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Volumetric and viscometric study on the interaction of amino acid (valine) with an aqueous solution of cationic surfactant, Cetyltrimethylammonium Bromide (CTAB), at 298.15, 303.15, 308.15, and 313.15 K

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Abstract

Interactions between the surfactant (CTAB) and amino acid (valine) were investigated using density and viscosity data. These data were utilized to calculate apparent molar volume, ϕ_v, and partial molar volume also known as limiting molar volume ϕ^0_v and these parameters were further used to find out solute-solvent interactions between amino acid and surfactant at 298.15, 303.15, 308.15 and 313.15 K temperatures.

Keywords: Surfactant; Amino Acid; Volumetric; Viscometric; Solute-solvent interactions

1. Introduction

Understanding the interactions between amino acids and surfactants is important for comprehending how proteins and surfactants interact. This knowledge is especially crucial because surfactants are used in many industrial processes. Surfactants, which are also called wetting agents, help to decrease the tension between two liquids by reducing the surface tension of a liquid. [1-13]. The reduction in interfacial tension allows liquids to spread more easily. Surfactants are widely used in various industries as they enhance the efficiency of industrial processes. Investigating how proteins interact with amphiphilic molecules is an important area of study, which has implications both in vivo and in technical fields. However, studying the effects of solvents/solutes on these complex biological macromolecules can be challenging due to their intricate three-dimensional structures. Therefore, it is more convenient to study the physicochemical properties of amino acids, which are the building blocks of proteins [14-17]. Studies on the interaction of amino acids with surfactants can contribute to understanding the surfactants as tools to isolate, solubilize, and manipulate membrane proteins for subsequent biochemical and physical characterization. Surfactants are substances that decrease the surface tension of liquids and they are used in many biological, agricultural, and chemical processes [18,19]. CTAB has applications in medicine as an apoptosis-promoting anticancer agent and in protein electrophoresis, DNA extraction buffer systems, and nanoparticle synthesis. The interaction between amino acids and surfactants is an essential aspect in the fields of biotechnology and the chemical industry. To find out this interaction, volumetric and viscometric studies can be helpful. In this context, the present paper reports on volumetric and viscometric studies of 0.010, 0.030, 0.050, and 0.070 molar concentrations of amino acid (valine) in 0.03 molar aqueous CTAB at different temperatures (298.15, 303.15, 308.15, and 313.15 K). These studies are expected to shed more light on the solute-solvent interaction between amino acids and surfactants, which is of great significance in various industrial applications.

2. Material and method

The amino acid valine (LobaChemie, Purity > 99%) was dried over P_2O_5 in a vacuum desiccator before use. Cetyltrimethylammonium bromide (analytical reagent grade) was used as received.First stock solution of 0.03 m CTAB

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was prepared in double distilled water and was used as a solvent to prepare (0.01, 0.02, 0.03, 0.04, and 0.05 m) solutions of the amino acid. The weightings were done on an electronic balance (Precisa XB-220A, Swiss make) with a precision of ±0.1m g. The density data of the solutions were measured by using a single stem pycnometer (bulb capacity 8 •$10^{-6}$$m^3$) of Borosil glass equipped with a calibrated capillary and a well-fitted cap at 298.15, 303.15, 308.15, and 313.15 K. Viscosities were measured with a Ubbelohde suspended level viscometer. Densities and viscosities were measured with an accuracy of ±0.01 kg m^{-3} and±3•10^{-6} N s m^{-2}, respectively. The temperature of the test solution during the measurements was maintained to an accuracy of ±0.02 K in an electronically controlled thermostated water bath (JULABO, Model-MD, Germany).

3. Results and discussion

3.1. Volumetric Study

Measured values of density, of 0.01, 0.02, 0.03, 0.04, and 0.05 m, valine in 0.03 m aqueous CTAB at 298.15, 303.15, 308.15, and 313.15 K are given in the table 1. The apparent molar volumes (ϕ_v), were determined from the solution densities using the following equation [20-24]:

$$\phi_v = \frac{M}{\rho} - \frac{1000(\rho-\rho_0)}{m\rho\rho_0} \quad \text{..... (1)}$$

where M is the molar mass of the solute, valine, and m is its molality; ρ_0 and ρare the densities of the solvent (aqueous CTAB) and solution, respectively. The limiting apparent molar volumes (ϕ^0_v) were calculated by applying a least-squares technique to the plots of ϕ_v vs. m using the following equation:

$$\phi_v = \phi^0_v + S^*_v\, m \quad \text{..... (2)}$$

where ϕ^0_v is the partial molar volume at infinite dilution and S^*_v is the experimental slope. It is seen from Table 1 that the value of density increases in the ternary system when there is an increase of the concentration of solute. This may be due to the presence of strong solute-solvent interactions. In other words, the increase in density is the result of the enhanced structure of the solvent mixture due to the presence of added solute (valine) [25]. The study's findings can be understood through the co-sphere overlap model, which suggests that the overlap of hydration cospheres has a negative impact. The research discovered that when two ionic species' cospheres overlap, the volume increases. However, when hydrophobic-hydrophobic and ion-hydrophobic groups overlap, the volume decreases.It is also seen from Table 2 that the ϕ^0_v values increase with the increase in temperature which may be related to the reduction in the electrostriction at the terminals. The solvation effect of valine zwitterions in the solvent [26-29], may also be attributed to the increase in ϕ^0_v values (Table 2) with an increase in temperature.

3.2. Viscometric Studies

The values of viscosities of 0.01, 0.02, 0.03, 0.04, and 0.05 m, valine in 0.03 m aqueous CTAB at 298.15, 303.15, 308.15, and 313.15 K as a function of the molality m of valine are given in table 1. The viscosity A and B coefficients for the valine in aqueous CTAB solutions were calculated from the Jones–Dole equation [30]:

$$\eta_r = \frac{\eta}{\eta_0} = 1 + Am^{1/2} + Bm \quad \text{.....(3)}$$

where η_r is the relative viscosity of the solution, η and η_0 are the viscosities of the solution (Valine + aqueous CTAB) and solvent (aqueous CTAB), respectively.The B -coefficient is empirical and provides information about the structural modifications induced by amino acid-aqueous CTAB interactions [31]. Table 2 contains the values of B-coefficients. The viscosity values, listed in Table 1, increase as the concentration of solute (valine) increases. When a solute is dissolved in a solvent, some of the solvent molecules are attracted to the solute due to solute-solvent interaction, causing an increase in viscosity [32]. Generally, the increase in viscosity of the solution while adding the solute points out the structure-making ability of solutes [33]. The positive values of B-coefficient in the present system (see Table 2) point out the strong solute-solvent interactions and also the solute's structure-making ability [34].

Table 1 Densities (ρ) and viscosities (η) of solutions of valine in CTAB + water solvents at different temperatures

m (mol. kg^{-1})	**T(K)**			
	298.15	**303.15**	**308.15**	**313.15**
Valine + 0.03 m aqueous CTAB				
ρ (kg m^{-3})				
0.00	0.99705	0.99566	0.99401	0.99225
0.01	0.99756	0.99610	0.99453	0.99276
0.02	0.99805	0.99660	0.99500	0.99327
0.03	0.99849	0.99700	0.99545	0.99375
0.04	0.99890	0.99755	0.99596	0.99410
0.05	0.99934	0.99790	0.99640	0.99460
10^3 η (N m^{-2} s)				
0.00	0.8994	0.8050	0.7258	0.6585
0.01	0.9070	0.8119	0.7319	0.6640
0.02	0.9147	0.8186	0.7380	0.6694
0.03	0.9229	0.8252	0.7444	0.6751
0.04	0.9300	0.8318	0.7502	0.6798
0.05	0.9373	0.8386	0.7554	0.6852

Table 2 Partial molar volume at infinite dilution (ϕ^0_v), experimental slope(S^*_v), and B-coefficient of viscosity (B) for valine in 0.03m aqueous CTAB at different temperatures

Property				
	298.15	**303.15**	**308.15**	**313.15**
$10^6.\ \phi^0_v$ /(m^3·mol^{-1})	89.125	89.275	90.511	90.678
$10^6.\ S^*_v$ (m^3·mol^{-1} kg^{-1})	35.002	34.012	28.435	27.000
10^3 .B /(m^3·mol^{-1})	0.465	0.444	0.430	0.426

4. Conclusion

The study shows that density increases in a ternary system with increased concentration of solute, due to the presence of strong solute-solvent interactions. The increase in density is the result of the enhanced structure of the solvent mixture due to the presence of added solute. The co-sphere overlap model explains that the overlap of hydration cospheres negatively impacts the volume, but hydrophobic-hydrophobic and ion-hydrophobic groups overlap and decrease the volume. Furthermore, the study found that ϕ^0_v values increase with temperature, which may be related to the reduction in the electrostriction at the terminals. The solvation effect of valine zwitterions in the solvent is also attributed to the increase in ϕ^0_v values with an increase in temperature. The B-coefficient values and their relation to the structural modifications induced by amino acid-aqueous CTAB interactions. It is observed that the viscosity values increase as the concentration of solute (valine) increases. The increase in viscosity is due to solute-solvent interaction, indicating the structure-making ability of solutes. The positive values of B-coefficient in the present system point out the strong solute-solvent interactions and the solute's structure-making ability.

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