrophobic groups results in a decrease in volume. The increase of φ_v^0 values with increasing temperature may also be attributed to the reduction in electrostriction with temperature. From these data it may be concluded that the solution of cations in water follows the order: $Mg^{2+} > K^+$. The same results were reported for some metal sulfates in water earlier [32].

The partial molar volume of transfer ($\Delta\bar{V}_{tr}$) for electrolytes from water to surfactant solution are presented in Tables 1 and 2, being calculated as follows:

$$(\Delta\bar{V}_{tr}) = \varphi_v^0(\mathrm{MS}) - \varphi_v^0(\mathrm{W}), \qquad (3)$$

where φ_v^0(MS) and φ_v^0(W) are the partial molar volumes at infinite dilution of the salts in mixed solvent (SDS–water) and in pure water, respectively. The increase of φ_v^0 and $\Delta\bar{V}_{tr}$ for all salts may be attributed to the decrease in electrostriction in the presence of SDS. Thus, the electrostriction effect, which brings about shrinkage in the volume of the solvent, is decreased in the mixed solvent as compared with in pure water.

The $\Delta\bar{V}_{tr}$ values are positive for potassium chloride, potassium nitrate, magnesium chloride, and magnesium nitrate at very low concentrations. The observed $\Delta\bar{V}_{tr}$ values of these salts from water to aqueous SDS system follow the order:

$$Mg(NO_3)_2 > MgCl_2 > KNO_3 > KCl.$$

The $\Delta\bar{V}_{tr}$ values for the magnesium salts are higher than those for the potassium salts in aqueous SDS solutions. This trend may be due to its higher charge and the small size of the Mg^{2+} ion (radius = 0.82 nm). Similar data have been presented by Badarayani and Kumar [33], who reported that 1:2 and 2:1 electrolytes such as Na_2SO_4 and $MgCl_2$, respectively, influence the apparent molar volume and transport properties of volumes and compressibilities of an aqueous amino acid solution more strongly than do 1:1 electrolytes such as KCl, KBr, and NaBr. Banipal et al. also reported significant positive $\Delta\bar{V}_{tr}$ values for some polyols and mono-, di-, and trisaccharides in presence of electrolytes such as NaCl [34], KCl, $SrCl_2$, $BaCl_2$, Gu-HCl [35], $CuCl_2$, and $ZnCl_2$ [36], and suggested that hydrophilic–ionic-type interaction dominates over the hydrophobic–ionic-type interactions. The $\Delta\bar{V}_{tr}$ values for saccharides in solutions of $CuCl_2$ and $ZnCl_2$ reported in [36] are almost twice those in NH_4Br. This again supports the view that divalent cations interact more strongly than monovalent cations with the salts.

The volume transfer values increase with increasing molalities of SDS. This can be rationalized by the co-sphere overlap model, as developed by Friedman and Krishnan [37]. The interaction between the salts and SDS molecules can be classified as follows:

(a) Ion–ion interactions between SO_4^{2-} of SDS and the K^+/Mg^{2+} group of salts
(b) Ion–ion interactions between the Na^+ of SDS and the Cl^-/NO_3^- ion of salts
(c) Hydrophilic–hydrophobic interactions between the hydrophilic/hydrophobic parts of the SDS and anion/cation part of the salts

Taking the co-sphere overlap model [29] as the guideline, (a) and (b) type of interactions would lead to positive $\Delta\bar{V}_{tr}$, since there is a reduction in the electrostriction effect and the overall water structure is enhanced. Interactions of type (c) would lead to negative $\Delta\bar{V}_{tr}$, because of the reduction of water structure that is formed around those groups as a result of co-sphere overlap. Since we have observed positive $\Delta\bar{V}_{tr}$ for the four electrolytes it is concluded that ion–ion and hydrophilic–hydrophilic group interactions are overall predominant over the hydrophobic–hydrophobic group interactions in the ternary system. The temperature dependence of φ_v for the mineral salts was studied in water and in different compositions (Fig. 1).

The values of φ_v^0 increase with increasing temperature for all salts, in water as well as in 0.007 and 0.01 m aqueous SDS solutions, thereby showing that solute–solute interactions are further strengthened with increasing temperature. The temperature dependence of φ_v^0 ($cm^3\ mol^{-1}$) in water for all salts can be expressed by the following expressions:

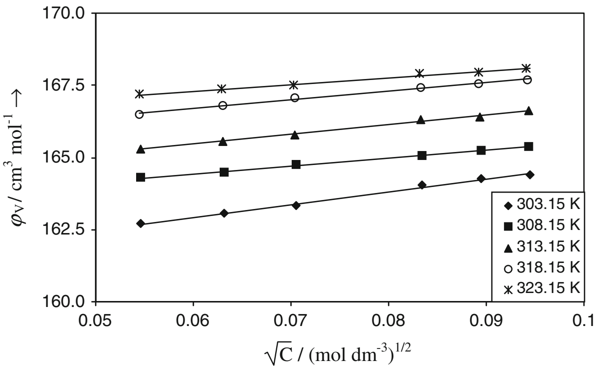

Fig. 1 Plots of apparent molar volume (φ_v) versus $\sqrt{C}$ for magnesium nitrate in 0.007 m aqueous SDS solution at different temperatures

$$\varphi_v^0 = 26.714 + 1.1270T - 0.0150T^2 \quad \text{for potassium chloride,} \tag{4}$$

$$\varphi_v^0 = -431.98 + 2.7167T - 0.0039T^2 \quad \text{for potassium nitrate,} \tag{5}$$

$$\varphi_v^0 = 271.35 - 1.322T + 0.0025T^2 \quad \text{for magnesium chloride,} \tag{6}$$

$$\varphi_v^0 = 157.35 + 1.7267T + 0.0007T^2 \quad \text{for magnesium nitrate.} \tag{7}$$

In 0.007 m SDS–water solution the expressions are:

$$\varphi_v^0 = 27.704 + 1.1027T + 0.0007T^2 \quad \text{for potassium chloride,} \tag{8}$$

$$\varphi_v^0 = 447.70 - 2.832T + 0.0049T^2 \quad \text{for potassium nitrate,} \tag{9}$$

$$\varphi_v^0 = 291.99 - 1.4814T + 0.0029T^2 \quad \text{for magnesium chloride,} \tag{10}$$

$$\varphi_v^0 = 157.32 + 1.7567T + 0.0007T^2 \quad \text{for magnesium nitrate.} \tag{11}$$

In 0.1 m SDS–water solution the expressions are:

$$\varphi_v^0 = 806.79 - 5.197T + 0.0087T^2 \quad \text{for potassium chloride,} \tag{12}$$

$$\varphi_v^0 = 599.08 - 3.778T + 0.0064T^2 \quad \text{for potassium nitrate,} \tag{13}$$

$$\varphi_v^0 = 627.97 - 3.6635T + 0.0064T^2 \quad \text{for magnesium chloride,} \tag{14}$$

$$\varphi_v^0 = 199.43 - 0.5809T + 0.0015T^2 \quad \text{for magnesium nitrate.} \tag{15}$$

In all expressions the temperature T is expressed in Kelvin. The molar volume expansibilities at infinite dilution, $\varphi_E^0 = [\partial\varphi_v^0/\partial T]_p$, calculated using expressions 4–15 for different salts in water and in 0.007 m and in 0.01 m SDS–water are also presented in Tables 1 and 2. It is evident from Tables 1 and 2 that the value of φ_E^0 decreases with increasing temperature for potassium chloride and potassium nitrate in water, but increases with increasing temperature for all the salts studied in 0.01 m aqueous SDS solution. The positive increase in φ_E^0 with increasing temperature for all the electrolytes may be due to the "caging effect" [38]. The variation of φ_E^0 with temperature for all electrolytes, in water as well as in 0.007 and 0.01 m aqueous SDS solutions, has been found to be linear. Representative plots are shown in Fig. 2. During the past few years, it has been emphasized by a number of workers that S_v is not the sole criterion for determining the structure making or breaking nature of any solute. Hepler [39] has developed a technique for examining the sign of various solutes in terms of long-range structure making or breaking capacities of the solutes in aqueous solutions using the general thermodynamic expression: $[\partial C_P/\partial P]_T = [\partial\varphi_v^o/\partial T]_p$. On the basis of this relation, it has been deduced that structure maker solutes should have positive values whereas structure breaker solutes have negative values. In this study it is observed from Table 1 that $[\partial\varphi_v^0/\partial T]_p$ for the solutions of salts (mentioned along with the respective expression) in water are positive for magnesium chloride and magnesium nitrate but negative for potassium chloride and potassium nitrate, showing that magnesium chloride and magnesium nitrate are structure makers whereas potassium chloride and potassium nitrate are structure breakers. A significant increase in $(\frac{\partial^2\varphi_v^0}{\partial T^2})$ values with increasing temperature for potassium chloride and potassium nitrate was observed in the SDS solutions. The structure breaking effect of potassium chloride and potassium nitrate decreases due to its interaction with SDS molecules, and thus more water molecules are released to the bulk water in the presence of SDS and these contribute to the positive $(\frac{\partial^2\varphi_v^0}{\partial T^2})$ observed. In 0.01 m aqueous SDS solution all four electrolytes [KCl, KNO_3, $MgCl_2$, $Mg(NO_3)_2$] show positive $[\partial\varphi_v^0/\partial T]_p$ values, thereby showing that all the electrolytes act as structure makers. In other words, addition

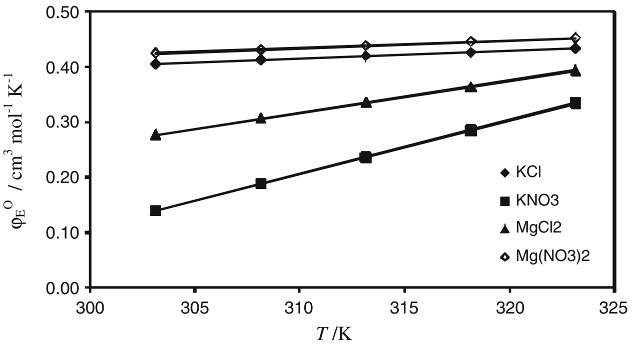

Fig. 2 Variation of limiting apparent molar volume expansibilities (φ_E^0) with temperature for some salts in 0.007 m SDS–water systems

of potassium chloride, potassium nitrate, magnesium chloride, and magnesium nitrate in 0.01 m aqueous SDS solution causes an increase in the structure of water.

Experimental

Potassium chloride (KCl), potassium nitrate (KNO_3), magnesium chloride ($MgCl_2.6H_2O$), and magnesium nitrate [$Mg(NO_3)_2.7H_2O$] were used after drying over P_2O_5 in a desiccator. The reagents were always placed in the desiccator over P_2O_5 to keep them in dry atmosphere. Freshly distilled water (sp. cond. $\sim 10^{-6}\ \Omega^{-1}\ cm^{-1}$) was used for preparing aqueous mixtures of SDS as well as the standard liquid. All the aqueous mixtures of SDS as well as the solutions of electrolytes were made by weight, and molalities (m) were converted into molarities (C) using the standard expression $C = 1{,}000\rho\ m/(1{,}000 + mM_2)$, where ρ is the solution density and M_2 is the molecular weight of an electrolyte.

Densities were measured with an Ostwald–Sprengel-type pycnometer having a bulb volume of 10 cm^3. The pycnometer was calibrated at 303.15, 308.15, 313.15, 318.15, and 323.15 K with double-distilled water. The pycnometer with the test solution was equilibrated in a water bath maintained within ±0.01 K of the desired temperature by means of a mercury-in-glass thermoregulator, and the temperature was determined using a calibrated thermometer and a Muller bridge. The pycnometer was then removed from the thermostatic bath, properly dried, and weighed. The evaporation losses remained insignificant during the time of actual measurement. Average of triplicate measurements was taken into account. The uncertainty in the experimental data for density was estimated to be $\pm 3 \times 10^{-5}$ g cm^{-3}.

Acknowledgments We acknowledge the Department of Chemistry, University of Rajshahi for providing laboratory facilities for the work.

References

1. Crooks WJ, Christian JD (2004) Indian J Chem 43A:1872
2. Krakowiak J, Strzelecki H, Grzybkowski W (2004) J Mol Liq 112:171
3. Paneda EG, Guardado P, Maestre A (2004) J Solution Chem 33:1277
4. Parmar ML, Awasthi RK, Guleria MK (2004) J Chem Sci 116:33
5. Parmar ML, Sharma OP, Guleria MK (2004) Indian J Chem 43A:1868
6. Warminska D, Krakowiak J, Grzybkowski W (2005) J Mol Liq 116:61
7. Zhao CW, Ma PS, Li JD (2005) J Chem Thermodyn 37:37
8. Krakowiak J, Koziel H, Grzybkowski W (2005) J Mol Liq 118:57
9. Salabat A, Shamshiri L, Sahrakar F (2005) J Mol Liq 118:67
10. Parmar ML, Guleria MK (2005) J Ind Chem Soc 82:648
11. Nikam PS, Shewale RP, Sawant AB, Hasan M (2005) J Chem Eng Data 50:487
12. Parmar ML, Banyal DS (2005) Indian J Chem 44A:1582
13. Touitou E, Levi-Schaffer F, Dayan N, Alhaiquem F, Riccieri F (1994) Int J Pharm 103:131
14. Jansen J, Treiner C, Vaution C, Puisieux F (1994) Int J Pharm 103:19
15. Chen J, Shimura S, Kirimura K, Usami S (1994) Biosci Biotechnol Biochem 58:773
16. Forney CE, Glatz CE (1995) Biotech Prog 11:260
17. Goddard ED, Ananthapadmanabhan KP (1993) Interaction of surfactants with polymers and protein. CRC, Boca Raton
18. Masson DO, Philos (1929) Mag 8:218
19. Millero FJ (1971) In: Horne RA (ed) Structure and transport process in water and aqueous solutions, Wiley Interscience, New York
20. Roy MN, Jha A, Choudhury A (2004) J Chem Eng Data 49:291
21. Brady GW (1941) J Phys Chem 28–29:464
22. Islam MN (1990) PhD Thesis, Delhi University, India
23. Desnoyer JE, Jolicoeur SS (1969) In: Bockris JOM, Conwey BE (eds) Modern Aspects of Electrochemistry. Plenum Press, New York
24. Reiss H (1965) Adv Chem Phys 9:1
25. Pierotti R (1965) J Phys Chem 69:81
26. Stillinger FH (1973) J Solution Chem 2:141
27. Hirata FZ, Arakawa K (1973) Bull Chem Soc Japan 46:3387
28. Shilo H, Ogawa T, Yoshiha H (1955) J Am Chem Soc 77:4980
29. Gurney RW (1953) Ionic process in solutions. McGraw Hill, New York
30. Frank HS, Evan MW (1945) J Chem Phys 13:507
31. Chlikian TV, Sarvzyam AP, Breslar KJ (1993) J Phys Chem 97:1017
32. Roy MN (2000) J Teach Res Chem 717
33. Kumar A, Badarayani R, Satpute DB (2005) J Chem Eng Data 50:1083
34. Banipal TS, Sharma S, Lark BS, Banipal PK (1999) Indian J Chem 38A:1106
35. Banipal TS, Singh K, Banipal PK (2004) Indian J Chem 43A:2549
36. Banipal PK, Kaur G, Banipal TS (2004) Indian J Chem 43A:35
37. Friedman HL, Krishnan CV (1973) Water: a comprehensive treatise. Plenum, New York
38. Millero FJ, Drost Harsen WJ (1968) Phys Chem 72:1758
39. Hepler L (1969) Can J Chem 47:4613