Transfer Properties of Amino Acids from Water to Aqueous Sodium Sulfate Solutions at 298.15 K

Chunli Liu and Chonggui Ren*

Department of Chemistry and Chemistry Engineering, Zao Zhuang University, Zao Zhuang 277160, PR China

Enthalpies of solution and densities of glycine, L-alanine, and L-serine in aqueous solutions of Na_2SO_4 were measured at 298.15 K. Transfer enthalpies ($\Delta_{tr}H$) and transfer partial molar volumes ($\Delta_{tr}V_\phi^0$) of amino acids from water to aqueous solutions of Na_2SO_4 were derived. The $\Delta_{tr}H$ of L-alanine are positive, and the $\Delta_{tr}H$ of glycine and L-serine are negative. The transfer volume of all three of the amino acids are positive. The relative order in the negative value of $\Delta_{tr}H$ of amino acids in the same concentration of Na_2SO_4 is L-serine < glycine < L-alanine, whereas the sequence of $\Delta_{tr}V_\phi^0$ is L-serine > glycine > L-alanine. The results are discussed in terms of the cosphere overlap model.

Introduction

The biological functions of proteins are strongly connected to their structures. The interactions between an inorganic salt and characteristic groups of proteins constitute one of the important factors of protein stabilization. Different salts have different influence; some tend to disrupt protein structures, whereas others protect them.[1] A variety of thermodynamic properties of amino acids in salt solutions such as enthalpies of solution,[2,3] dilution,[4,5] mixing,[6] and so on have been determined. But most of the research work focused on the thermodynamic properties between amino acids and alkali metal or alkaline earth halides. Sodium sulfate has a slight salting-in effect on the peptide group and a strong salting-out effect on the nonpolar groups, which leads to the fact that sodium sulfate stabilizes the native structure of proteins and hence distinguishes itself from the usual protein denaturants.[7] To understand the behavior of proteins in aqueous Na_2SO_4 solutions, we studied the transfer properties of glycine, L-alanine, and L-serine from water to aqueous Na_2SO_4 solutions.

Experimental Section

Glycine, L-alanine, and L-serine (biological reagent, purity > 99 %, Shanghai Chem.) were twice recrystallized from aqueous ethanol solutions and dried under vacuum at 348 K for 6 h. Na_2SO_4 (extra pure, purity > 99 % Tianjin Chem.) was used without further purification. All materials were stored over P_2O_5 prior to use. All solutions were freshly prepared by mass on a Mettler AE200 balance. The uncertainty of molalities, *m*, is less than $(2.0 \cdot 10^{-5})$ $mol \cdot kg^{-1}$.

The measurements of enthalpies of solution were carried out on a RD496 microcalorimeter at 298.15 K, as previously described.[8] The performance of the calorimeter and its reliability for the measurement were ascertained by determining the enthalpy of glycine ($14.15\ kJ \cdot mol^{-1}$)[9] in water, and the data compare well with literature data.[10,11]

The densities of the solutions were measured with an Anton Paar DMA 55 digital densimeter (Austria). The overall uncertainty of the density is dependent on the temperature control of the water bath, the concentration, and the digital densimeter; the uncertainty was estimated to be $1 \cdot 10^{-4}\ g \cdot cm^{-3}$. The densimeter was calibrated with twice distilled water and dried air.[12] The temperature was kept constant using a HAAKEC thermostat bath (Germany) with an uncertainty 0.02 K.

Table 1. Enthalpy of Solution of Glycine, L-Alanine, and L-Serine in Aqueous Solutions of Na_2SO_4 at 298.15 K[a]

$\frac{m}{mol \cdot kg^{-1}}$	$\frac{\Delta_{sol}H_{Gly}}{kJ \cdot mol^{-1}}$	$\frac{m}{mol \cdot kg^{-1}}$	$\frac{\Delta_{sol}H_{Ala}}{kJ \cdot mol^{-1}}$	$\frac{m}{mol \cdot kg^{-1}}$	$\frac{\Delta_{sol}H_{Ser}}{kJ \cdot mol^{-1}}$
0	14.15[9]	0	7.57[9]	0	11.34[9]
0.1999	13.85 ± 0.09	0.2000	7.60 ± 0.09	0.2000	10.34 ± 0.07
0.4986	13.58 ± 0.08	0.5000	7.68 ± 0.09	0.4992	9.74 ± 0.07
0.7004	13.23 ± 0.08	0.6999	7.76 ± 0.07	0.6998	9.58 ± 0.06
0.9979	12.90 ± 0.09	0.9993	7.85 ± 0.07	1.0001	9.49 ± 0.08
1.2000	12.78 ± 0.07	1.2000	7.95 ± 0.06	1.1998	9.43 ± 0.08

[a] The ± values are deviations based on the data of three iterations.

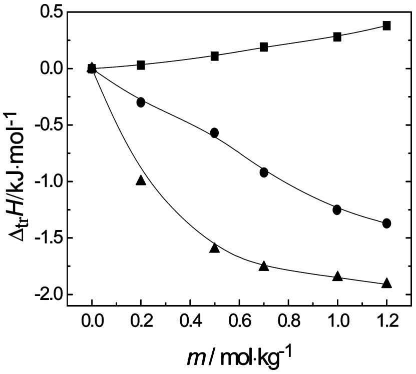

Figure 1. Enthalpy of transfer as a function of molality of Na_2SO_4 (*m*) at 298.15 K of: ●, glycine; ■, L-alanine; ▲, L-serine

Results and Discussion

The enthalpies of solution ($\Delta_{sol}H$) of amino acids in aqueous solutions of Na_2SO_4 are presented in Table 1. The enthalpies of transfer, $\Delta_{tr}H$, were derived from the differences between $\Delta_{sol}H$(s), the enthalpies of solution of amino acids in aqueous Na_2SO_4, and $\Delta_{sol}H$(w), the enthalpies of amino acids in pure water

---

* Corresponding author. Tel: +86 632 3785967. Fax: +86 632 3786819. E-mail: hxxliu@yahoo.cn.

10.1021/je900218z CCC: $40.75

$$\Delta_{\mathrm{tr}}H = \Delta_{\mathrm{sol}}H(\mathrm{s}) - \Delta_{\mathrm{sol}}H(\mathrm{w}) \qquad (1)$$

Figure 1 shows the variation of $\Delta_{\mathrm{tr}}H$ of amino acids with the molality of Na_2SO_4. The enthalpies of transfer of L-alanine are positive and increase with the increasing concentration of Na_2SO_4, whereas the enthalpies of glycine and L-serine are negative and decrease with the increasing concentration of Na_2SO_4. The relative order of $\Delta_{\mathrm{tr}}H$ of amino acids in the same concentration of Na_2SO_4 is L-serine < glycine < L-alanine.

The interaction between salt and amino acid can be assumed to be a sum of three contributions: electrostatic interaction, partial desolvation of solutes, and solvent reorganization.[13] The latter two are structural interaction. Because glycine, L-alanine, and L-serine have very similar dipole moments ($4.51 \cdot 10^{-29}$ C·m, $4.57 \cdot 10^{-29}$ C·m, and $4.57 \cdot 10^{-29}$ C·m, respectively), the contribution of electrostatic interaction to the transfer enthalpy should be approximately the same. Therefore, it is structure interaction that is responsible for the observed variation trends of $\Delta_{\mathrm{tr}}H$. According to the cosphere overlap model,[14,15] when two solute particles come close enough, their cospheres will overlap, and this is accompanied by the change in thermodynamic parameters. The structure interaction between amino acids and Na_2SO_4 can be separated into two types: (a) the hydrophilic−hydrophilic interaction between the zwitterionic headgroup of amino acid or the side group of L-serine and Na_2SO_4 and (b) the hydrophobic−hydrophilic interaction between the side group of L-alanine and Na_2SO_4.

Table 2. Densities and Apparent Molar Volume of Glycine, L-Alanine, and L-Serine in Different Concentration of Aqueous Na_2SO_4 Solutions (m) at 298.15 K

m_{Gly} / $\mathrm{mol \cdot kg^{-1}}$	ρ / $\mathrm{g \cdot cm^{-3}}$	V_ϕ / $\mathrm{cm^3 \cdot mol^{-1}}$	m_{Ala} / $\mathrm{mol \cdot kg^{-1}}$	ρ / $\mathrm{g \cdot cm^{-3}}$	V_ϕ / $\mathrm{cm^3 \cdot mol^{-1}}$	m_{Ser} / $\mathrm{mol \cdot kg^{-1}}$	ρ / $\mathrm{g \cdot cm^{-3}}$	V_ϕ / $\mathrm{cm^3 \cdot mol^{-1}}$
			$m = 0.2000\ \mathrm{mol \cdot kg^{-1}}$					
0	1.02193		0	1.02193		0	1.02193	
0.1171	1.02543	44.65	0.1214	1.02514	61.71	0.1030	1.02627	62.26
0.1624	1.02677	44.67	0.1689	1.02638	61.73	0.1578	1.02855	62.29
0.2705	1.02993	44.78	0.2497	1.02846	61.76	0.2107	1.03072	62.35
0.3482	1.03218	44.82	0.2925	1.02955	61.77	0.2899	1.03395	62.42
0.4486	1.03504	44.90	0.3915	1.03205	61.81	0.3857	1.03779	62.50
0.5666	1.03836	44.96	0.5148	1.03512	61.86	0.5093	1.04266	62.59
			$m = 0.4999\ \mathrm{mol \cdot kg^{-1}}$					
0	1.05730		0	1.05732		0	1.057310	
0.1044	1.06020	46.03	0.1003	1.05971	62.83	0.107	1.06154	63.83
0.1623	1.06179	46.06	0.1365	1.06056	62.84	0.1753	1.06419	63.87
0.2655	1.06460	46.11	0.1854	1.06170	62.87	0.2411	1.06673	63.90
0.3604	1.06714	46.16	0.2813	1.06391	62.92	0.3030	1.06908	63.95
0.4737	1.07013	46.21	0.3797	1.06612	62.97	0.3828	1.07208	63.98
0.5653	1.07253	46.25	0.4645	1.06803	63.01	0.4738	1.07546	64.02
			$m = 0.6999\ \mathrm{mol \cdot kg^{-1}}$					
0	1.07992		0	1.07994		0	1.07993	
0.1019	1.08261	46.82	0.1017	1.08217	63.55	0.0992	1.08368	64.65
0.1596	1.08411	46.84	0.1458	1.08313	63.56	0.1546	1.08575	64.67
0.2296	1.08592	46.86	0.2111	1.08453	63.56	0.2054	1.08764	64.69
0.3329	1.08856	46.88	0.2923	1.08626	63.57	0.2991	1.09107	64.73
0.4428	1.09134	46.91	0.3880	1.08828	63.59	0.4107	1.09508	64.77
0.5563	1.09416	46.95	0.4730	1.09004	63.60	0.4836	1.09768	64.78
	$m = 0.9868\ \mathrm{mol \cdot kg^{-1}}$			$m = 0.9979\ \mathrm{mol \cdot kg^{-1}}$			$m = 0.9999\ \mathrm{mol \cdot kg^{-1}}$	
0	1.11112		0	1.11228		0	1.11248	
0.1038	1.11366	47.62	0.0965	1.11416	64.23	0.1089	1.11635	65.55
0.1834	1.11559	47.64	0.1700	1.11557	64.26	0.1565	1.11801	65.57
0.2360	1.11685	47.64	0.2230	1.11658	64.27	0.2525	1.12133	65.61
0.3413	1.11936	47.66	0.2959	1.11795	64.29	0.3154	1.12348	65.63
0.4352	1.12157	47.67	0.3842	1.11959	64.31	0.3963	1.12622	65.65
0.5189	1.12352	47.67	0.4814	1.12136	64.33	0.5352	1.13083	65.68
	$m = 1.1960\ \mathrm{mol \cdot kg^{-1}}$			$m = 1.1998\ \mathrm{mol \cdot kg^{-1}}$			$m = 1.2001\ \mathrm{mol \cdot kg^{-1}}$	
0	1.13304		0	1.13346		0	1.13345	
0.1087	1.13556	48.12	0.0993	1.13520	64.83	0.1024	1.13692	66.11
0.1732	1.13704	48.12	0.1399	1.13591	64.83	0.1682	1.13913	66.12
0.2843	1.13956	48.13	0.2131	1.13717	64.84	0.2174	1.14076	66.14
0.3971	1.14208	48.14	0.2934	1.13854	64.84	0.3102	1.14379	66.16
0.4858	1.14404	48.15	0.3917	1.14019	64.85	0.4086	1.14696	66.18
0.5539	1.14553	48.16	0.4939	1.14187	64.86	0.4760	1.14911	66.21

Table 3. Standard Partial Molar Volume and Transfer Partial Molar Volume of Glycine, L-Alanine, and L-Serine in Aqueous Solutions of Na_2SO_4 at 298.15 K

glycine			L-alanine			L-serine		
m / $\mathrm{mol \cdot kg^{-1}}$	V_ϕ^0 / $\mathrm{cm^3 \cdot mol^{-1}}$	$\Delta_{\mathrm{tr}}V_\phi^0$ / $\mathrm{cm^3 \cdot mol^{-1}}$	m / $\mathrm{mol \cdot kg^{-1}}$	V_ϕ^0 / $\mathrm{cm^3 \cdot mol^{-1}}$	$\Delta_{\mathrm{tr}}V_\phi^0$ / $\mathrm{cm^3 \cdot mol^{-1}}$	m / $\mathrm{mol \cdot kg^{-1}}$	V_ϕ^0 / $\mathrm{cm^3 \cdot mol^{-1}}$	$\Delta_{\mathrm{tr}}V_\phi^0$ / $\mathrm{cm^3 \cdot mol^{-1}}$
0.2000	44.57	1.54 ± 0.10	0.2000	61.66	1.29 ± 0.08	0.2000	62.17	1.89 ± 0.05
0.4999	45.98	2.95 ± 0.08	0.4999	62.78	2.41 ± 0.06	0.4999	63.77	3.49 ± 0.13
0.6999	46.79	3.76 ± 0.12	0.6999	63.54	3.17 ± 0.12	0.6999	64.62	4.34 ± 0.07
0.9868	47.61	4.58 ± 0.07	0.9979	64.21	3.84 ± 0.08	0.9999	65.52	5.24 ± 0.11
1.1960	48.10	5.07 ± 0.07	1.1998	64.82	4.45 ± 0.06	1.2001	66.08	5.80 ± 0.09

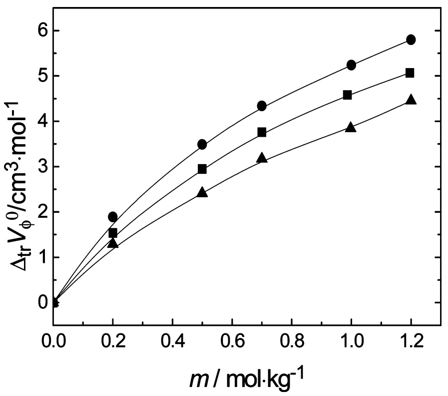

Figure 2. Transfer volumes as a function of molality of Na_2SO_4 (m) at 298.15 K of: ■, glycine; ▲, L-alanine; ●, L-serine.

The major interactions between glycine and Na_2SO_4 are type a, which give a negative contribution to the transfer enthalpy.[14,15] With the increasing concentration of Na_2SO_4 solutions, the hydrophilic−hydrophilic interaction increased, which lead to an enhancement of negative $\Delta_{tr}H$ value. For L-serine, the side group (−CH_2OH) lead to an additional hydrophilic−hydrophilic interaction, so the $\Delta_{tr}H$ of L-serine is less than that of glycine in the same concentration of Na_2SO_4 solutions. In the case of L-alanine, the two types of structure interaction mentioned above are involved. The −CH_3 group of L-alanine provides a tendency of hydrophobic−hydrophilic interaction, which cause a positive contribution to transfer enthalpy, and as a result, the transfer enthalpy of L-alanine is larger than that of glycine. The positive $\Delta_{tr}H$ value of L-alanine suggested that the interaction between the −CH_3 group and Na_2SO_4 makes quite a large contribution to the enthalpic function and even becomes predominant. It also indicates that Na_2SO_4 has a salting out effect on the hydrophobic group. It can be concluded that sodium sulfate tends to stabilize the hydrophobic interactions among the nonpolar groups with the proteins.

The experimentally measured densities of glycine, L-alanine, and L-serine in aqueous Na_2SO_4 solutions at 298.15 K are given in Table 2. Apparent molar volumes (V_ϕ) of the amino acids were calculated from the solution densities (ρ) using the equation

$$V_\phi = M/\rho - 1000(\rho - \rho_0)/m\rho\rho_0 \qquad (2)$$

where M is the molar mass of amino acid and ρ_0 is the density of aqueous Na_2SO_4 solution. Calculated apparent molar volumes for the amino acids are also listed in Table 2. The results can be fit by the equation

$$V_\phi = V_\phi^0 + B_v m \qquad (3)$$

where V_ϕ^0 is the infinite dilution apparent molar volume that equals the standard partial molar volume, and B_v is an experimentally determined parameter. The standard partial molar volumes for the amino acids in aqueous solutions of Na_2SO_4 at 298.15 K are given in Table 3. The V_ϕ^0 values of glycine, L-alanine, and L-serine in water at 298.15 K are (43.03, 60.37, and 60.49) cm^3·mol^{-1}, respectively.[16]

The partial molar volumes of transfer ($\Delta_{tr}V_\phi^0$) from water to aqueous Na_2SO_4 solutions have been calculated by eq 4 and are illustrated in Figure 2.

$$\Delta_{tr}V_\phi^0 = V_\phi^0(\text{in aqueous Na}_2\text{SO}_4\text{solutions}) - V_\phi^0(\text{in water}) \qquad (4)$$

The transfer volumes of the three amino acids are positive and increase with the increasing concentration of Na_2SO_4. The relative order of $\Delta_{tr}V_\phi^0$ of amino acids in the same concentration of Na_2SO_4 is L-serine > glycine > L-alanine.

These tendencies can also be well explained by the cosphere overlap model.[14,15] In infinite dilute solution, the values of transfer volume solely reflect the interactions between amino acids and Na_2SO_4. For polar species, because of the effect of electrostriction, the volume of water molecules is smaller in the solvation sphere, so the interactions of type a would relax some water molecules to the bulk, which gives a positive change in volume. For apolar species, contrarily, the hydrophobic hydration gives a positive volume contribution; interactions of type b would lead to a reduction in the structure of water, and as a result, there will be a negative change in volume. The positive $\Delta_{tr}V_\phi^0$ values of the three amino acids show that the contribution of electrostatic interaction between the zwitterionic headgroup of amino acids and ions to $\Delta_{tr}V_\phi^0$ is dominate, whereas the difference in $\Delta_{tr}V_\phi^0$ of amino acids in the same Na_2SO_4 solutions primarily comes from the influence of side group.

Conclusions

Experimental data for the enthalpy of solution and density of glycine, L-alanine, and L-serine in aqueous solutions of Na_2SO_4 were measured at 298.15 K. The influence of weak interactions between amino acids and Na_2SO_4 on transfer properties is discussed according to cosphere overlap model. It can be seen that the contributions of different interactions to transfer enthalpy and transfer partial molar volume are markedly different. The interactions between side group of amino acids and Na_2SO_4 give larger contributions to transfer enthalpy than to transfer partial molar volume, whereas electrostatic interactions between amino acids and ions give much more contribution to transfer partial molar volume than to transfer enthalpy.

Literature Cited

(1) Hippel, P. H.; Schleich, T. Ion Effects on the Solution Structure of Biological Macromolecules. *Acc. Chem. Res.* **1969**, *2*, 257–265.
(2) Palecz, B. Thermochemical Properties of L-α-Amino Acids in Electrolyte−Water Mixtures. *Fluid Phase Equilib.* **2000**, *167*, 253–261.
(3) Lu, Y.; Bai, T. C.; Xie, W.; Lu, J. S. The Enthalpic Interaction of α-Alanine with Alkali Metal Halides in Water at 298.15 K. *Thermochim. Acta* **1998**, *319*, 11–15.
(4) Yu, L.; Hu, X. G.; Lin, R. S.; Shao, S.; Zhang, H. L. Enthalpic Interactions of Glycine in Aqueous Sodium Halide Solutions. *Thermochim. Acta* **2001**, *378*, 1–8.
(5) Wang, X.; Xu, L.; Lin, R. S.; Sun, D. Z. Enthalpies of Dilution of Glycine, L-Alanine and L-Serine in Aqueous Potassium Chloride Solutions. *Thermochim. Acta* **2005**, *425*, 31–37.
(6) Davis, K. G.; Lilley, T. H. Aqueous Solutions Containing Amino Acids and Peptides. Part 25. The Enthalpy of Interaction at 298.15 K of Glycine with Potassium Halides. *Thermochim. Acta* **1986**, *107*, 267–276.
(7) Kumar, D. Apparent Molar Volume of Some Amino Acids in Aqueous Electrolytes Systems. *Can. J. Chem.* **1999**, *77*, 1288–1294.
(8) Lou, Y.; Lin, R. Enthalpy of Transfer of Amino Acids from Water to Aqueous Glucose Solutions at 298.15 K. *Thermochim. Acta* **1998**, *316*, 145–148.
(9) Liu, C. L.; Lin, R. S.; Xu, N. Enthalpies of Transfer of Amino Acids from Water to Aqueous Solutions of Alkali Metal Nitrates. *J. Chem. Eng. Data* **2005**, *50*, 2094–2096.
(10) Hamdlyyah, M. A.; Shehabuddin, A. Transfer Enthalpies and Entropies of Amino Acids from Water to Urea Solutions. *J. Chem. Eng. Data* **1982**, *27*, 74–76.
(11) Stern, J. H.; Stoner, S. J.; Doyle, G. L. Enthalpies of Transfer of Amino Acids and Sodium Chloride from Water to Aqueous Fructose at 25 °C. *J. Solution Chem.* **1981**, *10*, 263–268.
(12) Lin, G. M.; Bian, P. F.; Lin, R. S. The Limiting Partial Molar Volume and Transfer Partial Molar Volume of Glycylglycine in Aqueous Sodium Halide Solutions at 298.15 and 308.15 K. *J. Chem. Thermodyn.* **2006**, *38*, 144–151.

(13) Lilley, T. H.; Moses, E.; Tasker, I. R. Aqueous Solutions Containing Amino Acids and Peptides. Part 10. Enthalpy of Interaction of Glycine with Some Alkali Metal Chlorides at 298.15 K. *J. Chem. Soc., Faraday Trans. I* **1980**, *76*, 906–914.

(14) Desnoyers, J. E.; Arel, M.; Perron, G.; Jolicoeur, C. Apparent Molal Volumes of Alkali Halides in Water at 25°. Influence of Structural Hydration Interactions on the Concentration Dependence. *J. Phys. Chem.* **1969**, *73*, 3346–3351.

(15) Visser, C. D.; Perron, G.; Desnoyers, J. E. Volumes and Heat Capacities of Ternary Aqueous Systems at 25°. Mixtures of Urea, *tert*-Butyl Alcohol, Dimethylformamide, and Water. *J. Am. Chem. Soc.* **1977**, *99*, 5894–5900.

(16) Liu, C. L.; Zhou, L.; Lin, R. S. Interactions of Some Amino Acids with Aqueous *N*,*N*-Dimethylacetamide Solutions at 298.15 and 308.15 K: A Volumetric Approach. *J. Solution Chem.* **2007**, *36*, 923–937.

Received for review February 25, 2009. Accepted May 25, 2009.

JE900218Z