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Solution Behavior of Sugars and Pseudo-Sugar in Water at 298 K

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ABSTRACT

Densities (ρ) and viscosities (η) of dextrose, fructose and myoinositol have been measured in concentrate aqueous solution, concentration range 0.1-0.9 M at 298 K. From the density, the apparent molar volume (Φv) and partial molar volume (Φvo) were calculated. The viscosity coefficient B and A were calculated from the viscosity data using Jones-Dole equation for all the studied sugars and pseudo-sugar. The data were also analyzed for Stauarding equation. From these parameters, results were correlated with solute-solute, salvation of solute and solute-solvent interactions. All sugars and pseudo-sugar revealed structure making properties.

Keywords: Apparent molar volume, Partial molar volume, Jone-Dole equation, Myoinositol, Pseudo-sugar

INTRODUCTION

The molecular interactions of dilute as well as concentrate solution of sugars in water play an important role in expressing biological and medicinal processes of cellular systems. The volumetric and viscometric behavior of electrolytes and non-electrolytes provide useful information for solute-solvent and solute-solute interactions [1,2]. In this regard densities and viscosities were used for investigation of molecular interactions [3]. Apparent molar volume and partial molar volume of solute in solution are used to study solute-solvent affinity [4,5].

Aqueous solution of carbohydrates has been widely used in food and medicinal applications [6-10]. Carbohydrates and their derivatives are most important class of biomolecules and reveal their biological adaptability of various functions such as structure and protective metabolic recognition. In addition to bioavailability and metabolic stability, carbohydrate molecules display high receptor affinity and selectivity [11]. It is an essential component for maintaining cell viability, natural cell protective agent as well as energy reservoir in many organisms [12,13].

Among the cyclic polyols, Myo-inositol ($C_6H_{12}O_6$) is a cyclic sugar alcohol. It is also known as cyclitol. The chemistry of the cell is controlled by myo-inositol. There should be communication between outer and inner environment of a cell. The calcium channels of cell membrane can be opened by the derivative of myo-inositol (inositol-1,4,5-triophosphate). It allows the calcium ions to enter into the extracellular fluids [14].

The objective of this work is to work out volumetric and viscometeric parameters such as apparent molar volume (Φv), partial molar volume (Φ_v^o), *A* and *B Jone-Dole* constant and *Staurding* constant of dextrose, fructose and myoinositol in aqueous solution by using density and viscosity at various concentration and at 298 K.

MATERIALS AND METHODS

Dextrose, fructose and myoinositol used in this work were analytical grade with purity of >99% was procured from Loba Chemie (dextrose and fructose) and SHIMADZU. The water used for the preparation of solution was double distilled. The molar aqueous solutions of solutes were prepared by using digital electronic balance (Model-AJO20, aiwa) with an accuracy of ± 0.1 mg.

Densities (ρ) and viscosities (η) of aqueous solutions of dextrose, fructose and myoinositol were measured by using specific gravity bottle by relative measurement method with accuracy of ±0.1 $kg.m^{-3}$ and An Ostwald's viscometer was used for the measurement of viscosity of liquid mixtures with an accuracy of 0.0001 Nsm^2. The viscometer was calibrated before used. Time flow of water and liquid solutions were measured respectively.

RESULTS AND DISCUSSION

The density, ρ (g cm^{-3}) and viscosity data of dextrose, fructose and myoinositol measured at temperature 298 K as function of concentration, (mol dm^{-3}) are given in Table 1. Apparent molar volume can be calculated from the density data by using eq. (1) [15].

$$\Phi_v=M/\rho_o-1000\ (\rho-\rho_o)/C\rho_o \quad (1)$$

Where Φ_v, C, ρ, ρ_o and M are the apparent molar volume, molarity, density of the solution, density of solvent (water) and molar mass of solute, respectively.

When a solute dissolved into solvent to make solution, there may be changed in volume due to solute-solvent interactions; this changed volume is called apparent molar volume. Apparent molar volume at infinite dilution where the solute-solute interaction is completely vanished is called partial molar volume [16].

Apparent molar volume and partial molar volume are used to reveal hydration of solute and solute-solvent structural interactions. The smaller apparent molar volume values of sugars indicate strong hydration of solute molecules [17]. At higher concentration, hydration rate of solute (solute-solvent) interaction decreased and solute-solute interaction increased due to the increase in electrostatic attractions between solute molecules [16].

The apparent molar volume (Φv) data for dextrose, fructose and myoinositol can be expressed with Messon's relation given by eq. (2) least square fit method [18,19].

$$\Phi v=\Phi_v^o + S_v\sqrt{C} \quad (2)$$

Where, Φ_v^o, is partial molar volume, first coefficient of fit and known as partial molar volume. Partial molar volume provides information about solute-solvent interactions. The values of Φ_v^o and S_v for the sugars and myoinositol at 298 K in Table 1. The value of Φ_v^o and S_v were calculated with the help computer using the relation of Eq. (2). The Φ_v^o values are positive for dextrose, fructose and myoinositol specifying thereby positive interaction between solute and solvent molecules. The value S_v is negative for all the solutes, which indicates weak solute-solute interactions.

Relative viscosity of dextrose, fructose and myoinositol solutions at different concentrations was calculated considering solutes as monomer unit of polymer system. Thus, if η is the viscosity of solution and η_o is the viscosity of pure solvent at 298 K. The polymer species follow *Staurding* [20] the Eq. (3) is given by:

$$(\eta-\eta_o)/\eta_o=kn\ Cn \quad (3)$$

Where, *k* is constant for a given solute in a given solvent, C is the molar concentration of solute and n is the number of monomer units in polymer. The observed relative viscosity values for dextrose, fructose and myoinositol are given in the Table 2.

Table 1: Apparent molar volume (Φv), partial molar volume (Φvo) and Sv, dextrose, fructose and myoinositol at 298 K at different concentration

Concentration (mol dm^{-3})	$\sqrt{C}$	***Φv* (m^3 mol^{-1})**		
		Glucose	**Fructose**	**Myoinositol**
0.1	0.3162	135.51	133.51	123.48
0.2	0.4472	131.00	126.99	123.98
0.3	0.5477	128.82	127.49	117.47
0.4	0.6325	125.24	123.73	115.21
0.5	0.7071	125.09	122.48	111.05
0.6	0.7746	118.81	118.64	111.28
0.7	0.8367	117.04	116.61	109.87
0.8	0.8944	114.84	114.46	106.69
0.9	0.9487	113.01	112.79	104.65
Φ_v^o	(m^3 mol^{-1})	147.84	143.42	135.22
Sv	(m^3 $Kg^{1/2}$ $mol^{-3/2}$)	-36.24	-31.80	-31.66

Observed data were used to examine how for the results of viscosities of dextrose, fructose and myoinositol solutions agree with Eq. (3) applicable for polymers. Therefore, the relative viscosity values were plotted against different concentrations of studied sugars and non-sugar and for all these molecules plot shows linearity. At zero concentration, intercept value is found to be the minimum. The values of slope (*kn*) found for different studied solutes are presented in Table 3.

The structure making and structure breaking properties of solutes is also reported by considering *Jone-Dole* [21] eq. (4), in term of viscosity coefficient *B* and intercept *A*.

$$\eta/\eta_o=1+A+B\sqrt{C} \quad (4)$$

Where, η/η_o is the relative viscosity, C is molar concentration of solute, *A* and *B* are constants for the studied solute. *A*-coefficient represents the contribution from interionic electrostatic forces and the *B*- coefficient measures the order or disorder produced by the ions in case of electrolyte and solutes in case of non-electrolyte in the solvent structure [22]. Therefore $(\eta/\eta_o-1)/\sqrt{C}$ values were plotted against $\sqrt{C}$ shows linearity for all sugar solution with slope *B* and intercept *A*. The values of both the constants are reported in Table 3 for dextrose, fructose and myoinositol. The *Jone-Dole* equation is more useful for ionic solute because *A* gives information about interionic electrostatic forces. In our present study, sugars and myoinositol are covalent (non-electrolytes). Therefore, the values of A for all the studied solutes are very small because the interionic interaction is very poor in case of non-electrolytes. The very small values of intercept *A* may be due to hydrogen bonding or Vander Waal's forces.

It is observed from the results (Table 3), the values of coefficients *B* are positive for all the studied molecules in aqueous solutions designating that solute-solvent interactions/solute-solute interaction are more significant and all the sugars and non-sugar (myoinositol) behave as "structure maker". The values of coefficient *B* is in the order of myoinositol>fructose>Dextrose. The trends of variation of coefficient *B* of aqueous solution of dextrose, fructose and myo-inositol may be explained as shown in Table 3.

It is observed that strength of molecular interaction of carbohydrates (dextrose, fructose and myo-inositol) depends on molecular ring size and percentage of axial and equatorial hydroxyl groups. It is more favorable when the hydroxyl group is at the equatorial position [23]. It seems that strength of intermolecular interaction of equatorial –OH groups is more. Dextrose has more percentage of equatorial –OH group. It should have strong association with solvent molecules as compared to fructose and myo-inositol. The result shows that the trend of molecular association is in the order of dextrose<fructose<myo-inositol. This can be explained that dextrose is present as a pyranose ring, furanose and straight chain form. But most stable form of dextrose in aqueous medium is pyranose form. Fructose is present

Table 2: Relative viscosities (η/ηo) for dextrose, fructose and myoinositol at 298 K at different concentration

Concentration (C) (mol dm^{-3})	$\sqrt{C}$	(η/η_o) for sugars		
		Dextrose	Fructose	Myoinositol
0.1	0.3162	1.042	1.021	1.004
0.2	0.4472	1.077	1.052	1.035
0.3	0.5477	1.107	1.074	1.084
0.4	0.6325	1.147	1.123	1.137
0.5	0.7071	1.192	1.164	1.169
0.6	0.7746	1.238	1.222	1.228
0.7	0.8367	1.325	1.292	1.283
0.8	0.8944	1.396	1.360	1.370
0.9	0.9487	1.447	1.459	1.458

Table 3: Values of parameters of *Staurding* and *Jone-Dole* equation for dextrose, fructose and myoinositol at 298 K in aqueous solution

Sugars	(η/η_o-1) *vs. C*	$(\eta/\eta_o-1)/\sqrt{C}$ *vs.* $\sqrt{C}$	$B \times 10^3/\Phi^o_v$
Dextrose	*kn*=0.4959 dm^3 mol^{-1}	*B*=0.55 dm^3 mol^{-1} *A*=-0.084 dm$^{3/2}$ mol$^{-1/2}$	3.72
Fructose	*kn*=0.4961 dm^3 mol^{-1}	*B*=0.64 dm^3 mol^{-1} *A*=-0.183 dm$^{3/2}$ mol$^{-1/2}$	4.46
Myoinositol	*kn*=0.5089 dm^3 mol^{-1}	*B*=0.71 dm^3 mol^{-1} *A*=-0.236 dm$^{3/2}$ mol$^{-1/2}$	5.25

as a furanose ring as well as straight chain form which have five hydroxyl (–OH) group, but out of these five; two are attached to $–CH_2$ groups and not to the ring. It is known that the interactions between open chain aliphatic –OH groups and solvent molecules are more extensive than cyclic compounds with solvent [24]. Hence, fructose is somewhat more hydrated than dextrose. Myo-inositol is present as six membered rings and has same number of equatorial –OH groups as like dextrose, but one –OH group is more than in dextrose and fructose and hence forms more number of hydrogen bonds and reveals strong molecular interaction [25].

The Φ_v^o values for all sugars and non-sugar are positive which suggest that all the studied solutes interact with water molecules through hydrogen bonding (dipole-dipole interactions) of hydroxyl groups present in the solute molecules.

The observed constant *k* of dextrose, fructose and myoinositol has values in the same order of coefficient *B* which are reported in Table 3.

The solvation of any solute can be decided from the magnitude of B/Φ_v^o. These values are important indicators [26] as to whether a particular solute is solvated or unsolvated. If the value of this ratio is in between 0-2.5, solute is supposed to be unassociated species. If the value is greater than 2.5, it is solvated. Greater the value greater would be association [27]. From Table 3, it is observed that B/Φ_v^o flows the order myoinositol>fructose>dextrose.

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