Relative Permittivities for the Galactose + Glycine + Water Solution from (278.15 to 313.15) K

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Relative permittivities for the galactose + glycine + water solution have been measured from (278.15 to 313.15) K. Results indicate that the logarithmic values of the relative permittivities for the glycine + water solution increase with increasing molalities of glycine and decrease as the temperature rises. At given molalities, the relationship of the relative permittivity to the temperature can be expressed by a quadratic equation. At given temperatures and compositions of glycine, the dependence of the relative permittivities on the mole fraction of galactose can be described by a linear equation. At a given temperature and composition of galactose, the relationship between the relative permittivities and the mole fraction of glycine can be expressed by a quadratic equation. An empirical equation is proposed and used to relate log ε for the ternary solution to the temperature and compositions of the solution.

Introduction

Saccharides are very important in physiological processes. They not only are basic materials for energy metabolism in organisms but also play a significant role in the configuration of biological molecules.[1,2] Amino acids are also of importance in industrial processes and can be utilized as food additives and constituents of pharmaceutical products. Glycine is the simplest amino acid found in protein and is the principal amino acid for sugar cane. The knowledge of physical properties of the solvent is fundamental for understanding the behavior of solutions. Densities and static relative permittivities have a special interest because they are critical for solution chemistry.[3] For example, these properties can be very useful as a support for the efficient design and simulation of the separation process[4,5] and can be used to calculate the activity coefficients.[3]

In our previous work, relative permittivities for some binary saccharide + water systems from (278.15 to 313.15) K were studied as well as volumetric and viscosity properties.[6,7] It is also necessary to measure the physical properties for carbohydrate + amino acid + water systems.[8] In this work, we measured the static relative permittivities for the galactose + glycine + water system at temperatures ranging from (278.15 to 313.15) K in steps of 5 K. Some empirical equations are proposed to express the relationships of the relative permittivity with the temperature and/or the composition.

Experimental Section

Chemicals. High-purity D-(+)-galactose (> 99 %) and glycine (> 99 %) were obtained from Sigma Chemical Company. They were dried under vacuum to a constant weight and then stored over P_2O_5 in desiccators. The deionized water was doubly distilled over $KMnO_4$. The water sample with a conductivity from $(0.8\cdot10^{-4}$ to $1.0\cdot10^{-4})$ $S\cdot cm^{-1}$ at room temperature was used throughout the experiments.

Measurements of the Relative Permittivities. Solution relative permittivities (ε) were measured using a dielectric constant meter (Model Bl-870, Brookhaven Instrument Co., U.S.A.). The fluctuation of temperature was controlled within 0.02 K. Experimental details are described elsewhere.[7] Values of relative permittivities for pure water at different temperatures were taken from the reference[9] and were used for the calibration of the relative permittivity meter. All of the solutions were prepared by direct weighing of both the solute and the solvent and were degassed by using an ultrasonic cleaner (Model KQ3200E, Kunshan Ultrasonic Instrument Co., China). Then the solutions were deposited for 3−5 h to make them equal before measurement. The relative uncertainty of the molalities of galactose and glycine is evaluated to be about 0.2 %. The uncertainty in the relative permittivity was estimated to be 0.1.

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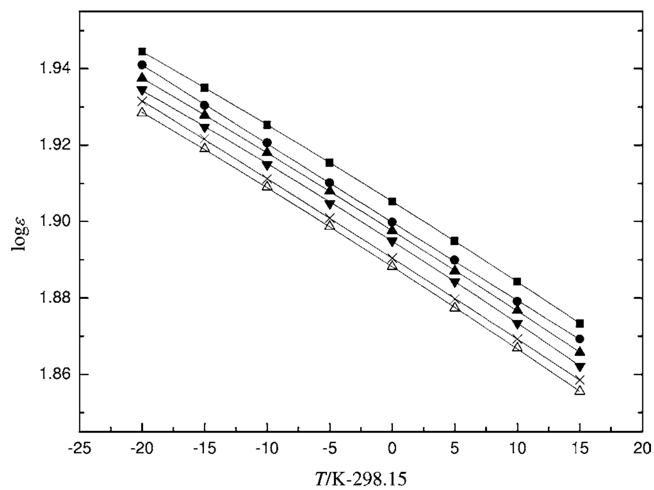

Figure 1. Variation of log ε with temperatures at different molalities of galactose when $m_{Gly} = 0.1000$ $mol\cdot kg^{-1}$. $m_{Gla}/mol\cdot kg^{-1}$: ■, 0.2; ●, 0.4; ▲, 0.6; ▼, 0.8; x, 1.0; △, 1.2. —, drawn according to eq 1.

Results and Discussion

Relationship between the Relative Permittivity and the Temperature. The experimentally measured relative permittivities and their logarithms for glycine + water and galactose + glycine + water solutions at different molalities and tempera-

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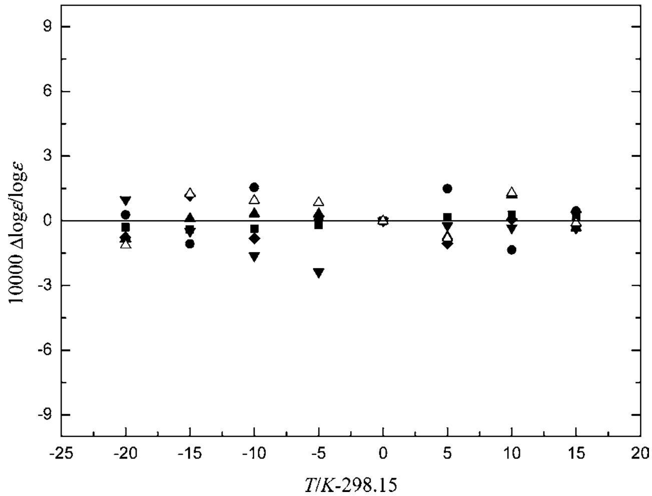

Figure 2. Fractional deviations $\Delta\log \varepsilon/\log \varepsilon = \{\log \varepsilon(\text{exptl}) - \log \varepsilon(\text{calcd})\}/\log \varepsilon(\text{calcd})$ of the values of log ε(exptl) for the galacose + glycine + water system from eq 1 as a function of *T*. m_{gly}/mol·kg^{-1}: ■, 0.2000; ●, 0.4000; ▲, 0.6000; ▼, 0.8000; ♦, 1.0000; △, 1.2000.

Table 1. Coefficients of the Equation $\log \varepsilon = A_1 - B_1(T/\text{K} - 298.15) + C_1(T/\text{K} - 298.15)^2$

m_{Gla}/mol·kg^{-1}	A_1[a]	$B_1 \cdot 10^3$	$C_1 \cdot 10^6$	SD[b]$\cdot 10^4$
0.2	1.905	2.056	−4.805	0
0.4	1.900	2.051	$3.396 \cdot 10^{-1}$	2
0.6	1.898	2.070	−3.645	1
0.8	1.895	2.089	−5.899	2
1.0	1.890	2.100	−2.028	1
1.2	1.888	2.110	−4.403	1
0.2	1.908	2.101	−3.747	2
0.4	1.905	2.113	−3.888	2
0.6	1.902	2.128	−4.443	3
0.8	1.898	2.118	−4.546	3
1.0	1.894	2.150	−5.440	3
1.2	1.890	2.143	−3.697	2
0.2	1.913	2.194	−7.265	3
0.4	1.910	2.220	−7.948	2
0.6	1.906	2.214	−8.492	2
0.8	1.903	2.216	−9.958	2
1.0	1.900	2.187	−7.771	2
1.2	1.897	2.263	$-1.001 \cdot 10^{1}$	2
0.2	1.919	2.283	$-1.138 \cdot 10^{1}$	4
0.4	1.914	2.331	$-1.183 \cdot 10^{1}$	5
0.6	1.909	2.208	−7.938	3
0.8	1.908	2.315	$-1.228 \cdot 10^{1}$	3
1.0	1.904	2.244	−9.686	3
1.2	1.902	2.343	$-1.279 \cdot 10^{1}$	2
0.2	1.922	2.361	$-1.137 \cdot 10^{1}$	3
0.4	1.918	2.400	$-1.095 \cdot 10^{1}$	5
0.6	1.915	2.450	$-1.014 \cdot 10^{1}$	5
0.8	1.911	2.455	$-1.349 \cdot 10^{1}$	7
1.0	1.909	2.397	$-1.304 \cdot 10^{1}$	3
1.2	1.904	2.411	−8.663	6

[a] Values of log ε at 298.15 K, which are taken from Table S2 of Supporting Information. [b] SD, standard deviation of the fit.

tures are shown in Tables S1 and S2 in Supporting Information, respectively. Wyman[10] and Owen et al.[11] expressed the relative permittivity of water as a function of temperature and pressure.

At a fixed ratio of galactose to glycine, the relationship between the relative permittivity and the thermodynamic temperature (*T*) can be expressed as (see Figures 1 and 2 for galactose + glycine + water, as an example)

$$\log \varepsilon = A_1 - B_1(T/\text{K} - 298.15) + C_1(T/\text{K} - 298.15)^2 \qquad (1)$$

where A_1 is the value of log ε at 298.15 K and B_1 and C_1 are empirical constants, whose values were obtained by the fit and are given in Table 1.

The relative permittivity not only is closely related to the macroscopic properties such as solubility, reaction rate constant, and so forth but also has a strong dependence on the microscopic molecular orientational distribution as well.[12] The relative permittivity decreases as the temperature rises, suggesting that the molecular ordering becomes weaker at higher temperature region.

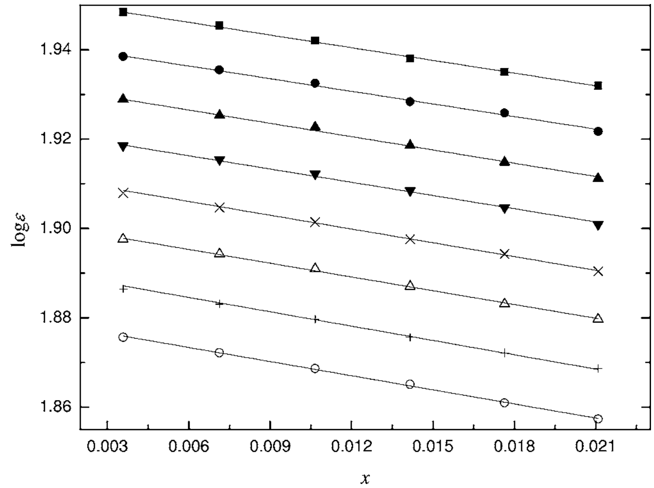

Figure 3. Variation of log ε with the mole fraction of galactose *x* at different temperatures when $m_{Gly} = 0.1500$ mol·kg^{-1}. *T*/K: ■, 278.15; ●, 283.15; ▲, 288.15; ▼, 293.15; x, 298.15; △, 303.15; +, 308.15; ○, 313.15. —, drawn according to eq 2.

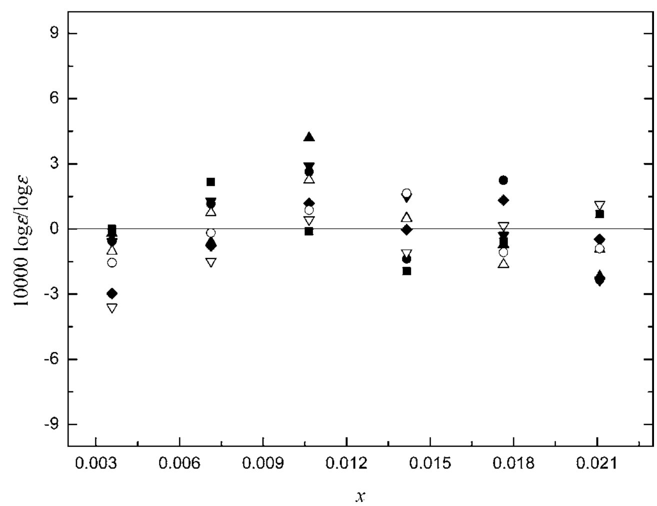

Figure 4. Fractional deviations $\Delta\log \varepsilon/\log \varepsilon = \{\log \varepsilon(\text{exptl}) - \log \varepsilon(\text{calcd})\}/\log \varepsilon(\text{calcd})$ of the values of log ε(exptl) for the galacose + glycine + water system from eq 2 as a function of *x*. *T*/K: ■, 278.15; •, 283.15; ▲, 288.15; ▼, 293.15; ♦, 298.15; △, 303.15; ▽, 308.15; ○, 313.15.

Relationship between the Relative Permittivity and the Composition of Galactose. Figures 3 and 4 show that the logarithmic values of the relative permittivities for the galactose + glycine + water mixtures decrease linearly with the increasing molar fraction (*x*) of galactose at a fixed ratio of glycine to water and a given temperature. Thus, we have

$$\log(\varepsilon/\varepsilon_0) = A_2 - B_2 x \qquad (2)$$

where ε_0 is the relative permittivity of pure water, A_2 is the value of log ε at the binary glycine + water solution at the given temperature, and B_2 is the empirical constant, whose values were obtained by the fits and are included in Table 2.

Relationship between the Relative Permittivity and the Composition of Glycine. At a fixed ratio of galactose to water and a given temperature, an empirical equation used to fit

Table 2. Coefficients of the Equation $\log(\varepsilon/\varepsilon_0) = A_2 - B_2x$

T/K	A_2[a]	B_2	SD[b]·10^4
278.15	1.947	$8.422 \cdot 10^{-1}$	6
283.15	1.937	$8.247 \cdot 10^{-1}$	7
288.15	1.927	$8.523 \cdot 10^{-1}$	7
293.15	1.917	$8.754 \cdot 10^{-1}$	8
298.15	1.907	$8.892 \cdot 10^{-1}$	9
303.15	1.897	$9.080 \cdot 10^{-1}$	9
308.15	1.886	$9.053 \cdot 10^{-1}$	8
313.15	1.875	$9.116 \cdot 10^{-1}$	8
278.15	1.952	$9.465 \cdot 10^{-1}$	3
283.15	1.942	$9.416 \cdot 10^{-1}$	4
288.15	1.933	$9.921 \cdot 10^{-1}$	4
293.15	1.922	$9.883 \cdot 10^{-1}$	4
298.15	1.912	1.028	3
303.15	1.902	1.027	3
308.15	1.891	1.070	3
313.15	1.880	1.053	2
278.15	1.957	$9.266 \cdot 10^{-1}$	4
283.15	1.947	$9.333 \cdot 10^{-1}$	2
288.15	1.938	$9.394 \cdot 10^{-1}$	2
293.15	1.927	$9.568 \cdot 10^{-1}$	3
298.15	1.917	$9.821 \cdot 10^{-1}$	4
303.15	1.906	1.034	6
308.15	1.895	1.040	7
313.15	1.883	1.084	9
278.15	1.962	$9.112 \cdot 10^{-1}$	13
283.15	1.952	$9.285 \cdot 10^{-1}$	11
288.15	1.943	$9.529 \cdot 10^{-1}$	11
293.15	1.933	$9.723 \cdot 10^{-1}$	11
298.15	1.922	1.001	11
303.15	1.911	1.030	9
308.15	1.899	1.060	8
313.15	1.887	1.124	15
278.15	1.968	$8.984 \cdot 10^{-1}$	6
283.15	1.958	$9.180 \cdot 10^{-1}$	4
288.15	1.948	$9.608 \cdot 10^{-1}$	2
293.15	1.937	$9.878 \cdot 10^{-1}$	5
298.15	1.926	1.029	5
303.15	1.914	1.043	5
308.15	1.902	1.049	9
313.15	1.888	1.100	13

[a] Values of log ε for glyine−water solutions taken from Table S1 of Supporting Information. [b] SD, standard deviation of the fit.

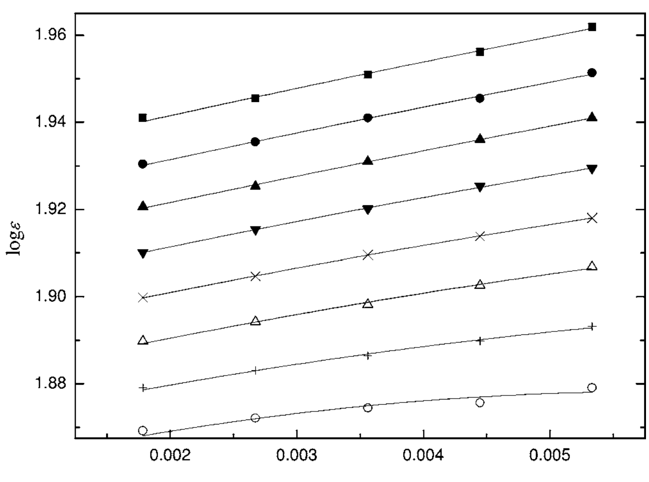

Figure 5. Variation of log ε with glycine at different temperatures when $m_{Gla} = 0.4000\ \mathrm{mol \cdot kg^{-1}}$. T/K: ■, 278.15; ●, 283.15; ▲, 288.15; ▼, 293.15; x, 298.15; Δ, 303.15; +, 308.15; ○, 313.15. −, drawn according to eq 3.

relative permittivity is expressed as (see Figures 5 and 6 for galactose + glycine + water, as an example)

$$\log(\varepsilon/\varepsilon_0) = A_3 + B_3x - C_3x^2 \quad (3)$$

where A_3 is the value of log ε for the binary galactose + water at a given temperature and B_3 and C_3 are the empirical constants, whose values were obtained and given in Table 3.

Relationship between the Relative Permittivity and the Composition of Ternary Solutions. Tables 1 to 3 indicate that the empirical parameters are not only as functions of the composition for galactose but also as functions of the composition for glycine. Consequently, an empirical equation is proposed to relate log ε to the compositions of galactose and glycine at

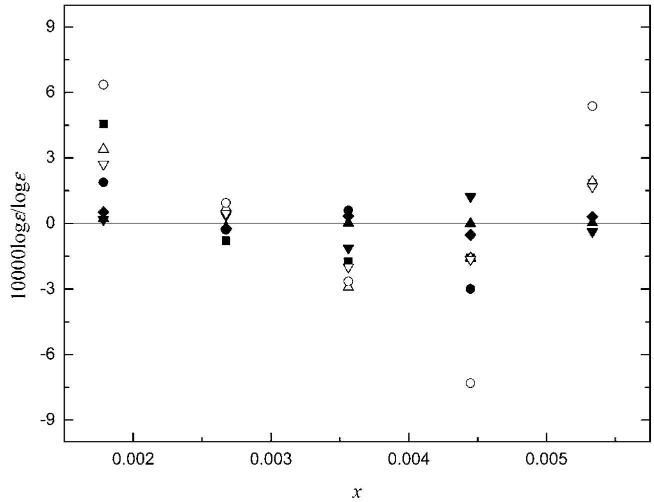

Figure 6. Fractional deviations $\Delta\log\ \varepsilon/\log\ \varepsilon = \{\log\ \varepsilon(\mathrm{exptl}) - \log\ \varepsilon(\mathrm{calcd})\}/\log\ \varepsilon(\mathrm{calcd})$ of the values of log ε(exptl) for the galactose + glycine + water system from eq 2 as a function of x. T/K: ■, 278.15; ●, 283.15; ▲, 288.15; ▼, 293.15; ♦, 298.15; △, 303.15; ▽, 308.15; ○, 313.15.

Table 3. Coefficients of the Equation $\log(\varepsilon/\varepsilon_0) = A_3 + B_3x - C_3x^2$

T/K	A_3[a]	B_3	C_3	SD[b]·10^4
278.15	1.932	6.451	$5.127 \cdot 10^{1}$	8
283.15	1.922	6.660	$1.139 \cdot 10^{2}$	9
288.15	1.913	6.563	$1.229 \cdot 10^{2}$	9
293.15	1.903	6.775	$1.836 \cdot 10^{2}$	11
298.15	1.893	6.525	$1.909 \cdot 10^{2}$	12
303.15	1.883	6.596	$2.526 \cdot 10^{2}$	11
308.15	1.872	6.631	$3.721 \cdot 10^{2}$	10
313.15	1.862	6.179	$4.019 \cdot 10^{2}$	11
278.15	1.928	6.773	$1.042 \cdot 10^{2}$	6
283.15	1.919	6.634	$1.046 \cdot 10^{2}$	4
288.15	1.909	6.476	$9.006 \cdot 10^{1}$	3
293.15	1.899	6.682	$1.697 \cdot 10^{2}$	2
298.15	1.889	6.543	$1.971 \cdot 10^{2}$	0.9
303.15	1.878	6.781	$2.688 \cdot 10^{2}$	6
308.15	1.868	6.517	$3.499 \cdot 10^{2}$	4
313.15	1.857	7.105	$6.013 \cdot 10^{2}$	12
278.15	1.926	6.147	$4.297 \cdot 10^{1}$	17
283.15	1.916	6.512	$1.279 \cdot 10^{2}$	13
288.15	1.906	6.632	$1.480 \cdot 10^{2}$	14
293.15	1.896	6.510	$1.653 \cdot 10^{2}$	11
298.15	1.885	6.824	$2.696 \cdot 10^{2}$	11
303.15	1.875	7.122	$3.539 \cdot 10^{2}$	9
308.15	1.864	7.560	$5.372 \cdot 10^{2}$	8
313.15	1.854	7.494	$6.776 \cdot 10^{2}$	7
278.15	1.922	6.319	$4.088 \cdot 10^{1}$	9
283.15	1.913	6.447	$9.850 \cdot 10^{1}$	8
288.15	1.903	6.673	$1.426 \cdot 10^{2}$	7
293.15	1.893	6.859	$2.271 \cdot 10^{2}$	9
298.15	1.882	7.216	$3.357 \cdot 10^{2}$	10
303.15	1.872	7.133	$3.821 \cdot 10^{2}$	9
308.15	1.861	7.152	$4.610 \cdot 10^{2}$	9
313.15	1.850	7.736	$7.318 \cdot 10^{2}$	7
278.15	1.919	6.443	$7.948 \cdot 10^{2}$	9
283.15	1.909	6.865	$1.544 \cdot 10^{2}$	8
288.15	1.899	6.669	$1.190 \cdot 10^{2}$	8
293.15	1.888	7.383	$2.445 \cdot 10^{2}$	8
298.15	1.876	8.144	$3.942 \cdot 10^{2}$	8
303.15	1.865	8.411	$4.683 \cdot 10^{2}$	9
308.15	1.853	9.487	$7.135 \cdot 10^{2}$	12
313.15	1.841	$1.038 \cdot 10^{1}$	$9.802 \cdot 10^{2}$	13
278.15	1.917	6.019	7.290	7
283.15	1.907	5.838	$-1.313 \cdot 10^{1}$	11
288.15	1.897	6.013	$2.823 \cdot 10^{1}$	13
293.15	1.886	6.758	$1.749 \cdot 10^{2}$	13
298.15	1.875	7.221	$3.133 \cdot 10^{2}$	13
303.15	1.864	7.392	$3.730 \cdot 10^{2}$	12
308.15	1.853	7.450	$4.552 \cdot 10^{2}$	15
313.15	1.841	8.094	$6.850 \cdot 10^{2}$	14

[a] Values of log ε for galactose−water solutions taken from ref 6. [b] SD, standard deviation of the fit.

Table 4. Coefficients of the Equation $\log \varepsilon = \sum_{i=0}^{n}\sum_{j=0}^{m} P_{ij}M^iN^j$

P_{ij}	composition (X) scales			composition (X) scales		
	x	m	w	x	m	w
		278.15 K			283.15 K	
P_{00}	1.935	1.935	1.935	1.925	1.925	1.925
P_{01}	6.250	$1.115 \cdot 10^{-1}$	1.747	6.117	$1.187 \cdot 10^{-1}$	1.764
P_{02}			$-1.088 \cdot 10^{1}$		$-3.899 \cdot 10^{-2}$	$-1.373 \cdot 10^{1}$
P_{10}	$-8.076 \cdot 10^{-1}$	$-1.018 \cdot 10^{-2}$	$-6.597 \cdot 10^{-2}$	$-7.862 \cdot 10^{-1}$	$-1.052 \cdot 10^{-2}$	$-6.923 \cdot 10^{-2}$
P_{11}	$-2.952 \cdot 10^{1}$	$-5.691 \cdot 10^{-2}$	-6.231	$-3.003 \cdot 10^{1}$	$-5.988 \cdot 10^{-2}$	-5.622
P_{12}		$1.1612 \cdot 10^{-1}$	$2.869 \cdot 10^{2}$		$1.407 \cdot 10^{-1}$	$2.683 \cdot 10^{2}$
$SD^a \cdot 10^4$	8	7	7	7	7	7
		288.15 K			293.15 K	
P_{00}	1.915	1.915	1.915	1.905	1.905	1.905
P_{01}	6.281	$1.284 \cdot 10^{-1}$	1.917	6.617	$1.257 \cdot 10^{-1}$	1.859
P_{02}		$-6.707 \cdot 10^{-2}$	$-2.014 \cdot 10^{1}$	$-1.316 \cdot 10^{2}$	$-7.321 \cdot 10^{-2}$	$-1.970 \cdot 10^{1}$
P_{10}	$-7.584 \cdot 10^{-1}$	$-1.041 \cdot 10^{-2}$	$-6.780 \cdot 10^{-2}$	$-8.507 \cdot 10^{-1}$	$-1.238 \cdot 10^{-2}$	$-8.125 \cdot 10^{-2}$
P_{11}	$-4.388 \cdot 10^{1}$	$-6.774 \cdot 10^{-2}$	-6.582	$-2.191 \cdot 10^{1}$	$-4.701 \cdot 10^{-2}$	-4.206
P_{12}		$1.622 \cdot 10^{-1}$	$3.058 \cdot 10^{2}$		$1.123 \cdot 10^{-1}$	$2.042 \cdot 10^{2}$
R^a	0.9962	0.9974	0.9974	0.9961	0.9966	0.9967
$SD^a \cdot 10^4$	8	7	7	8	8	8
		298.15 K			303.15 K	
P_{00}	1.895	1.895	1.895	1.885	1.885	1.885
P_{01}	6.715	$1.264 \cdot 10^{-1}$	1.869	6.381	$1.217 \cdot 10^{-1}$	1.820
P_{02}	$-1.878 \cdot 10^{2}$	$-8.710 \cdot 10^{-2}$	$-2.197 \cdot 10^{1}$	$-1.875 \cdot 10^{2}$	$-9.258 \cdot 10^{-2}$	$-2.376 \cdot 10^{1}$
P_{10}	$-8.327 \cdot 10^{-1}$	$-1.240 \cdot 10^{-2}$	$-8.115 \cdot 10^{-2}$	$-8.660 \cdot 10^{-1}$	$-1.251 \cdot 10^{-2}$	$-8.190 \cdot 10^{-2}$
P_{11}	-29.15	$-4.414 \cdot 10^{-2}$	-3.948	$-2.929 \cdot 10^{1}$	$-5.134 \cdot 10^{-2}$	-4.828
P_{12}		$9.825 \cdot 10^{-2}$	$1.739 \cdot 10^{2}$		$1.191 \cdot 10^{-1}$	209.1
$SD^a \cdot 10^4$	8	8	8	8	7	7
		308.15 K			313.15 K	
P_{00}	1.875	1.875	1.875	1.866	1.866	1.866
P_{01}	6.619	$1.242 \cdot 10^{-1}$	1.865	6.302	$1.140 \cdot 10^{-1}$	1.615
P_{02}	$-3.688 \cdot 10^{2}$	$-1.401 \cdot 10^{-1}$	$-3.356 \cdot 10^{1}$	$-4.783 \cdot 10^{2}$	$-1.568 \cdot 10^{-1}$	$-2.873 \cdot 10^{1}$
P_{10}	$-9.504 \cdot 10^{-1}$	$-1.184 \cdot 10^{-2}$	$-7.851 \cdot 10^{-2}$	$-9.806 \cdot 10^{-1}$	$-1.360 \cdot 10^{-2}$	$-1.025 \cdot 10^{-1}$
P_{11}		$-6.251 \cdot 10^{-2}$	-5.856		$-4.337 \cdot 10^{-2}$	$-8.276 \cdot 10^{-1}$
P_{12}		$1.602 \cdot 10^{-1}$	$2.552 \cdot 10^{2}$		$1.049 \cdot 10^{-1}$	
$SD^a \cdot 10^4$	8	7	7	9	9	9

[a] SD, standard deviation of the fit.

Table 5. Coefficients of the Equation $\log \varepsilon = \sum_{i=0}^{n}\sum_{j=0}^{m}\sum_{k=0}^{h} P_{ijk}M^iN^jT^k$

P_{ij}	composition (X) scales		
	x	m	w
P_{000}	1.895	1.895	1.895
P_{001}	$-1.838 \cdot 10^{-3}$	$-1.841 \cdot 10^{-3}$	$-1.853 \cdot 10^{-3}$
P_{002}	$2.539 \cdot 10^{-5}$	$2.454 \cdot 10^{-5}$	$3.167 \cdot 10^{-5}$
P_{010}	7.248	$1.288 \cdot 10^{-1}$	1.912
P_{011}	$-1.001 \cdot 10^{-1}$	$-1.789 \cdot 10^{-3}$	$-2.261 \cdot 10^{-2}$
P_{012}	$-1.670 \cdot 10^{-2}$	$-2.901 \cdot 10^{-3}$	$-5.210 \cdot 10^{-3}$
P_{020}	$-3.044 \cdot 10^{2}$	$-9.512 \cdot 10^{-2}$	$-2.431 \cdot 10^{1}$
P_{021}			
P_{022}	1.862	$5.734 \cdot 10^{-4}$	$1.571 \cdot 10^{-1}$
P_{100}	$-6.665 \cdot 10^{-1}$	$-1.183 \cdot 10^{-2}$	$-7.741 \cdot 10^{-2}$
P_{101}	$-1.436 \cdot 10^{-2}$	$-2.495 \cdot 10^{-4}$	$-1.628 \cdot 10^{-3}$
P_{102}	$-1.553 \cdot 10^{-3}$	$-2.638 \cdot 10^{-5}$	$-2.308 \cdot 10^{-4}$
P_{110}	$-1.758 \cdot 10^{2}$	$-5.452 \cdot 10^{-2}$	-5.073
P_{120}	$2.415 \cdot 10^{4}$	$1.296 \cdot 10^{-1}$	$2.291 \cdot 10^{2}$
P_{111}	7.054	$2.217 \cdot 10^{-3}$	$2.060 \cdot 10^{-1}$
P_{121}	$-9.346 \cdot 10^{2}$	$-5.115 \cdot 10^{-3}$	-9.139
P_{122}	$-1.252 \cdot 10^{2}$	$-6.797 \cdot 10^{-4}$	-1.281
P_{112}	$9.244 \cdot 10^{-1}$	$2.826 \cdot 10^{-4}$	$3.524 \cdot 10^{-2}$
$SD^a \cdot 10^4$	7	7	7

[a] SD, standard deviation of the fit.

given temperatures [which can be expressed as the mole fraction (x), molality (m), and mass fraction (w)]:

$$\log \varepsilon = \sum_{i=0}^{n}\sum_{j=0}^{m} P_{ij}M^iN^j \tag{4}$$

where P_{ij} are the empirical constants, P_{00} is the logarithm of the relative permittivity of pure water, and M and N are the compositions of galactose and glycine, respectively. Equation 4 can work well for the galactose + glycine + water system when $m = 2$ and $n = 2$. The P_{ij} values obtained are given in Table 4, along with the standard deviations of the fit. When the composition in the mixture is expressed as molality (m) and weight fraction (w), eq 4 works better for the studied systems.

The standard deviations of the fit in Table 4 can be conversed into those of ε. The converted values are less than 0.2, indicating that eq 4 with the parameters in Table 4 can be used to evaluate relatively accurate values of relative permittivities for the studied systems at any temperature and any composition in the experimental ranges.

Relationship of the Relative Permittivity with the Compositions and the Temperature. To relate $\log \varepsilon$ for the ternary solutions to the temperature and the compositions of the solutions, a universal empirical equation is proposed as follows:

$$\log \varepsilon = \sum_{i=0}^{n}\sum_{j=0}^{m}\sum_{k=0}^{h} P_{ijk}M^iN^jT^k \tag{5}$$

where P_{ijk} are the empirical constants and P_{000} is the logarithm of the relative permittivity for pure water at 298.15 K. Equation 5 can work well for the galactose + glycine + water solution when $n = 1$, $m = 2$, and $h = 2$. The compositions can be expressed as a molar fraction (x), molality (m), or a weight fraction (w). Values of P_{ijk} obtained are given in Table 5.

Conclusions

Relative permittivities for the galactose + glycine + water system were measured from (278.15 to 313.15) K. At given temperatures, relative permittivities for the ternary system decrease with increasing molalities of galactose but increase with increasing molalities of glycine. At given compositions, relative permittivities decrease as the temperature rises. An empirical equation is proposed and used well to relate relative permittivities to the compositions and the temperature for the studied system and it can be used to evaluate the relative permittivities for the ternary system in the range of experimental temperatures and compositions.

Supporting Information Available:

This material is available free of charge via the Internet at http://pubs.acs.org.

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