Chinese J. Chem. Eng., **11** (2) 185 – 190 (2003)

Measurement and Correlation on Viscosity and Apparent Molar Volume of Ternary System for L-ascorbic Acid in Aqueous D-Glucose and Sucrose Solutions*

ZHAO Changwei(赵长伟) and MA Peisheng(马沛生)**
School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, China

Abstract Viscosities and densities at several temperatures from 293.15 K to 313.15 K are reported for L-ascorbic acid in aqueous glucose and sucrose solutions at different concentrations. The parameters of density, viscosity coefficient B and partial molar volume are calculated by regression. The experimental results show that densities and viscosities decrease as temperature increases at the same solute and solvent (glucose and sucrose aqueous solution) concentrations, and increase with concentration of glucose and sucrose at the same solute concentration and temperature. B increases with concentration of glucose and sucrose and temperature. L-ascorbic acid is structure-breaker or structure-making for the glucose and sucrose aqueous solutions. Furthermore, the solute-solvent interactions in ternary systems of water-glucose-electrolyte and water-sucrose-electrolyte are discussed.
Keywords L-ascorbic acid, glucose, sucrose, density, viscosity

1 INTRODUCTION

Most of the chemical and biological functions of glucose, sucrose, glycerol, mannitol and sorbitol take place in aqueous medium. With the development of biochemical engineering, more and more attention has been paid to the measurement of thermodynamic properties for organic aqueous solutions. Like almost all general non-electrolyte solutes, these polyhydroxy compounds are expected to influence water structure[1], and the importance of the contribution from structural changes of the solvent to the thermodynamic and transport properties of aqueous solutions of biological molecules has been demonstrated[2,3]. Sugar is the element composing of amylase biopolymer, ascorbic acid (Vitamin C) which is a responsible nutrition for human body and works in variety of body metabolism. The study of its aqueous thermodynamic properties plays a leading role in solution theory and life science. Density and viscosity data provide useful information about various types of interactions occurring in ionic solutions. These studies are of great help in characterizing the structure and properties of solutions. The solution structure is of great importance in understanding the active nature of bioactive molecules in the body system. Various types of interactions exist between the ions in solution and lesideo ion-ion and ion-solvent interactions are of current interest in all branches of chemistry. These considerations promoted us to undertake the present study.

As one of the elementary physical property data, density of sugar aqueous solution has been studied in its measurement and investigation of apparent molar volume. Up to now, most research, however, is limited to the condition of 25℃ and dilute solutions. Viscosities of various electrolytes in aqueous solutions and organic solvents have been studied, but densities and viscosities of electrolyte-sugar-water ternary system are rarely reported[4]. Therefore, further study of its densities and viscosities can provide basic data for physiological process and medical effect and is indispensable for industrial production process and design research. In this paper, the densities and viscosities of ascorbic acid in glucose and sucrose aqueous solutions at several temperatures are studied systematically to provide additional information on solute-solute and solute-solvent interactions in these systems.

2 EXPERIMENTAL

2.1 Materials

D-glucose and sucrose (A.R.grade) were purified and dried by usual methods and stored in a desiccator over P_2O_5. L-ascorbic acid is A.R.grade. Doubly distilled water (sp. conductance $1.2\times10^{-4}\,s{\cdot}m^{-1}$ at 293.15 K) was used for the preparation of aqueous solutions.

2.2 Density measurement

Density was measured by using an equipment of Anton Paas DMA 55 whose accuracy can be obtained with $\pm10^{-5}\,g{\cdot}cm^{-3}$.

2.3 Viscosity measurement

Viscosity was measured with a modified Cannon-Ubbelohde suspended level viscometer. The time of

Received 2002-04-19, accepted 2002-11-01.
* Supported by the Educational Department Doctor Foundation of China (No. 2000005608).
** To whom correspondence should be addressed.

efflux of a constant volume of liquid through the capillary was measured with a precalibrated stopwatch corrected to 0.1 s. The viscometer was always held in vertical position with the help of a brass clamp in a water thermostat. Viscosities of L-ascorbic acid in aqueous D-glucose and sucrose solutions were computed using the well-known relation

$$\eta/\eta_0 = \rho t/\rho_0 t_0 \quad (1)$$

where η, ρ and t are viscosity, density and flow-time respectively of L-ascorbic acid in aqueous D-glucose and sucrose solution, and η_0, ρ_0 and t_0 are the corresponding quantities for aqueous D-glucose and sucrose solutions. All measurements were carried out in a well-stirred water thermostat fitted with a glass window. The variation of temperature of the bath was controlled to within ±0.01 K.

3 RESULTS AND DISCUSSION

The experimental densities and viscosities of L-ascorbic acid in 5% and 10% (by mass) glucose-water and sucrose-water ternary mixtures from 293.15 K to 313.15 K at atmospheric pressure are listed in Tables 1—2.

Table 1 Densities and viscosities of L-ascorbic acid+glucose+H_2O systems at different temperatures

m(ascorbic acid), mol·kg^{-1}	ρ, g·cm^{-3}					$\eta\times10^3$, kg·m^{-1}·s^{-1}				
	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
(5% glucose) +water										
0.0000	1.0152	1.0137	1.0095	1.0074	1.0053	1.0359	0.9185	0.8810	0.8131	0.7620
0.0483	1.0134	1.0131	1.0113	1.0104	1.0082	1.1403	0.9982	0.8857	0.8141	0.7646
0.1004	1.0184	1.0142	1.0128	1.0117	1.0105	1.1692	1.0265	0.9117	0.8160	0.7684
0.1551	1.0286	1.0258	1.0243	1.0239	1.0221	1.1977	1.0404	0.9209	0.8266	0.7786
0.2099	1.0317	1.0310	1.0305	1.0293	1.0269	1.2370	1.0768	0.9316	0.8671	0.7803
0.2463	1.0332	1.0314	1.0307	1.0296	1.0279	1.2381	1.0814	0.9478	0.8724	0.8033
0.3041	1.0339	1.0332	1.0324	1.0319	1.0304	1.2483	1.1157	1.0101	0.9027	0.8127
0.3542	1.0349	1.0341	1.0335	1.0328	1.0332	1.2592	1.1261	1.0213	0.9138	0.8288
0.4067	1.0359	1.0349	1.0343	1.0332	1.0328	1.3252	1.1342	1.0286	0.9306	0.8309
(10% glucose) +water										
0.0000	1.0290	1.0283	1.0260	1.0228	1.0210	1.2029	1.1148	0.9582	0.9151	0.8002
0.0493	1.0335	1.0329	1.0314	1.0305	1.0293	1.2831	1.1282	0.9913	0.9186	0.8096
0.1005	1.0413	1.0397	1.0383	1.0380	1.0357	1.3321	1.1498	1.0243	0.9293	0.8276
0.1542	1.0427	1.0425	1.0395	1.0387	1.0381	1.3468	1.1706	1.0527	0.9417	0.8436
0.2095	1.0453	1.0433	1.0419	1.0418	1.0405	1.3664	1.2308	1.0967	0.9856	0.8615
0.2464	1.0489	1.0455	1.0453	1.0444	1.0409	1.4085	1.2601	1.1236	1.0016	0.8839
0.3042	1.0490	1.0480	1.0471	1.0465	1.0411	1.4358	1.2837	1.1495	1.0239	0.9107
0.3542	1.0503	1.0487	1.0482	1.0478	1.0423	1.4594	1.3041	1.1654	1.0485	0.9364
0.4068	1.0516	1.0501	1.0496	1.0485	1.0454	1.5522	1.3201	1.1861	1.0939	0.9545

Table 2 Densities and viscosities of L-ascorbic acid+sucrose+H_2O systems at different temperatures

m(ascorbic acid), mol·kg^{-1}	ρ, g·cm^{-3}					$\eta\times10^3$, kg·m^{-1}·s^{-1}				
	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
(5% sucrose) +water										
0.0000	1.0172	1.0160	1.0143	1.0131	1.0079	1.0864	1.0073	0.8896	0.7962	0.7145
0.0492	1.0191	1.0189	1.0158	1.0148	1.0085	1.1549	1.0186	0.8962	0.8185	0.7705
0.1037	1.0243	1.0234	1.0211	1.0169	1.0131	1.1818	1.0424	0.9363	0.8359	0.7768
0.1549	1.0296	1.0292	1.0259	1.0248	1.0242	1.2036	1.0616	0.9562	0.8664	0.7921
0.2037	1.0371	1.0319	1.0312	1.0304	1.0286	1.2586	1.0909	0.9836	0.8814	0.8081
0.2466	1.0376	1.0358	1.0350	1.0325	1.0296	1.2743	1.1164	0.9932	0.9046	0.8133
0.3042	1.0378	1.0364	1.0347	1.0336	1.0311	1.3004	1.1358	1.0156	0.9243	0.8264
0.3542	1.0446	1.0436	1.0433	1.0421	1.0364	1.3542	1.1646	1.0543	0.9367	0.8462
0.4086	1.0466	1.0445	1.0442	1.0433	1.0374	1.3869	1.1986	1.0856	0.9598	0.8612
(10% sucrose) +water										
0.0000	1.0354	1.0348	1.0341	1.0332	1.0308	1.2215	1.1564	0.9863	0.9193	0.8169
0.0492	1.0361	1.0358	1.0356	1.0343	1.0327	1.3132	1.1602	1.0328	0.9226	0.8207
0.1037	1.0433	1.0417	1.0413	1.0405	1.0387	1.3643	1.2289	1.0542	0.9318	0.8361
0.1539	1.0449	1.0438	1.0427	1.0422	1.0417	1.3917	1.2537	1.0691	0.9462	0.8497
0.2071	1.0560	1.0544	1.0534	1.0522	1.0489	1.4225	1.2779	1.0938	0.9674	0.8669
0.2470	1.0578	1.0568	1.0553	1.0547	1.0533	1.4863	1.2916	1.1117	0.9921	0.8812
0.3025	1.0624	1.0618	1.0599	1.0590	1.0577	1.5382	1.3211	1.1342	1.0249	0.9064
0.3511	1.0676	1.0663	1.0653	1.0647	1.0641	1.5761	1.3644	1.1619	1.0455	0.9365
0.4002	1.0691	1.0672	1.0659	1.0653	1.0650	1.6341	1.3759	1.1944	1.1239	0.9996

3.1 The correlation function between density and temperature

The density of each solution was fitted into the following equation

$$\rho = \sum_{j=1}^{n} A_j T^j (n = 0, 1, 2, \cdots) \quad (2)$$

where A_j is parameter and T is temperature. j is the same for A_j and T^j. Coefficient A_j can be obtained by the method of least squares, which is listed in Table 3.

3.2 The correlation function between viscosity coefficient and B concentration

B coefficient of the viscosity equation of Jones and Dole[5]

$$\eta_r = 1 + A\sqrt{c} + Bc \quad (3)$$

which deals with ion-solvent interaction, is of particular importance in studying the interactions in ternary systems. Eq. (3) is valid for dilute solutions ($c < 0.1\,\mathrm{mol\cdot L^{-1}}$), but for concentrated solutions ($c > 0.1\,\mathrm{mol\cdot L^{-1}}$) , the effect of A is neglected so that the following relation holds

$$\eta_r = 1 + Bc \quad (4)$$

According to Eq. (4), B coefficient is obtained, as shown in Table 4.

Viscosity coefficient B originally introduced as an empirical term is found to depend upon solute-solvent interactions and on the relative size of solute and solvent molecules. Table 4 shows that B value of L-ascorbic acid increases with concentration of glucose and sucrose and temperature. Since B increases with temperature linearly, it can be correlated by the equation of $B = \alpha + \beta T$. Correlation results are listed in Table 5. The solute-solvent interaction increases with concentration of glucose and sucrose, and it also increases when there is a considerable decrease in the disorder of water due to dissolved glucose and sucrose molecules.

It is suggested that the viscosity coefficient B is a measure of the ion-dipole moment interaction between ions and solvent molecules. It can be said that the positive values of $\mathrm{d}B/\mathrm{d}T$ show the existence of a firm layer of water around the ions. The effect of solute size on B is apparent from the hydrodynamic theory applicable to particles in the liquid continuum.

Table 3 Regression parameters of density of L-ascorbic acid in aqueous solutions of glucose and sucrose

m(ascorbic acid) $\mathrm{mol\cdot kg^{-1}}$	A_0 $\mathrm{g\cdot cm^{-3}}$	A_1 $\mathrm{g\cdot cm^{-3}\cdot K^{-1}}$	A_2 $\mathrm{g\cdot cm^{-3}\cdot K^{-2}}$	A'_0 $\mathrm{g\cdot cm^{-3}}$	A'_1 $\mathrm{g\cdot cm^{-3}\cdot K^{-1}}$	A'_2 $\mathrm{g\cdot cm^{-3}\cdot K^{-2}}$
(5% glucose) +water						
0.0483	0.3297	0.0048	-8.1×10^{-6}	−1.6774	0.0183	-3.1×10^{-5}
0.1004	2.7778	−0.0113	2.2×10^{-5}	−0.8257	0.0128	-2.3×10^{-5}
0.1551	1.9288	−0.0057	9.1×10^{-6}	1.7962	−0.0048	7.2×10^{-6}
0.2099	−0.0755	1.0685	0	−0.0795	1.0685	0
0.2463	−0.0761	1.0685	0	−0.0791	1.0685	0
0.3041	−0.0743	1.0685	0	0.7131	0.0024	-5.2×10^{-6}
0.3542	0.9477	0.0007	-1.2×10^{-6}	−1.5797	0.0177	-3.1×10^{-5}
0.4067	1.2658	−0.0014	2.1×10^{-6}	−1.2433	0.0155	-3.2×10^{-5}
(10% glucose) +water						
0.0492	0.9395	0.0008	-2.1×10^{-6}	0.1142	0.0062	-1.1×10^{-5}
0.1005	1.0381	0.0003	-9.3×10^{-7}	0.7841	0.0019	-4.2×10^{-6}
0.1542	1.7683	−0.0046	7.2×10^{-6}	1.5639	−0.0033	5.2×10^{-6}
0.2095	−0.0572	1.0514	0	−0.0794	1.0685	0
0.2464	−0.0798	1.0685	0	−0.0574	1.0514	0
0.3042	−0.9345	0.0135	-2.1×10^{-5}	1.0292	0.0004	-1.1×10^{-6}
0.3542	−0.7936	0.0125	-2.1×10^{-5}	1.5901	−0.0033	5.2×10^{-6}
0.4068	0.0715	0.0067	-1.2×10^{-5}	2.1512	−0.007	1.3×10^{-5}

Table 4 Viscosity coefficients B of L-ascorbic acid in aqueous solutions of glucose and sucrose

$w\times10^2$	$B\times10^3$, $\mathrm{m^3\cdot mol^{-1}}$					B/ϕ_v^0				
	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
5% glucose	0.3976	0.4132	0.4185	0.4268	0.4326	5.78	6.43	8.69	9.13	9.34
10%glucose	0.4538	0.4862	0.4954	0.5013	0.5164	5.94	6.52	7.79	9.65	10.17
5% sucrose	0.4562	0.4659	0.4743	0.4786	0.4812	6.32	6.72	9.20	9.65	10.22
10%sucrose	0.5195	0.5246	0.5387	0.5424	0.5426	6.74	6.84	8.16	8.77	9.52

Note: B/ϕ_v^0 is solvation number.

Table 5 Regression parameters of L-ascorbic acid in glucose-water and sucrose-water between B and temperature

$w \times 10^2$	α	β
5% glucose	0.3901	0.0089
10%glucose	0.4421	0.0151
5% sucrose	0.4518	0.0061
10%sucrose	0.5136	0.0061

3.3 Apparent molar volume calculation and correlation

Apparent molar volumes ϕ_v of L-ascorbic acid in glucose-water and sucrose-water were calculated from the following equation

$$\phi_v = \frac{1000(\rho_0 - \rho)}{\rho_0 c} + \frac{M}{\rho} \tag{5}$$

where M, c, ρ_0 and ρ are the molar mass of solute, molar concentration of solute, density of solvent and solution, respectively. Values of ϕ_v are listed in Table 6.

From Table 6, the apparent molar volume decreases as temperature increases at the same concentration, and increases with concentration at the same temperature. These values are important basis of understanding solute-solvent interactions. The dependence of ϕ_v value on temperature and concentration gives information about solute-solute and solute-solvent interactions.

Since, for each solute studied, the apparent molar volume was found to be a linear function of molar concentration over the range studied, the partial molar volume (infinite dilution) ϕ_v^0 was obtained by the equation

$$\phi_v = \phi_v^0 + bc \tag{6}$$

in which b is the experimental slope. The evaluated values of ϕ_v^0 and b for Eq. (6) are given in Table 7.

Table 6 ϕ_v of ascorbic acid in glucose-water and sucrose-water at different temperatures

m	$\phi_v \times 10^6$, $m^3 \cdot mol^{-1}$				
(ascorbic acid), $mol \cdot kg^{-1}$	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
(5% Glucose) +water					
0.0483	74.2324	70.0143	58.5255	57.1296	55.4271
0.1004	83.0976	80.8369	63.9133	62.3221	60.6817
0.1551	91.3906	86.7898	70.9482	69.2347	67.4553
0.2099	96.0610	92.4433	75.3664	73.2672	72.8378
0.2463	104.5055	102.8573	89.2086	85.3643	83.9272
0.3041	112.9207	110.4926	99.8770	94.8624	93.0979
0.3542	118.7074	116.9334	107.3518	103.6521	96.8476
0.4067	123.3575	122.3272	114.0677	111.8648	107.9405
(10% Glucose) +water					
0.0492	82.3346	80.4153	64.7571	59.2817	57.3787
0.1005	92.2274	90.9717	82.3801	80.3315	79.2472
0.1542	94.8244	91.7289	86.3366	81.3895	80.8933
0.2095	98.5546	94.6541	87.6949	83.5333	81.3430
0.2464	105.6793	103.3986	95.3237	86.4956	84.4055
0.3042	117.2729	112.3049	104.0621	96.0312	95.7914
0.3542	120.7254	118.2732	110.5785	105.1955	103.6087
0.4068	127.1763	124.1685	115.1230	113.4361	112.7607
(5% Sucrose) +water					
	73.1946	69.3532	57.5950	56.7534	54.6524
	81.8428	79.1204	62.9976	61.6822	58.9979
	90.4538	85.4820	69.8156	68.2966	66.3451
	93.1110	91.5296	71.8514	70.0219	68.9260
	94.8255	93.3288	88.8887	83.1998	82.4424
	96.5782	95.3512	94.5312	92.3340	89.0816
	97.1024	96.6613	95.9265	94.0366	93.9174
	103.4154	102.7044	101.5018	100.8973	99.1176
(10% Sucrose) +water					
	72.3726	70.5731	63.8515	57.8399	54.4185
	76.5315	75.9064	73.1805	70.3370	66.9623
	81.4903	79.6939	76.2843	73.8701	70.1583
	84.0401	82.7493	80.2034	79.6753	76.0813
	91.5205	88.1333	87.3224	86.2229	82.4960
	93.9036	88.9523	87.8452	86.9217	84.5987
	101.5320	93.5060	90.3888	89.6353	88.8564
	108.7793	101.9699	93.4820	92.8379	90.9634

Table 7 ϕ_v^0 **and** b **of ascorbic acid in glucose-water and sucrose-water at different temperatures**

$w \times 10^2$	$\phi_v^0 \times 10^6$, $m^3 \cdot mol^{-1}$					$b \times 10^9$, $m^6 \cdot mol^{-2}$				
	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
5% glucose	68.731	64.289	48.153	46.723	46.326	139.42	147.06	154.21	158.02	160.37
10% glucose	76.455	74.568	63.611	51.968	50.777	124.47	126.21	130.06	148.51	149.02
5% sucrose	72.192	69.346	51.559	49.558	47.082	75.728	82.688	130.13	130.46	131.89
10%sucrose	77.081	76.641	66.015	61.846	57.019	99.464	79.352	80.351	81.806	87.018

Table 8 **Regression parameters of ascorbic acid in glucose-water and sucrose-water**

$w \times 10^2$	Regression parameters					
	ϕ_v^0			b		
	a_0 $m^3 \cdot mol^{-1}$	a_1 $m^3 \cdot mol^{-1} \cdot K^{-1}$	a_2 $m^3 \cdot mol^{-1} \cdot K^{-2}$	a'_0 $m^6 \cdot mol^{-2}$	a'_1 $m^6 \cdot mol^{-2} \cdot K^{-1}$	a'_2 $m^6 \cdot mol^{-2} \cdot K^{-2}$
5% glucose	82.598	−14.562	−1.4422	129.002	11.252	−0.9943
10%glucose	84.256	−7.222	0.0744	125.411	−2.561	1.4752
5% sucrose	84.381	−13.133	1.1279	41.968	35.774	−3.5161
10%sucrose	83.038	−5.695	0.0946	118.972	−23.376	3.4044

Since ϕ_v^0 is, by definition, free of solute-solute interactions, it provides information on solute-solvent interactions. In Table 7, the values of ϕ_v^0 for L-ascorbic acid in glucose-water and sucrose-water are positive and decrease as temperature increases at the same concentration of sugar, but b increases as temperature increases. These results can be explained by the co-sphere overlap model, developed by Friedman and Krishnan[6], in which the effect of overlap of hydration co-sphere is destructive.

The solvation of any solute can be judged from the magnitude of B/ϕ_v^0, *i.e.*, solvation number. These values are important indicators[7] as to whether a particular solute is solvated or not since a value between 0—2.5 corresponds to unsolvated species and any higher values correspond to solvated ones. In the present study the values of B/ϕ_v^0 (Table 4) are larger than 2.5, showing a distinct hydration. B/ϕ_v^0 increases with temperature. The trend is similar to that of B-coefficient.

Further, according to the equation $\phi_v^0 = \sum_{j=0}^{n} a_j T^j (n = 0, 1, 2, \cdots)$ and $b = \sum_{j=0}^{n} a'_j T^j (n = 0, 1, 2, \cdots)$, correlation results are obtained and listed in Table 8.

Through these correlation equations, and applying correlation results given for temperature and concentration, we can calculate partial molar volume ϕ_v^0, then applying Eq. (6), apparent molar volume can be obtained, and finally density for L-ascorbic acid can be obtained by Eq. (5). Therefore density can be obtained by correlation of apparent molar volume instead of by measurement.

4 CONCLUSIONS

(1) Viscosities and densities at several temperatures from 293.15 K to 313.15 K were measured for L-ascorbic acid in aqueous solutions of glucose and sucrose at different concentrations.

(2) The parameters of density and viscosity B are calculated by regression. Experimental results show that densities and viscosities decrease as temperature increases at the same concentration of solute and solvent (glucose and sucrose aqueous solution), and increase with concentration of glucose and sucrose at the same solute concentration and temperature. B increases with concentration of glucose and sucrose and temperature.

(3) Values of density and viscosity as well as their corresponding parameters obtained by regression for the B in the sucrose-water system were found to be higher than those in the glucose-water system at the same concentration and temperature.

NOMENCLATURE

A	regression coefficient, $L^{1/2} \cdot mol^{-1/2}$
$A_0, A_1, A_2, \cdots, A_j$	jth regression coefficient of density in glucose solution, $g \cdot cm^{-3} \cdot K^{-j}$
$A'_0, A'_1, A'_2, \cdots, A'_j$	jth regression coefficient of density in sucrose solution, $g \cdot cm^{-3} \cdot K^{-j}$
$a_0, a_1, a_2, \cdots, a_j$	jth regression coefficient of partial molar volume, $m^3 \cdot mol^{-1} \cdot K^{-j}$
$a'_0, a'_1, a'_2, \cdots, a'_j$	jth regression coefficient of b, $m^6 \cdot mol^{-2} \cdot K^{-j}$
B	viscosity coefficient, $L \cdot mol^{-1}$
b	regression coefficient of apparent molar volume, $m^6 \cdot mol^{-2}$
c	concentration of solution, $mol \cdot L^{-1}$
M	molar mass of solute, $g \cdot mol^{-1}$
m	concentration of ascorbic acid, $mol \cdot kg^{-1}$
T	absolute temperature, K
t	flow time of solution, s
t_0	flow time of solvent, s
w	mass fraction of glucose and sucrose
α	regression coefficient of B, $L \cdot mol^{-1}$
β	regression coefficient of B, $L \cdot mol^{-1} \cdot T^{-1}$

η viscosity of solution, $kg \cdot m^{-1} \cdot s^{-1}$
η_r relative viscosity
η_0 viscosity of solvent, $kg \cdot m^{-1} \cdot s^{-1}$
ρ density of solution, $g \cdot cm^{-3}$
ρ_0 density of solvent, $g \cdot cm^{-3}$
ϕ_v apparent molar volume, $m^3 \cdot mol^{-1}$
ϕ_v^0 partial molar volume, $m^3 \cdot mol^{-1}$

Superscripts

j jth power
n the biggest stage number

Subscripts

j stage number

REFERENCES

1 Moulik, S.P., Khan, D.P., "Activation parameters for fluidity of water influenced by glucose, sucrose, glycerol, mannitol & sorbitol", *Ind. J. Chem.*, **16A**, 16—19 (1978).
2 Hoiland, H. J., Thermodynamic Data for Biochemistry and Biotechnology, Springer-Verlag, Berlin (1986).
3 Vinon, K.S., "Studies on viscosity behavior of concentrated alkali halides in aqueous D-glucose solutions", *Ind. J. Chem.*, **20A**, 24—29 (1981).
4 Liu, W.B., Wu, Y.P. "Viscosity of NaCl and KCl in aqueous sucrose solutions", *Acta Phys-Chim.*, **11** (7), 590—595 (1995). (in Chinese)
5 Johns, D., Dole, M., "Transition state treatment of the relative viscosity of electrolytic solutions", *J. Am. Chem. Soc.*, **51** (3), 2950—2953 (1929).
6 Friedman, H.L., Krishnan, C.V., A Comprehensive Treatise, F. Franks. Ed, Plenum Press, New York (1973).
7 Takashi, I., "Theoretical study of for partial molar volume of amino acids in aqueous solutions: Implication of ideal fluctuation volume", *J. Chem. Phys.*, **112** (21), 9469—9478 (2000).