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Volumetric Properties and Refractive Indices of *N*,*N*′-Hexamethylenebisacetamide in Aqueous Glucose and Sucrose Solutions

Lina Dong, Min Liu,* Guangqian Li, Lili Wang, Dezhi Sun, Xilian Wei, and Youying Di

College of Chemistry and Chemical Engineering, Liaocheng University, Liaocheng 252059, People's Republic of China

ABSTRACT: Densities (ρ) of *N*,*N*′-hexamethylenebisacetamide (HMBA) in pure water and aqueous glucose and sucrose solutions have been measured at T = (288.15, 293.15, 298.15, 303.15, and 308.15) K with a quartz vibrating-tube densimeter. These experimental data have been used to calculate some important physical parameters, including apparent molar volumes (V_ϕ), limiting partial molar volumes (V_ϕ^0), and transfer partial molar volumes ($\Delta_{trs}V_\phi^0$). Another physical parameter, molar refraction at the sodium-D line (R_D), has been computed from the refractive index (n_D) measured by a refractometer at 298.15 K. The variations of all above parameters are discussed in terms of interactions occurring in the solutions.

INTRODUCTION

Volumetric properties of solute in aqueous solutions are of importance to elucidate the physicochemical phenomena occurring in simulated body fluids. Volumetric properties, such as limiting partial molar volumes, can provide valuable information and lead to a deeper understanding of intermolecular interactions.[1,2] Additionally, the refractive index is another thermodynamic parameter to illustrate the interactions in aqueous system.[3,4]

N,*N*′-Hexamethylenebisacetamide (HMBA), an efficient polar differentiation-inducing agent, has been proved to inhibit the proliferation and induce the differentiation of many kinds of cancer cells.[5,6] Researchers have show much attention to HMBA and have done plenty of studies on it because of its revulsive function.[7] Although saccharide solutions are important substances in biosystem, there is no systematic research, to the best of our knowledge, based on volumetric properties and the refractive index of HMBA in aqueous glucose and sucrose solutions. In this paper, we report the densities (ρ) and refractive indices (n_D) of HMBA in aqueous glucose and sucrose solutions [from (0 to 0.8000) mol·kg^{-1}] at different temperatures [from (288.15 to 308.15) K]. The values are used to compute apparent molar volumes (V_ϕ), limiting partial molar volumes (V_ϕ^0), transfer partial molar volumes ($\Delta_{trs}V_\phi^0$), and molar refraction at the sodium-D line (R_D). All of these parameters are discussed in terms of solute−solvent and solute−solute interactions occurring in the HMBA + glucose or sucrose + water systems.

EXPERIMENTAL SECTION

Materials. *N*,*N*′-Hexamethylenebisacetamide (HMBA) is obtained from Acros with the mass fraction better than 0.98. Sucrose is an analytical reagent with mass fraction > 0.99, which is purchased from Tianjin Kermel Chemical Reagent Company (Tianjin, China). Glucose is a product of Aladdin Chemistry Co. Ltd. (Shanghai, China) whose purity is better than 0.99. All of the reagents were stored over P_2O_5 in a vacuum desiccator for 72 h at room temperature prior to use without further purification. Twice-distilled water was used in the experiment.

Table 1. Comparison of Experimental Density (ρ) and Refractive Indices (n_D) with Literature Values at Different Temperatures

	ρ (g·cm^{-3})		n_D	
T (K)	exptl.	lit.	exptl.	lit.
		pure water		
288.15	0.999107	0.999099[8]		
293.15	0.998207	0.998203[8]		
298.15	0.997047	0.997043[8]	1.3320	1.3325[10]
303.15	0.995649	0.995645[8]		
308.15	0.994030	0.994029[8]		
		water + glucose (0.2 mol·kg^{-1})		
298.15	1.010377	1.010386[11]		
		water + glucose (0.8 mol·kg^{-1})		
298.15	1.047272	1.046847[11]		
		water + sucrose (0.1 mol·kg^{-1})		
298.15	1.009966	1.009900[12]		
		water + sucrose (0.2 mol·kg^{-1})		
298.15	1.022084	1.022120[12]		

Solutions Preparation. Solutions of different concentrations were prepared by weight using a Mettler Toledo AG 135 analytical balance with a precision of ± 0.01 mg. Stopperd glass cuvettes were used to avoid evaporation of solutions in the experiment. Besides, all liquids were degassed with ultrasonic waves and used within 12 h of preparation.

Density Measurements. Densities were measured with a quartz vibrating-tube densimeter (Anton Paar DMA 5000) thermostatted to ± 0.001 K. The precision of the instrument was

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Table 2. Values of Densities (ρ) and Apparent Molar Volumes (V_ϕ) of HMBA in Aqueous Glucose and Sucrose Solutions at T = (288.15, 293.15, 298.15, 303.15, and 308.15) K

	288.15 K		293.15 K		298.15 K		303.15 K		308.15 K	
m_{HMBA} ($mol \cdot kg^{-1}$)	ρ [a] ($g \cdot cm^{-3}$)	V_ϕ ($cm^3 \cdot mol^{-1}$)	ρ ($g \cdot cm^{-3}$)	V_ϕ ($cm^3 \cdot mol^{-1}$)	ρ ($g \cdot cm^{-3}$)	V_ϕ ($cm^3 \cdot mol^{-1}$)	ρ ($g \cdot cm^{-3}$)	V_ϕ ($cm^3 \cdot mol^{-1}$)	ρ ($g \cdot cm^{-3}$)	V_ϕ ($cm^3 \cdot mol^{-1}$)
					H_2O					
0.0000	0.999107 ± 0.000001		0.998207 ± 0.000002		0.997047 ± 0.000000		0.995649 ± 0.000002		0.994030 ± 0.000002	
0.0999	1.000159 ± 0.000001	189.71 ± 0.04	0.999201 ± 0.000002	190.46 ± 0.06	0.997982 ± 0.000001	191.28 ± 0.03	0.996530 ± 0.000001	192.09 ± 0.05	0.994869 ± 0.000001	192.82 ± 0.05
0.1498	1.000680 ± 0.000000	189.64 ± 0.02	0.999691 ± 0.000001	190.41 ± 0.03	0.998441 ± 0.000000	191.24 ± 0.01	0.996965 ± 0.000002	192.04 ± 0.03	0.995284 ± 0.000003	192.77 ± 0.05
0.1998	1.001225 ± 0.000000	189.44 ± 0.01	1.000198 ± 0.000000	190.26 ± 0.02	0.998923 ± 0.000002	191.07 ± 0.02	0.997419 ± 0.000001	191.88 ± 0.02	0.995708 ± 0.000001	192.66 ± 0.02
0.2500	1.001780 ± 0.000001	189.24 ± 0.01	1.000721 ± 0.000000	190.07 ± 0.02	0.999415 ± 0.000002	190.89 ± 0.02	0.997884 ± 0.000002	191.71 ± 0.02	0.996146 ± 0.000001	192.51 ± 0.02
0.3001	1.002341 ± 0.000002	189.05 ± 0.02	1.001247 ± 0.000001	189.90 ± 0.02	0.999908 ± 0.000000	190.74 ± 0.01	0.998347 ± 0.000000	191.57 ± 0.02	0.996580 ± 0.000001	192.39 ± 0.02
0.3503	1.002880 ± 0.000002	188.96 ± 0.01	1.001754 ± 0.000001	189.80 ± 0.01	1.000383 ± 0.000001	190.66 ± 0.01	0.998795 ± 0.000001	191.49 ± 0.02	0.997002 ± 0.000001	192.32 ± 0.01
0.3984	1.003424 ± 0.000001	188.79 ± 0.01	1.002262 ± 0.000002	189.65 ± 0.02	1.000865 ± 0.000001	190.50 ± 0.01	0.999248 ± 0.000002	191.35 ± 0.01	0.997432 ± 0.000002	192.18 ± 0.02
					$m_{glucose} = 0.0500\ mol \cdot kg^{-1}$					
0.0000	1.002576 ± 0.000000		1.001646 ± 0.000000		1.000463 ± 0.000001		0.999043 ± 0.000001		0.997458 ± 0.000002	
0.1000	1.003553 ± 0.000001	189.86 ± 0.03	1.002566 ± 0.000002	190.61 ± 0.04	1.001326 ± 0.000001	191.40 ± 0.03	0.999856 ± 0.000001	192.17 ± 0.03	0.998225 ± 0.000002	192.93 ± 0.06
0.1500	1.004051 ± 0.000002	189.70 ± 0.03	1.003031 ± 0.000003	190.48 ± 0.04	1.001763 ± 0.000000	191.28 ± 0.02	1.000267 ± 0.000000	192.06 ± 0.03	0.998605 ± 0.000001	192.88 ± 0.03
0.1998	1.004570 ± 0.000001	189.46 ± 0.01	1.003517 ± 0.000001	190.26 ± 0.01	1.002219 ± 0.000001	191.07 ± 0.02	1.000695 ± 0.000001	191.87 ± 0.02	0.998989 ± 0.000003	192.79 ± 0.04
0.2493	1.005079 ± 0.000000	189.30 ± 0.01	1.003994 ± 0.000002	190.12 ± 0.02	1.002667 ± 0.000002	190.93 ± 0.02	1.001114 ± 0.000001	191.75 ± 0.01	0.999379 ± 0.000002	192.67 ± 0.02
0.2913	1.005517 ± 0.000001	189.17 ± 0.01	1.004406 ± 0.000001	189.98 ± 0.01	1.003052 ± 0.000001	190.81 ± 0.01	1.001477 ± 0.000002	191.63 ± 0.01	0.999708 ± 0.000001	192.59 ± 0.02
0.3501	1.006151 ± 0.000002	188.93 ± 0.01	1.004997 ± 0.000001	189.78 ± 0.01	1.003608 ± 0.000001	190.61 ± 0.01	1.002000 ± 0.000001	191.44 ± 0.01	1.000179 ± 0.000002	192.45 ± 0.02
0.4000	1.006696 ± 0.000001	188.74 ± 0.01	1.005507 ± 0.000002	189.60 ± 0.01	1.004085 ± 0.000002	190.45 ± 0.01	1.002448 ± 0.000002	191.29 ± 0.01	1.000613 ± 0.000001	192.25 ± 0.01
					$m_{glucose} = 0.1000\ mol \cdot kg^{-1}$					
0.0000	1.005997 ± 0.000000		1.005045 ± 0.000001		1.003835 ± 0.000001		1.002394 ± 0.000001		1.000746 ± 0.000002	
0.0999	1.006891 ± 0.000001	190.07 ± 0.03	1.005885 ± 0.000002	190.79 ± 0.05	1.004613 ± 0.000002	191.64 ± 0.05	1.003129 ± 0.000001	192.34 ± 0.03	1.001441 ± 0.000001	193.05 ± 0.05
0.1500	1.007379 ± 0.000002	189.72 ± 0.03	1.006336 ± 0.000001	190.51 ± 0.02	1.005051 ± 0.000001	191.24 ± 0.02	1.003525 ± 0.000002	192.08 ± 0.03	1.001810 ± 0.000002	192.84 ± 0.04
0.2001	1.007861 ± 0.000002	189.53 ± 0.02	1.006793 ± 0.000001	190.30 ± 0.02	1.005465 ± 0.000001	191.12 ± 0.02	1.003918 ± 0.000002	191.93 ± 0.02	1.002177 ± 0.000000	192.71 ± 0.02
0.2492	1.008341 ± 0.000001	189.35 ± 0.01	1.007237 ± 0.000002	190.15 ± 0.02	1.005878 ± 0.000001	190.99 ± 0.01	1.004311 ± 0.000001	191.78 ± 0.01	1.002539 ± 0.000001	192.60 ± 0.02
0.3001	1.008839 ± 0.000001	189.19 ± 0.01	1.007697 ± 0.000000	190.02 ± 0.01	1.006315 ± 0.000000	190.84 ± 0.01	1.004717 ± 0.000000	191.65 ± 0.01	1.002918 ± 0.000001	192.49 ± 0.02
0.3499	1.009326 ± 0.000000	189.06 ± 0.01	1.008154 ± 0.000001	189.89 ± 0.01	1.006739 ± 0.000002	190.73 ± 0.01	1.005116 ± 0.000001	191.54 ± 0.01	1.003289 ± 0.000000	192.38 ± 0.01
0.4001	1.009845 ± 0.000001	188.86 ± 0.01	1.008642 ± 0.000001	189.70 ± 0.01	1.007184 ± 0.000002	190.57 ± 0.01	1.005531 ± 0.000002	191.40 ± 0.01	1.003676 ± 0.000001	192.26 ± 0.01
					$m_{glucose} = 0.2000\ mol \cdot kg^{-1}$					
0.0000	1.012639 ± 0.000002		1.011635 ± 0.000002		1.010377 ± 0.000002		1.008897 ± 0.000002		1.007207 ± 0.000001	
0.1000	1.013413 ± 0.000002	190.09 ± 0.06	1.012353 ± 0.000001	190.83 ± 0.05	1.011043 ± 0.000002	191.57 ± 0.06	1.009515 ± 0.000002	192.32 ± 0.06	1.007784 ± 0.000002	193.05 ± 0.05
0.1501	1.013832 ± 0.000002	189.81 ± 0.04	1.012739 ± 0.000002	190.58 ± 0.04	1.011404 ± 0.000002	191.33 ± 0.04	1.009851 ± 0.000001	192.09 ± 0.04	1.008095 ± 0.000002	192.85 ± 0.03
0.1999	1.014261 ± 0.000001	189.56 ± 0.02	1.013144 ± 0.000000	190.32 ± 0.02	1.011772 ± 0.000001	191.12 ± 0.02	1.010195 ± 0.000001	191.89 ± 0.02	1.008411 ± 0.000001	192.68 ± 0.02
0.2501	1.014709 ± 0.000000	189.32 ± 0.02	1.013552 ± 0.000000	190.13 ± 0.02	1.012158 ± 0.000000	190.91 ± 0.02	1.010545 ± 0.000001	191.73 ± 0.02	1.008735 ± 0.000001	192.53 ± 0.01
0.2999	1.015165 ± 0.000002	189.09 ± 0.02	1.013972 ± 0.000002	189.92 ± 0.02	1.012539 ± 0.000002	190.75 ± 0.02	1.010901 ± 0.000002	191.57 ± 0.02	1.009075 ± 0.000002	192.35 ± 0.02
0.3497	1.015597 ± 0.000000	188.98 ± 0.01	1.014372 ± 0.000001	189.82 ± 0.01	1.012914 ± 0.000000	190.64 ± 0.01	1.011251 ± 0.000000	191.45 ± 0.01	1.009391 ± 0.000000	192.27 ± 0.01

Table 2. Continued

m_{HMBA}	288.15 K		293.15 K		298.15 K		303.15 K		308.15 K	
(mol·kg^{-1})	ρ [a] (g·cm^{-3})	V_ϕ (cm^3·mol^{-1})	ρ (g·cm^{-3})	V_ϕ (cm^3·mol^{-1})	ρ (g·cm^{-3})	V_ϕ (cm^3·mol^{-1})	ρ (g·cm^{-3})	V_ϕ (cm^3·mol^{-1})	ρ (g·cm^{-3})	V_ϕ (cm^3·mol^{-1})
0.4001	1.016065 ± 0.000001	188.79 ± 0.01	1.014806 ± 0.000002	189.64 ± 0.01	1.013311 ± 0.000001	190.49 ± 0.01	1.011624 ± 0.000002	191.30 ± 0.01	1.009741 ± 0.000002	192.12 ± 0.01
					$m_{glucose} = 0.3000$ mol·kg^{-1}					
0.0000	1.019211 ± 0.000000		1.018155 ± 0.000000		1.016853 ± 0.000001		1.015330 ± 0.000001		1.013627 ± 0.000001	
0.1000	1.019807 ± 0.000002	190.66 ± 0.04	1.018697 ± 0.000002	191.38 ± 0.04	1.017348 ± 0.000000	192.08 ± 0.02	1.015782 ± 0.000000	192.79 ± 0.04	1.014025 ± 0.000001	193.64 ± 0.03
0.1502	1.020148 ± 0.000000	190.32 ± 0.01	1.019006 ± 0.000001	191.08 ± 0.02	1.017631 ± 0.000002	191.80 ± 0.03	1.016040 ± 0.000000	192.54 ± 0.01	1.014255 ± 0.000001	193.40 ± 0.02
0.2001	1.020531 ± 0.000002	189.91 ± 0.02	1.019361 ± 0.000001	190.67 ± 0.01	1.017949 ± 0.000000	191.46 ± 0.01	1.016337 ± 0.000001	192.18 ± 0.02	1.014521 ± 0.000002	193.07 ± 0.02
0.2499	1.020910 ± 0.000000	189.64 ± 0.01	1.019703 ± 0.000001	190.44 ± 0.01	1.018267 ± 0.000001	191.22 ± 0.01	1.016622 ± 0.000002	192.00 ± 0.01	1.014785 ± 0.000000	192.86 ± 0.01
0.2999	1.021313 ± 0.000001	189.37 ± 0.01	1.020072 ± 0.000001	190.18 ± 0.01	1.018608 ± 0.000002	190.97 ± 0.02	1.016936 ± 0.000001	191.76 ± 0.01	1.015062 ± 0.000001	192.66 ± 0.01
0.3501	1.021702 ± 0.000002	189.19 ± 0.01	1.020427 ± 0.000001	190.02 ± 0.01	1.018931 ± 0.000000	190.83 ± 0.01	1.017232 ± 0.000001	191.63 ± 0.01	1.015339 ± 0.000002	192.50 ± 0.01
0.3983	1.022125 ± 0.000001	188.92 ± 0.01	1.020815 ± 0.000002	189.77 ± 0.01	1.019292 ± 0.000002	190.58 ± 0.01	1.017578 ± 0.000002	191.36 ± 0.01	1.015636 ± 0.000002	192.30 ± 0.01
					$m_{glucose} = 0.5000$ mol·kg^{-1}					
0.0000	1.031873 ± 0.000000		1.030726 ± 0.000000		1.029342 ± 0.000000		1.027748 ± 0.000001		1.025959 ± 0.000000	
0.1000	1.032229 ± 0.000001	190.68 ± 0.02	1.031020 ± 0.000002	191.49 ± 0.04	1.029572 ± 0.000003	192.36 ± 0.06	1.027947 ± 0.000002	192.95 ± 0.03	1.026119 ± 0.000003	193.66 ± 0.06
0.1500	1.032472 ± 0.000002	190.23 ± 0.03	1.031233 ± 0.000001	191.03 ± 0.03	1.029751 ± 0.000002	191.92 ± 0.03	1.028101 ± 0.000003	192.58 ± 0.03	1.026256 ± 0.000003	193.28 ± 0.04
0.1998	1.032732 ± 0.000000	189.90 ± 0.00	1.031464 ± 0.000001	190.70 ± 0.01	1.029962 ± 0.000002	191.53 ± 0.02	1.028292 ± 0.000001	192.19 ± 0.01	1.026402 ± 0.000002	193.02 ± 0.02
0.2501	1.033034 ± 0.000002	189.52 ± 0.02	1.031735 ± 0.000002	190.33 ± 0.02	1.030211 ± 0.000002	191.13 ± 0.02	1.028496 ± 0.000002	191.90 ± 0.02	1.026608 ± 0.000001	192.63 ± 0.01
0.3000	1.033305 ± 0.000000	189.35 ± 0.00	1.031983 ± 0.000002	190.13 ± 0.01	1.030429 ± 0.000000	190.95 ± 0.00	1.028687 ± 0.000000	191.73 ± 0.01	1.026760 ± 0.000001	192.53 ± 0.01
0.3500	1.033639 ± 0.000003	189.03 ± 0.02	1.032262 ± 0.000002	189.90 ± 0.02	1.030682 ± 0.000003	190.71 ± 0.02	1.028915 ± 0.000002	191.50 ± 0.02	1.026985 ± 0.000002	192.24 ± 0.01
0.3999	1.034065 ± 0.000001	188.55 ± 0.01	1.032670 ± 0.000001	189.38 ± 0.01	1.031062 ± 0.000001	190.19 ± 0.01	1.029242 ± 0.000002	191.06 ± 0.01	1.027281 ± 0.000002	191.82 ± 0.01
					$m_{glucose} = 0.8000$ mol·kg^{-1}					
0.0000	1.050044 ± 0.000000		1.048764 ± 0.000001		1.047272 ± 0.000001		1.045576 ± 0.000000		1.043699 ± 0.000001	
0.0998	1.049899 ± 0.000002	192.08 ± 0.04	1.048574 ± 0.000002	192.73 ± 0.04	1.047023 ± 0.000002	193.56 ± 0.04	1.045303 ± 0.000001	194.10 ± 0.04	1.043387 ± 0.000000	194.82 ± 0.02
0.1472	1.049939 ± 0.000001	191.40 ± 0.01	1.048580 ± 0.000001	192.14 ± 0.02	1.047015 ± 0.000000	192.88 ± 0.01	1.045259 ± 0.000001	193.58 ± 0.01	1.043323 ± 0.000001	194.31 ± 0.02
0.1998	1.050032 ± 0.000002	190.79 ± 0.02	1.048647 ± 0.000001	191.52 ± 0.01	1.047034 ± 0.000001	192.37 ± 0.01	1.045271 ± 0.000000	193.00 ± 0.02	1.043301 ± 0.000002	193.80 ± 0.02
0.2501	1.050154 ± 0.000002	190.32 ± 0.02	1.048729 ± 0.000002	191.10 ± 0.02	1.047105 ± 0.000002	191.88 ± 0.02	1.045302 ± 0.000002	192.60 ± 0.02	1.043319 ± 0.000003	193.36 ± 0.02
0.3002	1.050279 ± 0.000001	189.98 ± 0.01	1.048823 ± 0.000002	190.78 ± 0.01	1.047169 ± 0.000001	191.57 ± 0.01	1.045332 ± 0.000001	192.34 ± 0.01	1.043324 ± 0.000002	193.11 ± 0.01
0.3500	1.050448 ± 0.000003	189.62 ± 0.02	1.048951 ± 0.000001	190.45 ± 0.01	1.047267 ± 0.000002	191.25 ± 0.01	1.045401 ± 0.000003	192.04 ± 0.02	1.043366 ± 0.000001	192.83 ± 0.01
0.4000	1.050675 ± 0.000002	189.19 ± 0.01	1.049160 ± 0.000002	190.00 ± 0.01	1.047467 ± 0.000002	190.76 ± 0.01	1.045556 ± 0.000003	191.60 ± 0.01	1.043495 ± 0.000001	192.40 ± 0.01
					$m_{sucrose} = 0.0500$ mol·kg^{-1}					
0.0000	1.005674 ± 0.000000		1.004731 ± 0.000000		1.003532 ± 0.000000		1.002105 ± 0.000001		1.000461 ± 0.000001	
0.0998	1.006588 ± 0.000000	189.92 ± 0.02	1.005587 ± 0.000002	190.68 ± 0.04	1.004328 ± 0.000002	191.50 ± 0.04	1.002852 ± 0.000002	192.26 ± 0.02	1.001169 ± 0.000001	192.96 ± 0.03
0.1499	1.007071 ± 0.000001	189.67 ± 0.02	1.006037 ± 0.000000	190.46 ± 0.01	1.004755 ± 0.000000	191.24 ± 0.01	1.003247 ± 0.000000	192.05 ± 0.02	1.001530 ± 0.000000	192.86 ± 0.02
0.1999	1.007558 ± 0.000001	189.48 ± 0.01	1.006492 ± 0.000000	190.28 ± 0.01	1.005176 ± 0.000001	191.10 ± 0.01	1.003645 ± 0.000000	191.89 ± 0.02	1.001904 ± 0.000000	192.70 ± 0.01
0.2498	1.008061 ± 0.000001	189.25 ± 0.01	1.006961 ± 0.000001	190.07 ± 0.01	1.005614 ± 0.000002	190.90 ± 0.02	1.004051 ± 0.000001	191.73 ± 0.01	1.002291 ± 0.000000	192.52 ± 0.01
0.2997	1.008568 ± 0.000002	189.06 ± 0.02	1.007432 ± 0.000002	189.90 ± 0.02	1.006056 ± 0.000002	190.73 ± 0.02	1.004467 ± 0.000002	191.56 ± 0.02	1.002676 ± 0.000002	192.38 ± 0.02

Table 2. Continued

m_{HMBA} (mol·kg^{-1})	288.15 K ρ^a (g·cm^{-3})	288.15 K V_ϕ (cm^3·mol^{-1})	293.15 K ρ (g·cm^{-3})	293.15 K V_ϕ (cm^3·mol^{-1})	298.15 K ρ (g·cm^{-3})	298.15 K V_ϕ (cm^3·mol^{-1})	303.15 K ρ (g·cm^{-3})	303.15 K V_ϕ (cm^3·mol^{-1})	308.15 K ρ (g·cm^{-3})	308.15 K V_ϕ (cm^3·mol^{-1})
0.3500	1.009060 ± 0.000000	188.95 ± 0.01	1.007892 ± 0.000000	189.79 ± 0.01	1.006489 ± 0.000000	190.62 ± 0.00	1.004868 ± 0.000000	191.47 ± 0.01	1.003049 ± 0.000001	192.30 ± 0.01
0.4001	1.009582 ± 0.000001	188.76 ± 0.01	1.008372 ± 0.000002	189.64 ± 0.01	1.006938 ± 0.000001	190.48 ± 0.01	1.005290 ± 0.000002	191.32 ± 0.01	1.003443 ± 0.000002	192.17 ± 0.01
					$m_{sucrose} = 0.1000$ mol·kg^{-1}					
0.0000	1.012182 ± 0.000001		1.011201 ± 0.000001		1.009966 ± 0.000000		1.008504 ± 0.000001		1.006834 ± 0.000000	
0.1001	1.012975 ± 0.000002	189.99 ± 0.05	1.011939 ± 0.000001	190.71 ± 0.02	1.010645 ± 0.000001	191.52 ± 0.02	1.009135 ± 0.000002	192.27 ± 0.05	1.007421 ± 0.000001	193.02 ± 0.02
0.1497	1.013398 ± 0.000002	189.71 ± 0.03	1.012322 ± 0.000002	190.53 ± 0.03	1.011016 ± 0.000001	191.23 ± 0.02	1.009477 ± 0.000002	192.02 ± 0.03	1.007733 ± 0.000001	192.82 ± 0.02
0.1998	1.013846 ± 0.000002	189.43 ± 0.02	1.012736 ± 0.000002	190.26 ± 0.02	1.011391 ± 0.000002	191.04 ± 0.02	1.009825 ± 0.000002	191.84 ± 0.02	1.008064 ± 0.000002	192.61 ± 0.02
0.2500	1.014305 ± 0.000001	189.18 ± 0.01	1.013155 ± 0.000001	190.05 ± 0.01	1.011778 ± 0.000001	190.86 ± 0.01	1.010183 ± 0.000001	191.67 ± 0.01	1.008397 ± 0.000003	192.45 ± 0.03
0.2995	1.014759 ± 0.000000	188.99 ± 0.01	1.013576 ± 0.000001	189.86 ± 0.01	1.012169 ± 0.000001	190.68 ± 0.01	1.010556 ± 0.000000	191.47 ± 0.01	1.008735 ± 0.000001	192.30 ± 0.01
0.3498	1.015213 ± 0.000001	188.85 ± 0.01	1.013994 ± 0.000000	189.73 ± 0.01	1.012565 ± 0.000000	190.53 ± 0.00	1.010909 ± 0.000000	191.37 ± 0.01	1.009065 ± 0.000001	192.20 ± 0.01
0.3991	1.015684 ± 0.000002	188.65 ± 0.01	1.014435 ± 0.000001	189.53 ± 0.01	1.012957 ± 0.000001	190.39 ± 0.01	1.011292 ± 0.000001	191.19 ± 0.01	1.009405 ± 0.000002	192.08 ± 0.01
					$m_{sucrose} = 0.2000$ mol·kg^{-1}					
0.0000	1.024442 ± 0.000001		1.023385 ± 0.000001		1.022084 ± 0.000001		1.020565 ± 0.000001		1.018841 ± 0.000002	
0.1000	1.025000 ± 0.000001	190.08 ± 0.03	1.023889 ± 0.000000	190.80 ± 0.02	1.022533 ± 0.000000	191.57 ± 0.02	1.020967 ± 0.000002	192.31 ± 0.03	1.019197 ± 0.000001	193.08 ± 0.04
0.1500	1.025335 ± 0.000002	189.66 ± 0.03	1.024191 ± 0.000001	190.42 ± 0.02	1.022801 ± 0.000001	191.24 ± 0.02	1.021207 ± 0.000002	192.01 ± 0.03	1.019411 ± 0.000002	192.81 ± 0.04
0.1996	1.025671 ± 0.000001	189.41 ± 0.01	1.024491 ± 0.000002	190.21 ± 0.02	1.023071 ± 0.000002	191.03 ± 0.02	1.021461 ± 0.000001	191.77 ± 0.01	1.019631 ± 0.000001	192.61 ± 0.02
0.2488	1.026021 ± 0.000002	189.16 ± 0.02	1.024812 ± 0.000001	189.96 ± 0.01	1.023372 ± 0.000002	190.76 ± 0.02	1.021721 ± 0.000002	191.57 ± 0.02	1.019864 ± 0.000001	192.42 ± 0.02
0.2998	1.026400 ± 0.000000	188.92 ± 0.01	1.025152 ± 0.000000	189.75 ± 0.01	1.023677 ± 0.000000	190.57 ± 0.01	1.021998 ± 0.000000	191.39 ± 0.01	1.020115 ± 0.000001	192.24 ± 0.01
0.3501	1.026769 ± 0.000002	188.74 ± 0.01	1.025494 ± 0.000002	189.56 ± 0.01	1.023968 ± 0.000001	190.45 ± 0.01	1.022290 ± 0.000000	191.19 ± 0.01	1.020361 ± 0.000002	192.11 ± 0.02
0.3999	1.027163 ± 0.000002	188.52 ± 0.01	1.025852 ± 0.000001	189.36 ± 0.01	1.024311 ± 0.000002	190.21 ± 0.01	1.022569 ± 0.000001	191.06 ± 0.01	1.020619 ± 0.000002	191.96 ± 0.01
					$m_{sucrose} = 0.3000$ mol·kg^{-1}					
0.0000	1.036524 ± 0.000000		1.035394 ± 0.000000		1.034031 ± 0.000001		1.032455 ± 0.000001		1.030684 ± 0.000001	
0.0999	1.036789 ± 0.000000	190.70 ± 0.00	1.035599 ± 0.000002	191.48 ± 0.04	1.034181 ± 0.000002	192.26 ± 0.04	1.032565 ± 0.000002	192.93 ± 0.02	1.030747 ± 0.000002	193.71 ± 0.05
0.1501	1.036991 ± 0.000002	190.24 ± 0.03	1.035769 ± 0.000001	191.03 ± 0.01	1.034321 ± 0.000001	191.83 ± 0.02	1.032669 ± 0.000001	192.61 ± 0.03	1.030823 ± 0.000001	193.42 ± 0.03
0.2001	1.037208 ± 0.000002	189.92 ± 0.02	1.035951 ± 0.000002	190.73 ± 0.02	1.034471 ± 0.000002	191.55 ± 0.02	1.032800 ± 0.000001	192.30 ± 0.02	1.030923 ± 0.000002	193.15 ± 0.03
0.2502	1.037423 ± 0.000001	189.71 ± 0.01	1.036136 ± 0.000001	190.53 ± 0.01	1.034621 ± 0.000000	191.37 ± 0.01	1.032914 ± 0.000000	192.18 ± 0.01	1.031019 ± 0.000002	192.99 ± 0.02
0.2997	1.037699 ± 0.000001	189.36 ± 0.01	1.036380 ± 0.000000	190.18 ± 0.00	1.034842 ± 0.000000	191.01 ± 0.01	1.033106 ± 0.000001	191.83 ± 0.01	1.031184 ± 0.000000	192.65 ± 0.01
0.3499	1.037994 ± 0.000001	189.04 ± 0.01	1.036639 ± 0.000001	189.89 ± 0.01	1.035061 ± 0.000001	190.75 ± 0.01	1.033308 ± 0.000002	191.54 ± 0.01	1.031358 ± 0.000000	192.38 ± 0.01
0.4002	1.038253 ± 0.000002	188.89 ± 0.01	1.036854 ± 0.000002	189.76 ± 0.01	1.035259 ± 0.000002	190.59 ± 0.01	1.033467 ± 0.000003	191.42 ± 0.01	1.031479 ± 0.000001	192.30 ± 0.01
					$m_{sucrose} = 0.5000$ mol·kg^{-1}					
0.0000	1.059359 ± 0.000000		1.058095 ± 0.000001		1.056615 ± 0.000000		1.054931 ± 0.000000		1.053067 ± 0.000000	
0.1000	1.059025 ± 0.000001	192.09 ± 0.02	1.057703 ± 0.000001	192.86 ± 0.02	1.056171 ± 0.000001	193.61 ± 0.02	1.054443 ± 0.000001	194.33 ± 0.02	1.052534 ± 0.000001	195.09 ± 0.02
0.1500	1.058944 ± 0.000001	191.60 ± 0.01	1.057591 ± 0.000002	192.38 ± 0.02	1.056030 ± 0.000002	193.15 ± 0.03	1.054276 ± 0.000002	193.90 ± 0.01	1.052342 ± 0.000002	194.68 ± 0.03
0.2001	1.058931 ± 0.000000	191.04 ± 0.00	1.057550 ± 0.000000	191.82 ± 0.00	1.055958 ± 0.000000	192.61 ± 0.00	1.054178 ± 0.000001	193.37 ± 0.00	1.052218 ± 0.000001	194.17 ± 0.01
0.2499	1.058971 ± 0.000002	190.51 ± 0.02	1.057552 ± 0.000002	191.32 ± 0.02	1.055926 ± 0.000002	192.14 ± 0.02	1.054113 ± 0.000002	192.94 ± 0.02	1.052126 ± 0.000002	193.76 ± 0.02

Table 2. Continued

m_{HMBA} (mol·kg^{-1})	288.15 K ρ[a] (g·cm^{-3})	288.15 K V_ϕ (cm^3·mol^{-1})	293.15 K ρ (g·cm^{-3})	293.15 K V_ϕ (cm^3·mol^{-1})	298.15 K ρ (g·cm^{-3})	298.15 K V_ϕ (cm^3·mol^{-1})	303.15 K ρ (g·cm^{-3})	303.15 K V_ϕ (cm^3·mol^{-1})	308.15 K ρ (g·cm^{-3})	308.15 K V_ϕ (cm^3·mol^{-1})
0.3000	1.059079 ± 0.000002	189.94 ± 0.01	1.057624 ± 0.000001	190.77 ± 0.01	1.055966 ± 0.000002	191.60 ± 0.01	1.054125 ± 0.000002	192.41 ± 0.01	1.052111 ± 0.000002	193.24 ± 0.01
0.3497	1.059121 ± 0.000001	189.71 ± 0.01	1.057634 ± 0.000000	190.54 ± 0.00	1.055968 ± 0.000002	191.32 ± 0.01	1.054079 ± 0.000001	192.20 ± 0.01	1.052038 ± 0.000000	193.03 ± 0.00
0.4003	1.059234 ± 0.000002	189.36 ± 0.01	1.057716 ± 0.000002	190.20 ± 0.01	1.055995 ± 0.000002	191.05 ± 0.01	1.054099 ± 0.000003	191.87 ± 0.01	1.052051 ± 0.000003	192.66 ± 0.01
					$m_{sucrose}$ = 0.8000 mol·kg^{-1}					
0.0000	1.089543 ± 0.000001		1.088099 ± 0.000001		1.086461 ± 0.000001		1.084645 ± 0.000001		1.082653 ± 0.000001	
0.1001	1.088479 ± 0.000001	192.96 ± 0.03	1.086969 ± 0.000000	193.80 ± 0.03	1.085279 ± 0.000001	194.56 ± 0.03	1.083410 ± 0.000001	195.36 ± 0.03	1.081377 ± 0.000001	196.10 ± 0.03
0.1501	1.088214 ± 0.000002	191.51 ± 0.03	1.086671 ± 0.000002	192.35 ± 0.03	1.084953 ± 0.000002	193.12 ± 0.03	1.083058 ± 0.000002	193.92 ± 0.03	1.081001 ± 0.000002	194.68 ± 0.03
0.2000	1.087954 ± 0.000002	190.79 ± 0.02	1.086389 ± 0.000001	191.59 ± 0.01	1.084640 ± 0.000002	192.38 ± 0.02	1.082727 ± 0.000002	193.14 ± 0.02	1.080647 ± 0.000002	193.91 ± 0.02
0.2500	1.087976 ± 0.000000	189.37 ± 0.01	1.086381 ± 0.000001	190.17 ± 0.01	1.084599 ± 0.000001	190.98 ± 0.01	1.082651 ± 0.000002	191.78 ± 0.01	1.080544 ± 0.000001	192.56 ± 0.01
0.3001	1.087496 ± 0.000001	189.92 ± 0.01	1.085870 ± 0.000000	190.73 ± 0.01	1.084059 ± 0.000001	191.55 ± 0.01	1.082083 ± 0.000003	192.36 ± 0.01	1.079951 ± 0.000003	193.15 ± 0.02
0.3497	1.087061 ± 0.000002	190.23 ± 0.01	1.085399 ± 0.000002	191.06 ± 0.01	1.083564 ± 0.000001	191.87 ± 0.01	1.081562 ± 0.000003	192.69 ± 0.01	1.079403 ± 0.000003	193.50 ± 0.02
0.4003	1.086606 ± 0.000003	190.51 ± 0.01	1.084942 ± 0.000003	191.28 ± 0.01	1.083022 ± 0.000003	192.23 ± 0.01	1.081054 ± 0.000003	192.91 ± 0.01	1.078882 ± 0.000003	193.70 ± 0.02

[a] Data are expressed as experimental mean ± S.D. (N = 3).

Table 3. Limiting Partial Molar Volumes (V_ϕ^0) and Experimental Slopes (S_V) of HMBA in Aqueous Glucose and Sucrose Solutions at T = (288.15, 293.15, 298.15, 303.15, and 308.15) K

$m_{solvent}$ mol·kg^{-1}	V_ϕ^0, cm^3·mol^{-1} 288.15 K	293.15 K	298.15 K	303.15 K	308.15 K	S_V, cm^3·kg·mol^{-2} 288.15 K	293.15 K	298.15 K	303.15 K	308.15 K
					H_2O					
0.0000	190.07 ± 0.04	190.80 ± 0.04	191.60 ± 0.04	192.38 ± 0.03	193.07 ± 0.03	−3.23 ± 0.15	−2.87 ± 0.14	−2.74 ± 0.15	−2.60 ± 0.13	−2.21 ± 0.10
					glucose					
0.0500	190.24 ± 0.02	190.96 ± 0.02	191.73 ± 0.02	192.48 ± 0.02	193.21 ± 0.05	−3.73 ± 0.08	−3.39 ± 0.07	−3.20 ± 0.07	−2.96 ± 0.06	−2.23 ± 0.17
0.1000	190.34 ± 0.07	191.04 ± 0.06	191.82 ± 0.09	192.56 ± 0.05	193.24 ± 0.03	−3.78 ± 0.25	−3.42 ± 0.21	−3.22 ± 0.32	−2.98 ± 0.18	−2.51 ± 0.13
0.2000	190.45 ± 0.06	191.16 ± 0.06	191.86 ± 0.05	192.60 ± 0.04	193.31 ± 0.04	−4.31 ± 0.23	−3.92 ± 0.22	−3.57 ± 0.20	−3.33 ± 0.16	−3.06 ± 0.13
0.3000	191.15 ± 0.08	191.84 ± 0.08	192.52 ± 0.06	193.21 ± 0.06	194.03 ± 0.06	−5.75 ± 0.30	−5.34 ± 0.30	−4.97 ± 0.24	−4.68 ± 0.24	−4.47 ± 0.22
0.5000	191.28 ± 0.08	192.05 ± 0.09	192.95 ± 0.10	193.47 ± 0.09	194.18 ± 0.08	−6.67 ± 0.30	−6.54 ± 0.35	−6.79 ± 0.37	−5.92 ± 0.32	−5.78 ± 0.30
0.8000	192.80 ± 0.15	193.43 ± 0.13	194.25 ± 0.14	194.75 ± 0.13	195.45 ± 0.12	−9.27 ± 0.55	−8.75 ± 0.50	−8.86 ± 0.51	−8.00 ± 0.47	−7.76 ± 0.43
					sucrose					
0.0500	190.25 ± 0.05	190.98 ± 0.04	191.77 ± 0.05	192.52 ± 0.04	193.24 ± 0.03	−3.81 ± 0.17	−3.45 ± 0.15	−3.33 ± 0.17	−3.08 ± 0.13	−2.72 ± 0.12
0.1000	190.36 ± 0.06	191.09 ± 0.04	191.81 ± 0.05	192.57 ± 0.04	193.28 ± 0.05	−4.42 ± 0.24	−3.97 ± 0.15	−3.69 ± 0.19	−3.51 ± 0.15	−3.13 ± 0.18
0.2000	190.46 ± 0.08	191.17 ± 0.06	191.92 ± 0.06	192.64 ± 0.06	193.38 ± 0.05	−5.01 ± 0.29	−4.64 ± 0.23	−4.37 ± 0.24	−4.12 ± 0.21	−3.66 ± 0.19
0.3000	191.19 ± 0.08	191.94 ± 0.09	192.71 ± 0.08	193.39 ± 0.07	194.16 ± 0.07	−5.99 ± 0.31	−5.71 ± 0.32	−5.51 ± 0.28	−5.10 ± 0.25	−4.86 ± 0.25
0.5000	192.94 ± 0.13	193.68 ± 0.13	194.42 ± 0.12	195.10 ± 0.11	195.86 ± 0.09	−9.33 ± 0.50	−9.08 ± 0.48	−8.82 ± 0.45	−8.38 ± 0.42	−8.23 ± 0.35
0.8000	195.18 ± 0.37	196.05 ± 0.35	196.78 ± 0.35	197.59 ± 0.32	198.30 ± 0.32	−23.00 ± 2.02	−23.31 ± 1.91	−22.98 ± 1.92	−23.06 ± 1.77	−22.80 ± 1.75

Table 4. Transfer Partial Molar Volumes ($\Delta_{trs}V_\phi^0$) of HMBA in Aqueous Glucose and Sucrose Solutions at T = (288.15, 293.15, 298.15, 303.15, and 308.15) K

$m_{solvent}$	$\Delta_{trs}V_\phi^0$, $cm^3 \cdot mol^{-1}$				
$mol \cdot kg^{-1}$	288.15 K	293.15 K	298.15 K	303.15 K	308.15 K
			glucose		
0.0500	0.17 ± 0.06	0.16 ± 0.06	0.13 ± 0.06	0.10 ± 0.05	0.14 ± 0.08
0.1000	0.27 ± 0.11	0.24 ± 0.10	0.22 ± 0.13	0.18 ± 0.08	0.17 ± 0.06
0.2000	0.38 ± 0.10	0.36 ± 0.10	0.26 ± 0.09	0.22 ± 0.07	0.24 ± 0.07
0.3000	1.08 ± 0.12	1.04 ± 0.12	0.92 ± 0.10	0.83 ± 0.09	0.96 ± 0.09
0.5000	1.21 ± 0.12	1.25 ± 0.13	1.35 ± 0.14	1.09 ± 0.12	1.11 ± 0.11
0.8000	2.73 ± 0.19	2.63 ± 0.17	2.65 ± 0.18	2.37 ± 0.16	2.38 ± 0.15
			sucrose		
0.0500	0.18 ± 0.09	0.18 ± 0.08	0.17 ± 0.09	0.14 ± 0.07	0.17 ± 0.06
0.1000	0.29 ± 0.10	0.29 ± 0.08	0.21 ± 0.09	0.19 ± 0.07	0.21 ± 0.08
0.2000	0.39 ± 0.12	0.37 ± 0.10	0.32 ± 0.10	0.26 ± 0.09	0.31 ± 0.08
0.3000	1.12 ± 0.12	1.14 ± 0.13	1.11 ± 0.12	1.01 ± 0.10	1.09 ± 0.10
0.5000	2.87 ± 0.17	2.88 ± 0.17	2.82 ± 0.16	2.72 ± 0.14	2.79 ± 0.12
0.8000	5.11 ± 0.41	5.25 ± 0.39	5.18 ± 0.39	5.21 ± 0.35	5.23 ± 0.35

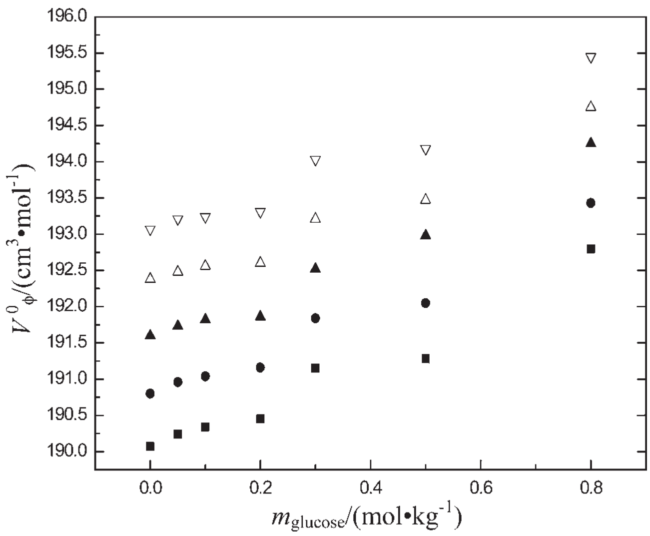

Figure 1. Variation of limiting partial molar volume of HMBA (V_ϕ^0) versus the molality of glucose in aqueous solution at T = 288.15 K (■), 293.15 K (●), 298.15 K (▲), 303.15 K (Δ), and 308.15 K (∇). (Since the tendency of V_ϕ^0 versus the molality of sucrose is very close to glucose, V_ϕ^0 versus $m_{sucrose}$ can be omitted.)

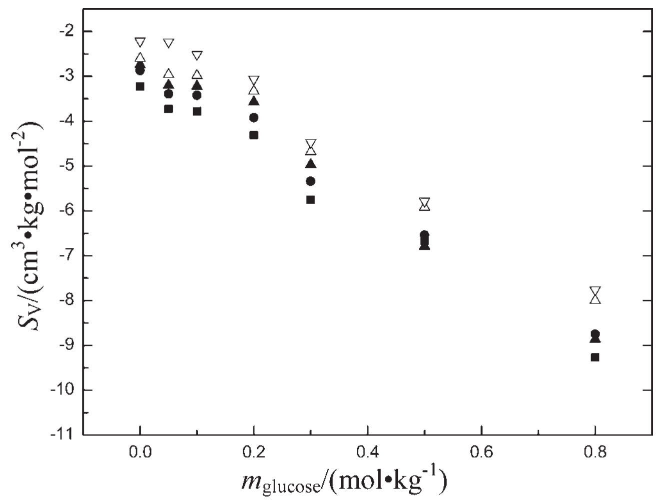

Figure 2. Variation of experimental slope (S_v) versus the molality of glucose in aqueous solution at T = 288.15 K(■), 293.15 K (●), 298.15 K (▲), 303.15 K (Δ), and 308.15 K(∇). (Since the tendency of S_v vs molality of sucrose is very close to glucose, S_v versus $m_{sucrose}$ can be omitted.)

± 2 × 10^{-6} $g \cdot cm^{-3}$. The apparatus was calibrated at 293.15 K with twice-distilled, freshly degassed water and dry air. The densities of twice-distilled water and dry air at 293.15 K were 0.998203[8] $g \cdot cm^{-3}$ and 0.001205[9] $g \cdot cm^{-3}$, respectively. The average of triplicate values for each sample was as its final result. The estimated uncertainties of measured densities were found to be within 0.0005 $g \cdot cm^{-3}$.

Refractive Index Measurements. Refractive indices were measured with a model-2W refractometer (Shanghai, China) after calibration with twice-distilled water at 293.15 K (1.3325[10]). Distilled water was circulated into the apparatus through a thermostatically controlled bath maintained constant to ± 0.02 K. The average of three readings was taken for the refractive index value. The uncertainties of measured refractive indices were found to be within 0.0003.

Densities and refractive indices of pure water and water + glucose or sucrose given in Table 1 were compared with literature values.

RESULTS AND DISCUSSION

Volumetric Properties. Densities (ρ) of HMBA in pure water, aqueous glucose, and sucrose solutions at T = (288.15, 293.15, 298.15, 303.15, and 308.15) K were shown in Table 2. The apparent molar volumes (V_ϕ) of HMBA were calculated

Table 5. Refractive Indices (n_D) and Molar Refraction at the Sodium-D Line (R_D) of HMBA in Aqueous Glucose and Sucrose Solutions at T = 298.15 K

m_{HMBA}, mol·kg^{-1}	n_D	R_D, cm^3·mol^{-1}	m_{HMBA}, mol·kg^{-1}	n_D	R_D, cm^3·mol^{-1}	m_{HMBA}, mol·kg^{-1}	n_D	R_D, cm^3·mol^{-1}
	H_2O			$m_{glucose}$ = 0.0500 mol·kg^{-1}			$m_{glucose}$ = 0.1000 mol·kg^{-1}	
0.0000	1.3320 ± 0.0002	3.7054 ± 0.0041	0.0000	1.3331 ± 0.0001	3.7339 ± 0.0020	0.0000	1.3343 ± 0.0001	3.7634 ± 0.0020
0.0999	1.3350 ± 0.0001	3.8001 ± 0.0021	0.1000	1.3361 ± 0.0002	3.8295 ± 0.0041	0.0999	1.3372 ± 0.0001	3.8589 ± 0.0021
0.1498	1.3365 ± 0.0000	3.8477 ± 0.0004	0.1500	1.3377 ± 0.0001	3.8786 ± 0.0021	0.1500	1.3389 ± 0.0001	3.9093 ± 0.0021
0.1998	1.3380 ± 0.0002	3.8954 ± 0.0042	0.1998	1.3391 ± 0.0001	3.9255 ± 0.0021	0.2001	1.3402 ± 0.0000	3.9559 ± 0.0001
0.2500	1.3396 ± 0.0001	3.9445 ± 0.0021	0.2493	1.3404 ± 0.0002	3.9713 ± 0.0042	0.2492	1.3419 ± 0.0001	4.0061 ± 0.0021
0.3001	1.3409 ± 0.0002	3.9904 ± 0.0042	0.2913	1.3420 ± 0.0000	4.0156 ± 0.0001	0.3001	1.3431 ± 0.0002	4.0523 ± 0.0043
0.3503	1.3420 ± 0.0001	4.0344 ± 0.0021	0.3501	1.3432 ± 0.0001	4.0666 ± 0.0021	0.3499	1.3445 ± 0.0001	4.1001 ± 0.0022
0.3984	1.3433 ± 0.0001	4.0793 ± 0.0021	0.4000	1.3449 ± 0.0001	4.1173 ± 0.0022	0.4001	1.3459 ± 0.0002	4.1482 ± 0.0043
	$m_{glucose}$ = 0.2000 mol·kg^{-1}			$m_{glucose}$ = 0.3000 mol·kg^{-1}			$m_{glucose}$ = 0.5000 mol·kg^{-1}	
0.0000	1.3368 ± 0.0001	3.8242 ± 0.0021	0.0000	1.3392 ± 0.0001	3.8839 ± 0.0021	0.0000	1.3443 ± 0.0001	4.0075 ± 0.0021
0.1000	1.3398 ± 0.0000	3.9223 ± 0.0001	0.1000	1.3422 ± 0.0002	3.9839 ± 0.0042	0.1000	1.3472 ± 0.0002	4.1099 ± 0.0043
0.1501	1.3415 ± 0.0001	3.9737 ± 0.0021	0.1502	1.3434 ± 0.0001	4.0310 ± 0.0021	0.1500	1.3486 ± 0.0000	4.1606 ± 0.0001
0.1999	1.3430 ± 0.0000	4.0230 ± 0.0001	0.2001	1.3450 ± 0.0000	4.0821 ± 0.0001	0.1998	1.3500 ± 0.0000	4.2112 ± 0.0001
0.2501	1.3444 ± 0.0002	4.0715 ± 0.0043	0.2499	1.3466 ± 0.0001	4.1333 ± 0.0022	0.2501	1.3513 ± 0.0001	4.2610 ± 0.0022
0.2999	1.3459 ± 0.0001	4.1210 ± 0.0022	0.2999	1.3480 ± 0.0000	4.1826 ± 0.0001	0.3000	1.3528 ± 0.0002	4.3130 ± 0.0044
0.3497	1.3474 ± 0.0001	4.1707 ± 0.0022	0.3501	1.3493 ± 0.0001	4.2312 ± 0.0022	0.3500	1.3541 ± 0.0001	4.3629 ± 0.0022
0.4001	1.3488 ± 0.0001	4.2197 ± 0.0022	0.3983	1.3510 ± 0.0001	4.2827 ± 0.0022	0.3999	1.3553 ± 0.0001	4.4112 ± 0.0022
	$m_{glucose}$ = 0.8000 mol·kg^{-1}			$m_{sucrose}$ = 0.0500 mol·kg^{-1}			$m_{sucrose}$ = 0.1000 mol·kg^{-1}	
0.0000	1.3510 ± 0.0000	4.1843 ± 0.0001	0.0000	1.3343 ± 0.0001	3.7646 ± 0.0020	0.0000	1.3368 ± 0.0001	3.8259 ± 0.0021
0.0998	1.3534 ± 0.0001	4.2865 ± 0.0022	0.0998	1.3373 ± 0.0001	3.8610 ± 0.0021	0.1001	1.3398 ± 0.0000	3.9242 ± 0.0001
0.1472	1.3549 ± 0.0001	4.3388 ± 0.0022	0.1499	1.3389 ± 0.0000	3.9105 ± 0.0001	0.1497	1.3411 ± 0.0000	3.9710 ± 0.0001
0.1998	1.3566 ± 0.0001	4.3973 ± 0.0022	0.1999	1.3404 ± 0.0001	3.9590 ± 0.0021	0.1998	1.3427 ± 0.0001	4.0214 ± 0.0021
0.2501	1.3579 ± 0.0002	4.4497 ± 0.0045	0.2498	1.3419 ± 0.0002	4.0076 ± 0.0042	0.2500	1.3440 ± 0.0000	4.0689 ± 0.0001
0.3002	1.3592 ± 0.0000	4.5020 ± 0.0001	0.2997	1.3432 ± 0.0002	4.0542 ± 0.0043	0.2995	1.3454 ± 0.0001	4.1171 ± 0.0022
0.3500	1.3606 ± 0.0001	4.5553 ± 0.0023	0.3500	1.3447 ± 0.0001	4.1034 ± 0.0022	0.3498	1.3469 ± 0.0002	4.1670 ± 0.0043
0.4000	1.3618 ± 0.0002	4.6061 ± 0.0046	0.4001	1.3470 ± 0.0000	4.1612 ± 0.0001	0.3991	1.3483 ± 0.0001	4.2153 ± 0.0022
	$m_{sucrose}$ = 0.2000 mol·kg^{-1}			$m_{sucrose}$ = 0.3000 mol·kg^{-1}			$m_{sucrose}$ = 0.5000 mol·kg^{-1}	
0.0000	1.3415 ± 0.0001	3.9479 ± 0.0021	0.0000	1.3458 ± 0.0001	4.0658 ± 0.0021	0.0000	1.3542 ± 0.0001	4.3030 ± 0.0022
0.1000	1.3445 ± 0.0002	4.0494 ± 0.0042	0.0999	1.3487 ± 0.0002	4.1772 ± 0.0043	0.1000	1.3571 ± 0.0001	4.4141 ± 0.0022
0.1500	1.3460 ± 0.0000	4.1002 ± 0.0001	0.1501	1.3502 ± 0.0000	4.2338 ± 0.0001	0.1500	1.3582 ± 0.0000	4.4657 ± 0.0001
0.1996	1.3474 ± 0.0001	4.1499 ± 0.0022	0.2001	1.3517 ± 0.0003	4.2904 ± 0.0066	0.2001	1.3597 ± 0.0001	4.5218 ± 0.0023
0.2488	1.3488 ± 0.0001	4.1992 ± 0.0022	0.2502	1.3530 ± 0.0000	4.3452 ± 0.0001	0.2499	1.3611 ± 0.0002	4.5765 ± 0.0046
0.2998	1.3502 ± 0.0002	4.2500 ± 0.0044	0.2997	1.3542 ± 0.0001	4.3983 ± 0.0022	0.3000	1.3626 ± 0.0002	4.6325 ± 0.0046
0.3501	1.3516 ± 0.0001	4.3005 ± 0.0022	0.3499	1.3554 ± 0.0002	4.4522 ± 0.0045	0.3497	1.3641 ± 0.0002	4.6884 ± 0.0046
0.3999	1.3530 ± 0.0003	4.3506 ± 0.0067	0.4002	1.3570 ± 0.0000	4.5110 ± 0.0001	0.4003	1.3653 ± 0.0001	4.7417 ± 0.0023
				$m_{sucrose}$ = 0.8000 mol·kg^{-1}				
0.0000	1.3656 ± 0.0001	4.6581 ± 0.0023	0.2000	1.3712 ± 0.0002	4.8972 ± 0.0047	0.3497	1.3748 ± 0.0002	5.0700 ± 0.0048
0.1001	1.3683 ± 0.0000	4.7773 ± 0.0005	0.2500	1.3723 ± 0.0001	4.9521 ± 0.0024	0.4003	1.3759 ± 0.0002	5.1281 ± 0.0049
0.1501	1.3698 ± 0.0001	4.8378 ± 0.0023	0.3001	1.3740 ± 0.0000	5.0166 ± 0.0001			

from the equation[13]

$$V_\phi = M/\rho - 1000(\rho - \rho_0)/(m\rho\rho_0) \quad (1)$$

where M, m, ρ, and ρ_0 are the molar mass of the solute (HMBA), the molality of the solute, and the densities of solution and solvent, respectively. The uncertainty of m was ±0.0001 mol·kg^{-1}. The calculated values of V_ϕ along with the uncertainties of ρ and ρ_0 are listed in Table 2. According to the law of propagation of uncertainty and the above uncertainties of the measured variables, the combined standard uncertainties of V_ϕ at a confidence level of 0.95 (k = 2) was found to be within ± 0.06 cm^3·mol^{-1}. V_ϕ is the function of molality of the solute and reflects interactions between solute and solute. Table 2 shows that the values of V_ϕ increase with the ascent of temperature and decrease with the elevated solute concentrations.

From the V_ϕ values, the curves of V_ϕ versus molality were drawn, and the plots were found to be linear with negative slopes in the concentration range studied in all cases. So the partial molar volume of HMBA at infinite dilution (V_ϕ^0) was obtained by least-squares fitting to the following equation:

$$V_\phi = V_\phi^0 + S_V m \quad (2)$$

where S_v is the experimental slope. The calculated values of V_ϕ^0 and S_V along with their standard deviations are summarized in Table 3. The change tendencies of V_ϕ^0 and S_V with increasing molarities of glucose are clearly demonstrated by the curves in Figures 1 and 2.

Partial molar volume of transfer at infinite dilution ($\Delta_{trs}V_\phi^0$) of HMBA from pure water to the aqueous glucose and sucrose solutions were calculated using the following equation:

$$\Delta_{trs}V_\phi^0 = V_\phi^0(\text{in aqueous glucose or sucrose solutions}) - V_\phi^0(\text{in pure water}) \quad (3)$$

The values of $\Delta_{trs}V_\phi^0$ are illustrated in Table 4. The values of V_ϕ^0 and $\Delta_{trs}V_\phi^0$ show the nature of solute−solvent interactions, whereas S_v values show that of solute−solute interactions.

First, it can be seen from Table 3 that the S_V values are all negative over the whole molality range of the aqueous saccharide solutions and the temperature range investigated. The negative values of S_V suggest that the hydrophobic−hydrophobic interactions and the hydrophobic−hydrophilic interactions are predominant over the hydrogen bond interactions between two HMBA molecules. This conclusion agrees well with that obtained by the analysis of the effect of different interaction on enthalpic interaction coefficient h_2 in our previous study.[14]

Second, the data in Tables 3 and 4 also show that the values of V_ϕ^0 and $\Delta_{trs}V_\phi^0$ are all positive in our experimental conditions. This may be interpreted from the fact that the hydrophilic−ionic group interactions play the dominant role during the overall interaction processes in the studied ternary systems.

Third, it is apparent that both V_ϕ^0 and $\Delta_{trs}V_\phi^0$ values of sucrose are larger than that of glucose of the same molality at the same temperature, while S_V value for sucrose system is more negative than that for glucose system. This may be explained as follows: On one side, for the solutions of the same molality, aqueous sucrose solutions contain about twice the number of OH groups compared to aqueous glucose solutions, which leads to larger hydrogen bond interactions in sucrose solutions than those in glucose solutions. On the other side, the enhancement of solute−solvent interactions caused by the number of OH groups weakens the hydrogen bond interactions between two HMBA molecules, which leads to the values of S_V decrease.

Fourth, the values of V_ϕ^0 and S_V increase with the ascent of the temperature. That is, V_ϕ^0 becomes more positive while S_V becomes less negative. This indicates the positive contribution of temperature to volume. At higher temperature, the electrostriction effect of the solvent is reduced and the solvent molecules from the secondary solvation layer are released into the bulk of the solvent, which leads to the expansion of the solution.[15]

Fifth, the values of V_ϕ^0 increase with the increasing molalities of saccharide solutions while the change trend for the values of S_V is contrary. This conclusion is consistent with the influence of the number of OH groups on the values of V_ϕ^0 and S_V in the third discussion.

Refractive Index. In consideration of the fact that there are fractional changes in the values of refractive index, the data of that are only measured at 298.15 K. The data of refractive indices (n_D) at the temperature of 298.15 K presented in Table 5 show an increasing tendency with the increasing molality of the solute. This behavior is consistent with the results which show the effect of HMBA molality on the apparent molar volume, indicating that the refractive index is directly related to the interactions in the solution. Molar refraction at the sodium-D line (R_D) were

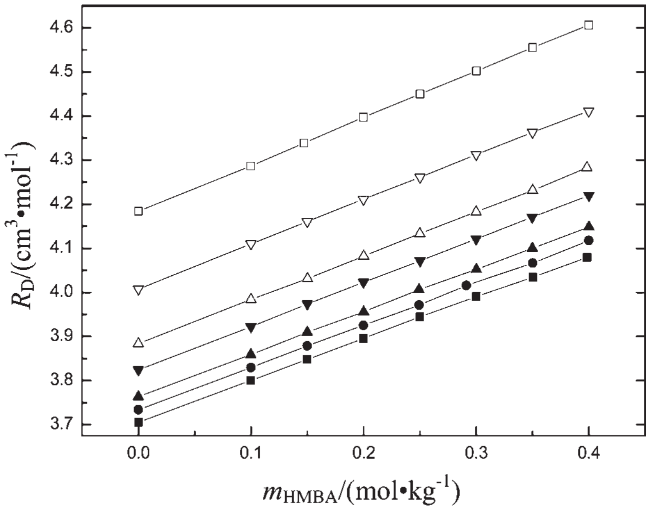

Figure 3. Variation of molar refraction at the sodium-D line (R_D) versus the molality of HMBA in pure water and aqueous glucose solution at 298.15 K. Pure water (■); $m_{glucose}$ = 0.0500 mol·kg^{-1} (●); $m_{glucose}$ = 0.1000 mol·kg^{-1} (▲); $m_{glucose}$ = 0.2000 mol·kg^{-1} (▼); $m_{glucose}$ = 0.3000 mol·kg^{-1} (Δ); $m_{glucose}$ = 0.5000 mol·kg^{-1} (∇); $m_{glucose}$ = 0.8000 mol·kg^{-1}(□). (Since the tendency of R_D versus m_{HMBA} in aqueous sucrose solution is very close to glucose, R_D versus m_{HMBA} in aqueous sucrose solution can be omitted.)

computed with the Lorentz−Lorenz equation[16]

$$R_D = [(n_D^2 - 1)/(n_D^2 + 2)] \sum x_i M_i/\rho \quad (4)$$

where x_i and M_i are the mole fraction and molecular weight of the ith component of the mixture, respectively.

The calculated values of R_D along with the uncertainties of n_D and R_D are also listed in Table 5. The calculated uncertainties of R_D based on the law of propagation of uncertainty at a confidence level of 0.95 (k = 2) were estimated to be within ± 0.0067 cm^3·mol^{-1}. Figure 3 shows an obvious increasing trend of R_D with the increase of molarity of solvent. The higher the molality of saccharide is, the stronger the solute−solvent interactions are, and the more positive of the contribution to the value of R_D will be.

CONCLUSIONS

In the present work, the densities (ρ) and refractive indices (n_D) have been measured. Apparent molar volumes (V_ϕ), limiting partial molar volumes (V_ϕ^0), experimental slope (S_v), transfer partial molar volumes ($\Delta_{trs}V_\phi^0$) of HMBA from water to aqueous glucose or sucrose solutions, and molar refractions at the sodium-D line have been obtained from the experiment. The values of V_ϕ^0 are positive while those of S_v are negative, and they all increase with the ascent of the temperature. In addition, the calculated values of R_D increase with the molalities of saccharide. The parameters and variation tendencies have been discussed in terms of solute−solvent interactions and solute−solute interactions.

AUTHOR INFORMATION

Corresponding Author

*E-mail: panpanliumin@163.com. Fax: +86-635-8239196.

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■ REFERENCES

(1) Li, S. Q.; Sang, W. Q.; Lin, R. S. Partial molar volumes of glycine, L-alanine, and L-serine in aqueous glucose solutions at T = 298.15 K. *J. Chem. Thermodyn.* **2002**, *34*, 1761–1768.

(2) Bobicz, D.; Grzybkowski, W.; Lewandowski, A. Apparent molar volumes of divalent transition metal chlorides and perchlorates in dimethyl sulfoxide solutions. *J. Mol. Liq.* **2003**, *105*, 93–104.

(3) Jiménez, E.; Casas, H.; Segade, L.; Franjo, C. Surface Tensions, Refractive Indexes and Excess Molar Volumes of Hexane + 1-Alkanol Mixtures at 298.15 K. *J. Chem. Eng. Data* **2000**, *45*, 862–866.

(4) In, S. J.; Park., S. J. Excess molar volumes and refractive indices at 298.15 K for the binary and ternary mixtures of diisopropyl ether + ethanol + 2,2,4-trimethylpentane. *J. Ind. Eng. Chem.* **2008**, *14*, 377–381.

(5) Ren, X.; Wen, P. E.; Yang, W. H.; Tang, T. H.; Ren, H. Q.; Zhang, Z. H.; Zhao, H. T.; Fan, H.; Qiao, G. J.; Jiang, G. H. Molecular mechanism underlying differentiation of HL-60 cells induced by hexamethylene bisacetamid. *J. Exper. Hematol.* **2008**, *16*, 1030–1034.

(6) Tang, J.; Niu, J. W.; Xu, D. H.; Li, Z. X.; Li, Q. F.; Chen, J. A. Alteration of nuclear matrix-intermediate filament system and differential expression of nuclear matrix proteins during human hepatocarcinoma cell differentiation. *World. J. Gastroenterol.* **2007**, *13*, 2791–2797.

(7) Cecchinato, V.; Erba, E.; Basile, A.; Scarpati, B.; Fazi, C.; Brando, B.; Comi, P.; Chiararmonte, R. Hexamethylene bisacetamide inhibits malignant phenotype in T-ALL cell lines. *Leukemia Res.* **2008**, *32*, 791–797.

(8) Sadeghi, R.; Parhizkar, H. Volumetric, isentropic compressibility and electrical conductivity of solutions of tri-sodium phosphate in 1-propanol + water mixed-solvent media over the temperature range of 283.15−303.15 K. *Fluid Phase Equilib.* **2008**, *265*, 173–183.

(9) Weast, R. C. *CRC Handbook of Chemistry and Physics*, 53rd ed.; The Chemistry Rubber Co.: Cleveland, OH, 1973.

(10) Dean, J. A. *Lange's Handbook of Chemistry*; McGraw-Hill Book Company Inc: New York, 1960.

(11) Zhuo, K. L.; Wang, J. J.; Yue, Y. K.; Wang, H. Q. Volumetric properties for the monosaccharide (D-xylose, D-arabinose, D-glucose, D-galactose)−NaCl−water systems at 298.15 K. *Carbohyd. Res.* **2000**, *328*, 383–391.

(12) Wu, B.; Zhang, Y. M.; Wang, H. P. Volumetric Properties and Conductivities of 1-Butyl-3-methylimidazolium Tetrafluoroborate + Sucrose + Water Mixtures. *J. Chem. Eng. Data* **2009**, *54*, 1430–1434.

(13) Li, H.; Xu, X. Y.; Chi, C. J.; Liu, M.; Di, Y. Y.; Sun, D. Z. Molar Volumes and Refractive Indexes of Hexane-1,2,3,4,5,6-hexol in Aqueous Solutions of 1-Propanol and 2-Propanol. *J. Chem. Eng. Data* **2010**, *55*, 2909–2913.

(14) Li, G. Q.; Liu, M.; Wang, L. L.; Zhu, L. Y.; Sun, D; Di, Z.; Enthalpic, Y. Y. Interaction Coefficients of N,N′-Hexamethylenebisacetamide in Aqueous Glucose and Sucrose Solutions at 298.15 K. *J. Chem. Eng. Data* **2010**, *55*, 4239–4243.

(15) Nain, A. K.; Chand, D. Volumetric, ultrasonic, and viscometric behaviour of glycine, DL-alanine, and L-valine in aqueous 1,4-butanediol solutions at different temperature. *J. Chem. Thermodyn.* **2009**, *41*, 243–249.

(16) Ali, A.; Hyder, S.; Sabir, S.; Chand, D.; Nain, A. K. Volumetric, viscometric, and refractive index behaviour of a-amino acids and their groups' contribution in aqueous D-glucose solution at different temperatures. *J. Chem. Thermodyn.* **2006**, *38*, 136–143.