Concentration Effect of Sodium Chloride and Potassium Chloride on Enthalpies of Mixing of *N*-Glycylglycine with D-Mannitol in Aqueous Solutions at 298.15 K

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The enthalpies of mixing of *N*-glycylglycine with D-mannitol in aqueous sodium chloride and potassium chloride solutions have been determined by using flow-mix isothermal microcalorimetry at 298.15 K. The results, along with the enthalpies of dilution of these solutes, have been analyzed using the McMillan−Mayer theory to obtain the heterotactic enthalpic interaction coefficients (h_{xy}, h_{xxy}, and h_{xyy}). It has been found that the heterotactic enthalpic pairwise interaction coefficients h_{xy} between *N*-glycylglycine and D-mannitol in aqueous sodium chloride or potassium chloride solutions are negative and become less negative as the molality of sodium chloride or potassium chloride increases. The results have been interpreted from the point of view of solute−solute interactions and solvation effects.

Introduction

The folding, structural stability, and dynamics of globular proteins are thought to be extensively controlled by the interactions of the macromolecules with water. Various added substances affect these interactions and consequently alter their functional properties, e.g., catalytic activity, thermostability, surface activity, and structure formation.[1−3]

It is well-known that sugars and polyhydric alcohols help in stabilizing the native conformation of globular proteins or reducing the extent of denaturation by other reagents.[4−8] D-Mannitol is a naturally occurring six-carbon sugar alcohol (polyol), which is widely used in the food, chemical, and pharmaceutical industries, as well as in medicine.[9] It has a sweet cool taste, and it is only partially metabolized by humans and does not induce hyperglycemia, which makes it a suitable component of diabetic food products.[10] In medicine, mannitol is used as a powerful osmotic diuretic, and in many types of surgery it is used for prevention of kidney failure and for reduction of brain edema.[11,12] On the other hand, sodium chloride and potassium chloride are electrolytes that bear an extraordinary important function in biological systems. In addition, small peptides, which contain more complex structure and more components of proteins than amino acids, are often used as model compounds of protein.[13−16] Therefore, studies on the interactions of *N*-glycylglycine (diglycine) with D-mannitol in aqueous sodium chloride and potassium chloride solutions will be helpful to understand the stabilizing mechanism of proteins in biological systems. As a continuation of our previous study,[17,18] the present work is aimed at measuring the enthalpies of mixing of diglycine with D-mannitol in aqueous sodium chloride and potassium chloride solutions. By analyzing the results, the heterotactic enthalpic interaction coefficients of diglycine with D-mannitol in aqueous salt solutions with different molalities are obtained.

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Experimental Section

Materials. Diglycine was purchased from the Tokyo Chemical Industry Co., Ltd. (Japan), and its purity was better than 99 %. It was used without further purification. D-Mannitol was purchased from Aldrich (mass fraction > 99 %). It was dried under reduced pressure at 323 K before being used. Analytical reagent grade sodium chloride and potassium chloride (mass fraction > 99 %, Tianjin Kermel Chemical Reagent Co.) were recrystallized from distilled water and dried under reduced pressure at 393 K. All of the reagents were stored over P_2O_5 in a vacuum desiccator for 72 h at room temperature prior to use. Twice-distilled water was deionized by a quartz sub-boiling purifier. All of the solutions were prepared by weight, using a Mettler AG 135 balance with precision to 0.00001 g. The molality range of the aqueous sodium chloride or potassium chloride solutions was (0 to 0.60) mol·kg^{-1}. The molality ranges of the aqueous diglycine and D-mannitol solutions were (0.08 to 0.35) mol·kg^{-1}. All of the solutions were degassed ultrasonically and used within 12 h of preparation.

Apparatus and Procedure. The enthalpies of dilution and mixing were determined with a 2277-204 measuring cylinder supported by a Thermometric 2277 thermal activity monitor (Thermometric, Sweden) at 298.15 K. The baseline stability (over a period of 24 h) of the Thermometric 2277 thermal activity monitor is 0.2 μW. The solutions were pumped through the mixing-flow vessel of the calorimeter using VS2-10R MIDI dual-channel pumps. The flow rates were determined from the mass of the samples delivered in 6 min. The variation of flow rates was less than 0.1 % both before and after a complete dilution experiment. The relative mean deviation of the mass weighed and the thermal power determined were 0.01 % and 0.3 %, respectively. According to the error propagation, the relative mean deviation of the enthalpies of dilution and mixing was less than 1 %. The details of this apparatus, associated

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Table 1. Enthalpies of Mixing of Mannitol (*x*) and Diglycine (*y*) along with Those of Their Dilution in Water and Aqueous Sodium Chloride Solutions at 298.15 K

m(NaCl)	$m_{x,i}$	$m_{y,i}$	m_x	m_y	$\Delta H_{\mathrm{dil}(x)}$	$\Delta H_{\mathrm{dil}(y)}$	ΔH_{mix}	ΔH^*
(mol·kg^{-1})	(mol·kg^{-1})	(mol·kg^{-1})	(mol·kg^{-1})	(mol·kg^{-1})	(J·kg^{-1})	(J·kg^{-1})	(J·kg^{-1})	(J·kg^{-1})
0.0000	0.0800	0.0800	0.0403	0.0414	−0.12	1.21	−1.30	−2.40
	0.1000	0.1000	0.0505	0.0517	−0.18	1.89	−1.75	−3.46
	0.1200	0.1200	0.0605	0.0623	−0.26	2.71	−2.08	−4.53
	0.1500	0.1500	0.0755	0.0789	−0.40	4.20	−2.72	−6.52
	0.1800	0.1800	0.0906	0.0943	−0.58	6.00	−3.45	−8.87
	0. 2000	0.2000	0.1009	0.1048	−0.71	7.37	−3.95	−10.61
	0.2200	0.2200	0.1105	0.1152	−0.86	8.87	−4.55	−12.56
	0.2500	0.2500	0.1251	0.1327	−1.11	11.32	−5.73	−15.94
	0.2800	0.2800	0.1402	0.1489	−1.40	14.07	−6.93	−19.61
	0.3000	0.3000	0.1504	0.1589	−1.60	16.07	−7.59	−22.05
	0.3200	0.3200	0.1600	0.1709	−1.83	18.14	−8.82	−25.13
	0.3500	0.3500	0.1742	0.1866	−2.21	21.51	−10.25	−29.56
0.1000	0.0800	0.0800	0.0410	0.0419	−0.12	0.81	−0.58	−1.27
	0.1000	0.1000	0.0517	0.0520	−0.19	1.48	−0.77	−2.05
	0.1200	0.1200	0.0619	0.0623	−0.28	2.30	−0.91	−2.92
	0.1500	0.1500	0.0771	0.0784	−0.45	3.72	−1.32	−4.59
	0.1800	0.1800	0.0926	0.0932	−0.66	5.50	−1.67	−6.52
	0.2000	0.2000	0.1022	0.1035	−0.82	6.74	−2.00	−7.92
	0.2200	0.2200	0.1116	0.1133	−1.00	8.28	−2.16	−9.45
	0.2500	0.2500	0.1276	0.1290	−1.29	10.53	−3.06	−12.29
	0.2800	0.2800	0.1425	0.1444	−1.63	13.02	−3.90	−15.28
	0.3000	0.3000	0.1529	0.1541	−1.88	14.88	−4.35	−17.35
	0.3200	0.3200	0.1629	0.1643	−2.15	16.85	−4.93	−19.63
	0.3500	0.3500	0.1783	0.1794	−2.59	19.95	−5.80	−23.16
0. 2000	0.0800	0.0800	0.0402	0.0420	−0.12	0.77	−0.31	−0.96
	0.1000	0.1000	0.0502	0.0524	−0.20	1.31	−0.47	−1.58
	0.1200	0.1200	0.0599	0.0630	−0.30	2.02	−0.53	−2.26
	0.1500	0.1500	0.0749	0.0784	−0.48	3.33	−0.85	−3.70
	0.1800	0.1800	0.0898	0.0939	−0.70	4.86	−1.22	−5.38
	0.2000	0.2000	0.0999	0.1045	−0.87	6.04	−1.47	−6.64
	0.2200	0.2200	0.1094	0.1148	−1.07	7.26	−1.79	−7.98
	0.2500	0.2500	0.1245	0.1305	−1.39	9.48	−2.27	−10.35
	0.2800	0.2800	0.1391	0.1460	−1.77	11.95	−2.81	−12.99
	0.3000	0.3000	0.1489	0.1574	−2.04	13.53	−3.44	−14.93
	0.3200	0.3200	0.1586	0.1661	−2.34	15.46	−3.70	−16.83
	0.3500	0.3500	0.1735	0.1815	−2.83	18.62	−4.38	−20.17
0.3000	0.0800	0.0800	0.0401	0.0413	−0.12	0.66	−0.32	−0.86
	0.1000	0.1000	0.0500	0.0518	−0.21	1.16	−0.48	−1.43
	0.1200	0.1200	0.0599	0.0618	−0.31	1.80	−0.67	−2.15
	0.1500	0.1500	0.0747	0.0771	−0.51	3.00	−0.83	−3.32
	0.1800	0.1800	0.0896	0.0924	−0.75	4.46	−1.18	−4.89
	0.2000	0.2000	0.0994	0.1026	−0.94	5.59	−1.38	−6.03
	0.2200	0.2200	0.1092	0.1126	−1.15	6.83	−1.56	−7.24
	0.2500	0.2500	0.1235	0.1276	−1.51	8.90	−2.05	−9.45
	0.2800	0.2800	0.1388	0.1426	−1.90	11.21	−2.60	−11.91
	0.3000	0.3000	0.1485	0.1533	−2.20	12.86	−3.02	−13.68
	0.3200	0.3200	0.1579	0.1632	−2.52	14.64	−3.41	−15.53
	0.3500	0.3500	0.1712	0.1783	−3.04	17.48	−3.91	−18.35
0.4000	0.0800	0.0800	0.0394	0.0415	−0.17	0.81	−0.21	−0.85
	0.1000	0.1000	0.0493	0.0521	−0.26	1.33	−0.35	−1.42
	0.1200	0.1200	0.0591	0.0625	−0.38	1.97	−0.49	−2.08
	0.1500	0.1500	0.0738	0.0776	−0.60	3.17	−0.75	−3.31
	0.1800	0.1800	0.0886	0.0937	−0.87	4.61	−1.04	−4.78
	0.2000	0.2000	0.0979	0.1040	−1.08	5.72	−1.22	−5.86
	0.2200	0.2200	0.1077	0.1139	−1.31	6.93	−1.51	−7.13
	0.2500	0.2500	0.1222	0.1295	−1.69	8.94	−1.89	−9.14
	0.2800	0.2800	0.1366	0.1445	−2.13	11.19	−2.39	−11.46
	0.3000	0.3000	0.1464	0.1550	−2.44	12.80	−2.88	−13.24
	0.3200	0.3200	0.1560	0.1649	−2.78	14.52	−3.42	−15.16
	0.3500	0.3500	0.1698	0.1801	−3.34	17.26	−4.03	−17.95
0.5000	0.0800	0.0800	0.0392	0.0400	−0.18	0.65	−0.32	−0.80
	0.1000	0.1000	0.0489	0.0501	−0.28	1.12	−0.36	−1.20
	0.1200	0.1200	0.0589	0.0604	−0.41	1.68	−0.44	−1.71
	0.1500	0.1500	0.0734	0.0748	−0.65	2.73	−0.71	−2.79
	0.1800	0.1800	0.0879	0.0901	−0.94	4.01	−0.96	−4.04
	0.2000	0.2000	0.0977	0.1000	−1.16	5.00	−1.25	−5.09
	0.2200	0.2200	0.1073	0.1100	−1.40	6.09	−1.38	−6.07
	0.2500	0.2500	0.1215	0.1250	−1.81	7.92	−1.76	−7.86
	0.2800	0.2800	0.1360	0.1397	−2.28	9.97	−2.25	−9.94
	0.3000	0.3000	0.1452	0.1502	−2.62	11.45	−2.65	−11.48
	0.3200	0.3200	0.1548	0.1593	−2.99	13.00	−2.94	−12.95
	0.3500	0.3500	0.1695	0.1743	−3.59	15.61	−3.46	−15.48

Table 1. Continued

m(NaCl) / (mol·kg^{-1})	$m_{x,i}$ / (mol·kg^{-1})	$m_{y,i}$ / (mol·kg^{-1})	m_x / (mol·kg^{-1})	m_y / (mol·kg^{-1})	$\Delta H_{\mathrm{dil}(x)}$ / (J·kg^{-1})	$\Delta H_{\mathrm{dil}(y)}$ / (J·kg^{-1})	ΔH_{mix} / (J·kg^{-1})	ΔH^* / (J·kg^{-1})
0.6000	0.0800	0.0800	0.0408	0.0410	−0.20	0.54	−0.19	−0.53
	0.1000	0.1000	0.0511	0.0512	−0.32	0.95	−0.34	−0.97
	0.1200	0.1200	0.0612	0.0613	−0.46	1.46	−0.50	−1.50
	0.1500	0.1500	0.0762	0.0767	−0.71	2.42	−0.77	−2.47
	0.1800	0.1800	0.0912	0.0918	−1.02	3.60	−1.05	−3.63
	0.2000	0.2000	0.1012	0.1019	−1.26	4.50	−1.28	−4.52
	0.2200	0.2200	0.1112	0.1120	−1.52	5.49	−1.46	−5.43
	0.2500	0.2500	0.1264	0.1270	−1.95	7.15	−1.80	−6.99
	0.2800	0.2800	0.1416	0.1420	−2.44	9.01	−2.20	−8.77
	0.3000	0.3000	0.1511	0.1523	−2.80	10.35	−2.60	−10.15
	0.3200	0.3200	0.1609	0.1626	−3.19	11.77	−3.00	−11.57
	0.3500	0.3500	0.1755	0.1776	−3.83	14.06	−3.64	−13.87

equipment, and the experimental procedure have been reported elsewhere.[19−23]

Results and Discussion

According to the McMillian−Mayer theory,[24−26] the excess enthalpy $H^{\mathrm{E}}(m_x,m_y)$ of a solution containing 1 kg of solvent, m_x mol of solute x, and m_y mol of solute y can be expressed in terms of a virial expansion of the molalities

$$\begin{aligned} H^{\mathrm{E}}(m_x,m_y) &= H(m_x,m_y) - H^* - H^{\infty}_{x,m} - H^{\infty}_{y,m} \\ &= h_{xx}m_x^2 + 2h_{xy}m_xm_y + h_{yy}m_y^2 + h_{xxx}m_x^3 + \\ &\quad 3h_{xxy}m_x^2m_y + 3h_{xyy}m_xm_y^2 + h_{yyy}m_y^3 + ... \end{aligned} \tag{1}$$

Here, $H(m_x,m_y)$ is the absolute enthalpy of the solution; H^* is the standard enthalpy of 1 kg of pure solvent; and $H^{\infty}_{x,m}$ and $H^{\infty}_{y,\mathrm{m}}$ are the limiting partial molar enthalpies of species x and y, respectively. The h_{ij} and h_{ijk} terms are the enthalpic virial coefficients representing the pairwise and triplet interactions between the subscripted species. To evaluate these coefficients, an auxiliary function ΔH^* is introduced, which is defined as

$$\begin{aligned} \Delta H^* &= \Delta H_{\mathrm{mix}} - \Delta H_{\mathrm{dil}(x)} - \Delta H_{\mathrm{dil}(y)} \\ &= H^{\mathrm{E}}(m_xm_y) - H^{\mathrm{E}}(m_x) - H^{\mathrm{E}}(m_y) \end{aligned} \tag{2}$$

and combining eqs 1 and 2 yields

$$\Delta H^* = 2h_{xy}m_xm_y + 3h_{xxy}m_x{}^2m_y + 3h_{xyy}m_xm_y{}^2 + ... \tag{3}$$

To obtain the experimental quantity ΔH^*, it is necessary to know the enthalpies of dilution of x and y in aqueous sodium chloride and potassium chloride solutions. The enthalpy of dilution, $\Delta H_{\mathrm{dil}(x)}$, of solution x was calculated from the equation

$$\Delta H_{\mathrm{dil}(x)} = P_x/(f_x + f_{\mathrm{s}} - m_{x,i}M_xf_x) \tag{4}$$

where P_x is the dilution thermal power of solute x; $m_{x,i}$ is the initial molality of the solution x before dilution; M_x is the molar mass of solute x; and f_x and f_{s} are the flow rates of solution x and the solvent, respectively. The dilution enthalpies $\Delta H_{\mathrm{dil}(y)}$ of solution y can be calculated from eq 4 as long as subscript x in eq 4 is replaced by y.

The final molality m_x was calculated from the equation

$$m_x = m_{x,i}f_x/[f_{\mathrm{s}}(m_{x,i}M_x + 1) + f_x] \tag{5}$$

The enthalpy of mixing, ΔH_{mix}, of an aqueous x solution and an aqueous y solution was calculated from the equation

$$\Delta H_{\mathrm{mix}} = P_{\mathrm{mix}}/(f_x + f_y - m_{x,i}M_xf_x - m_{y,i}M_yf_y) \tag{6}$$

The experimental values of enthalpies of dilution and mixing of D-mannitol (x) with diglycine (y) in aqueous sodium chloride and potassium chloride solutions are given in Table 1 and Table 2, respectively, together with those of ΔH^*. The data were fitted by eq 3 using a least-squares procedure to obtain the heterotactic enthalpic interaction coefficients (Table 3 and Table 4).

Due to the complexities of the interaction among three or four solute molecules, it is difficult to display their regularities with increasing molalities of aqueous salt solutions.[27,28] So only the pairwise interactions are considered here. The enthalpic pairwise interaction coefficients, h_{xy}, are a measure of the solvent-mediated solute−solute interactions, and therefore, their values are treated as a result of competition between the solvation effects and solute−solute interaction. It is generally accepted that the h_{xy} coefficients are attributed to the interactions between two solvated solute molecules and is very sensitive to the solvent variation. The interaction of two solvated species can be represented as the partial dehydration of the solutes and the direct interaction caused by short-range molecular forces.[29]

From Tables 3 and 4 and the corresponding plots in the Supporting Information, we can see that the investigated values of h_{xy} for diglycine−mannitol in water or in aqueous sodium chloride and potassium chloride solutions are negative. These results indicate that the mutual approach of a diglycine molecule and a mannitol molecule in water and aqueous sodium chloride or potassium chloride solutions is an exoergic process. This could be attributed to the following cooperative effects: (1) partial dehydration of the hydration shell (positive contribution to h_{xy}), (2) solvent reorganization in the neighborhood of the hydrophobic groups (negative contribution to h_{xy}),[30] (3) direct interaction between solute molecules and interaction of the solute molecules with the coexisting ions in the solvents. This direct interaction is comprised of three types of interaction: (i) dipole−dipole interaction between the polar groups (carbonyl group, amino group, and carboxyl group) of diglycine and the hydroxyl group of D-mannitol molecules (negative contribution to h_{xy}); (ii) hydrophobic−hydrophilic interaction between the apolar group of diglycine and the hydroxyl group of D-mannitol

Table 2. Enthalpies of Mixing of Mannitol (*x*) and Diglycine (*y*) along with Those of Their Dilution in Aqueous Potassium Chloride Solutions at 298.15 K

m(KCl)	$m_{x,i}$	$m_{y,i}$	m_x	m_y	$\Delta H_{\mathrm{dil}(x)}$	$\Delta H_{\mathrm{dil}(y)}$	ΔH_{mix}	ΔH^*
(mol·kg^{-1})	(mol·kg^{-1})	(mol·kg^{-1})	(mol·kg^{-1})	(mol·kg^{-1})	(J·kg^{-1})	(J·kg^{-1})	(J·kg^{-1})	(J·kg^{-1})
0.1000	0.0800	0.0800	0.0410	0.0419	−0.17	1.64	−0.63	−2.10
	0.1000	0.1000	0.0514	0.0523	−0.26	2.40	−0.77	−2.92
	0.1200	0.1200	0.0618	0.0628	−0.35	3.29	−0.95	−3.88
	0.1500	0.1500	0.0765	0.0784	−0.53	4.88	−1.33	−5.68
	0.1800	0.1800	0.0918	0.0940	−0.74	6.76	−1.70	−7.72
	0.2000	0.2000	0.1019	0.1045	−0.89	8.17	−2.13	−9.41
	0.2200	0.2200	0.1122	0.1149	−1.06	9.67	−2.46	−11.07
	0.2500	0.2500	0.1268	0.1305	−1.35	12.27	−3.08	−14.00
	0.2800	0.2800	0.1421	0.1461	−1.68	15.13	−3.76	−17.21
	0.3000	0.3000	0.1520	0.1566	−1.92	17.20	−4.24	−19.53
	0.3200	0.3200	0.1621	0.1671	−2.18	19.41	−4.84	−22.07
	0.3500	0.3500	0.1770	0.1826	−2.60	22.98	−5.78	−26.15
0.2000	0.0800	0.0800	0.0399	0.0424	−0.20	1.30	−0.64	−1.74
	0.1000	0.1000	0.0500	0.0529	−0.30	1.95	−0.77	−2.42
	0.1200	0.1200	0.0596	0.0634	−0.41	2.73	−0.92	−3.24
	0.1500	0.1500	0.0745	0.0789	−0.61	4.12	−1.22	−4.73
	0.1800	0.1800	0.0892	0.0951	−0.85	5.77	−1.56	−6.48
	0.2000	0.2000	0.0990	0.1053	−1.02	7.01	−1.82	−7.81
	0.2200	0.2200	0.1087	0.1161	−1.22	8.35	−2.19	−9.31
	0.2500	0.2500	0.1232	0.1319	−1.55	10.57	−2.65	−11.67
	0.2800	0.2800	0.1377	0.1474	−1.92	13.02	−3.24	−14.34
	0.3000	0.3000	0.1475	0.1578	−2.18	14.77	−3.76	−16.34
	0.3200	0.3200	0.1576	0.1676	−2.48	16.62	−4.27	−18.42
	0.3500	0.3500	0.1713	0.1827	−2.95	19.57	−4.96	−21.58
0.3000	0.0800	0.0800	0.0405	0.0424	−0.22	0.83	−0.57	−1.18
	0.1000	0.1000	0.0507	0.0530	−0.32	1.30	−0.65	−1.63
	0.1200	0.1200	0.0608	0.0635	−0.45	1.87	−0.96	−2.38
	0.1500	0.1500	0.0757	0.0793	−0.67	2.90	−1.33	−3.56
	0.1800	0.1800	0.0907	0.0951	−0.93	4.09	−1.76	−4.92
	0.2000	0.2000	0.1007	0.1056	−1.12	5.00	−1.99	−5.87
	0.2200	0.2200	0.1107	0.1160	−1.34	5.98	−2.31	−6.95
	0.2500	0.2500	0.1256	0.1319	−1.70	7.60	−2.81	−8.71
	0.2800	0.2800	0.1401	0.1469	−2.12	9.38	−3.32	−10.58
	0.3000	0.3000	0.1503	0.1563	−2.42	10.69	−3.47	−11.74
	0.3200	0.3200	0.1600	0.1684	−2.75	11.99	−4.08	−13.32
	0.3500	0.3500	0.1740	0.1843	−3.30	14.11	−4.61	−15.42
0.4000	0.0800	0.0800	0.0396	0.0435	−0.22	1.07	−0.77	−1.62
	0.1000	0.1000	0.0496	0.0543	−0.34	1.61	−0.86	−2.13
	0.1200	0.1200	0.0592	0.0651	−0.47	2.28	−1.03	−2.84
	0.1500	0.1500	0.0739	0.0795	−0.71	3.48	−1.24	−4.01
	0.1800	0.1800	0.0887	0.0947	−1.00	4.92	−1.65	−5.57
	0.2000	0.2000	0.0983	0.1059	−1.22	6.01	−1.95	−6.74
	0.2200	0.2200	0.1081	0.1160	−1.45	7.20	−2.22	−7.97
	0.2500	0.2500	0.1226	0.1324	−1.85	9.17	−2.71	−10.03
	0.2800	0.2800	0.1367	0.1466	−2.30	11.37	−3.23	−12.31
	0.3000	0.3000	0.1464	0.1577	−2.63	12.93	−3.74	−14.05
	0.3200	0.3200	0.1561	0.1679	−2.97	14.58	−4.36	−15.97
	0.3500	0.3500	0.1701	0.1855	−3.54	17.13	−5.30	−18.89
0.5000	0.0800	0.0800	0.0403	0.0427	−0.23	1.78	−0.84	−2.38
	0.1000	0.1000	0.0503	0.0533	−0.35	2.45	−0.86	−2.96
	0.1200	0.1200	0.0605	0.0638	−0.50	3.20	−0.94	−3.64
	0.1500	0.1500	0.0755	0.0795	−0.75	4.45	−1.16	−4.86
	0.1800	0.1800	0.0906	0.0956	−1.06	5.90	−1.41	−6.25
	0.2000	0.2000	0.1003	0.1061	−1.29	6.95	−1.68	−7.34
	0.2200	0.2200	0.1102	0.1165	−1.55	8.09	−1.98	−8.52
	0.2500	0.2500	0.1249	0.1321	−1.97	9.93	−2.52	−10.48
	0.2800	0.2800	0.1396	0.1485	−2.45	11.96	−3.18	−12.69
	0.3000	0.3000	0.1493	0.1579	−2.80	13.39	−3.70	−14.29
	0.3200	0.3200	0.1596	0.1693	−3.19	14.94	−4.37	−16.13
	0.3500	0.3500	0.1742	0.1838	−3.81	17.38	−5.25	−18.82
0.6000	0.0800	0.0800	0.0397	0.0425	−0.23	1.00	−0.40	−1.16
	0.1000	0.1000	0.0497	0.0534	−0.36	1.48	−0.56	−1.68
	0.1200	0.1200	0.0596	0.0643	−0.51	2.05	−0.75	−2.29
	0.1500	0.1500	0.0742	0.0798	−0.78	3.07	−1.03	−3.32
	0.1800	0.1800	0.0888	0.0956	−1.10	4.31	−1.43	−4.64
	0.2000	0.2000	0.0989	0.1061	−1.34	5.26	−1.72	−5.63
	0.2200	0.2200	0.1087	0.1165	−1.62	6.30	−2.05	−6.74
	0.2500	0.2500	0.1228	0.1322	−2.07	8.07	−2.50	−8.51
	0.2800	0.2800	0.1377	0.1480	−2.58	10.07	−3.19	−10.68
	0.3000	0.3000	0.1473	0.1580	−2.95	11.55	−3.55	−12.15
	0.3200	0.3200	0.1568	0.1685	−3.35	13.14	−3.93	−13.72
	0.3500	0.3500	0.1711	0.1841	−4.00	15.76	−4.39	−16.15

Table 3. Enthalpic Interaction Coefficients of *N*-Glycylglycine with Mannitol in Water and Aqueous Sodium Chloride Solutions at 298.15 K

m(NaCl)	h_{xy}	h_{xxy}	h_{xyy}	
(mol·kg^{-1})	(J·kg·mol^{-2})	(J·kg^2·mol^{-3})	(J·kg^2·mol^{-3})	SD
0.0000	−502 ± 12	1934 ± 785	−1582 ± 701	0.0687
0.1000	−398 ± 5	1449 ± 784	−1313 ± 792	0.0358
0.2000	−328 ± 4	−614 ± 337	608 ± 325	0.0316
0.3000	−297 ± 5	−787 ± 415	735 ± 388	0.0354
0.4000	−283 ± 5	−2372 ± 1322	2195 ± 1243	0.0433
0.5000	−259 ± 6	1178 ± 889	−1162 ± 864	0.0479
0.6000	−238 ± 3	2598 ± 473	−2522 ± 459	0.0231

Table 4. Enthalpic Interaction Coefficients of *N*-Glycylglycine with Mannitol in Aqueous Potassium Chloride Solutions at 298.15 K

m(KCl)	h_{xy}	h_{xxy}	h_{xyy}	
(mol·kg^{-1})	(J·kg·mol^{-2})	(J·kg^2·mol^{-3})	(J·kg^2·mol^{-3})	SD
0.1000	−438 ± 10	5649 ± 2801	−5311 ± 2683	0.0470
0.2000	−365 ± 3	−919 ± 413	−967 ± 391	0.0249
0.3000	−318 ± 5	801 ± 314	−469 ± 287	0.0430
0.4000	−293 ± 6	−774 ± 329	722 ± 291	0.0412
0.5000	−283 ± 4	−1102 ± 519	1087 ± 496	0.0359
0.6000	−257 ± 4	−2716 ± 1196	2543 ± 1108	0.0331

molecules (positive contribution to h_{xy}); and (iii) dipole−ion interaction between the polar groups of diglycine molecules or the hydroxyl group of D-mannitol molecules and the ions (Na^+, K^+, or Cl^-) of the solvent (negative contribution to h_{xy}).

The value of h_{xy} for diglycine−mannitol in aqueous potassium chloride solutions is less than that in aqueous sodium chloride solutions. This kind of difference is mainly ascribed to the different ion radius. Marcus specified that K^+ is a structure-breaking ion, while Na^+ is a borderline ion.[31] The interaction between the polar groups of diglycine molecules or the hydroxyl group of mannitol molecules and the ions of the solvent is an exothermic process. The dehydration of diglycine molecules and mannitol molecules in aqueous potassium chloride solutions is more difficult than that in aqueous sodium chloride solutions, which is an endothermic process. The resulting sign of h_{xy} is a consequence of the competitive equilibrium between the above effects.

On the other hand, the values of h_{xy} for the diglycine−mannitol system increase positively with elevation of molality of sodium chloride and potassium chloride solutions. This variation trend is the result of the influence of sodium/potassium chloride on the interaction of the diglycine molecules with polyol molecules. The larger the molality of sodium/potassium chloride, the more difficult the departure of water molechles from the ions or solute molecules, which gives a negative contribution to h_{xy}. Consequently, the value of h_{xy} of the investigated systems becomes less negative with the elevated molality of sodium chloride or potassium chloride.

Supporting Information Available:

Plots of enthalpic pair interaction coefficients (h_{xy}) of diglycine with D-mannitol versus the molality m of sodium chloride and potassium chloride in aqueous solutions at 298.15 K. This material is available free of charge via the Internet at http://pubs.acs.org.

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