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Acoustical Studies of Aqueous Solution of D(+)-Galactose at Different Temperature

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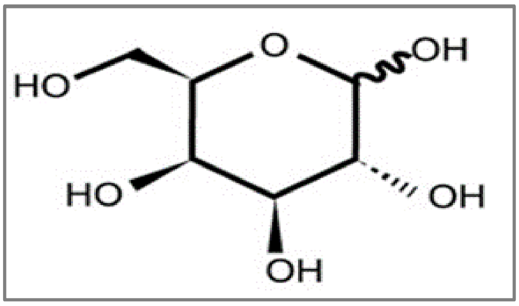
ABSTRACT

The present ultrasonic investigation deals with behavior and intermolecular interaction of D(+)-Galactose (monosaccharide) in aqueous medium. Density (ρ), viscosity (η) and ultrasonic velocity (U) of solution has been measured at different temperature with different concentration. By using experimental values, acoustic parameter such as acoustic Impedance (Z), adiabatic compressibility (β_{ad}), relaxation time (τ) ,classical absorption (α/f^2), apparent molal compressibility (ϕ_k),apparent molal volume (ϕ_v), relative Association (R_A), surface Tension (σ), have been evaluated. The results have been discussed in terms of evaluated acoustical parameters.

Graphical Abstract

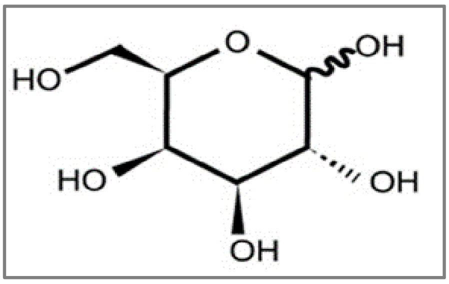


D(+)-Galactose.

Keywords: Molecular interactions, Ultrasonic velocity, Adiabatic compressibility, Surface tension.

INTRODUCTION

In 1856 Galactose was found in milk for the 1st time which was studied by Louis Pasteur. The word galactose is come from Greek word galakt. It is commonly known as carbohydrate which is a main source of metabolic energy for plant and animal. This occurs in nature in D-form. D(+)-galactose has biological importance [1]. It is energy providing nutrient in living nature. It is found in milk of mammals and some fruit and vegetables like avocado, sugar beet, kiwi, and celery and also in glycol-lipids of nervous tissue. It is a colorless solid [2] and a component of the disaccharide lactose [3]. The physical properties of this compound make it useful in industrial application such as for the low - calories sweetener and it can be used in artificial sugar and medicinal drug.



D(+)-Galactose.

The ultrasonic measurement is useful to determine thermodynamic parameters. Ultrasonic investigation in water- carbohydrate solution is essential for better understanding of biophysics and chemistry. It is also useful to determine molecular interaction between molecules of liquid mixture of Monosaccharide. The complete information of thermodynamic properties of the organic compounds makes it useful in industrial and non-industrial applications [4]. From the practical point of view, physical and chemical properties play an important role in its applicability and to understand the molecular properties of the mixture [5]. In the present investigation we have experimentally measured density (ρ), viscosity (η) and ultrasonic velocity (U) of aqueous D-Galactose, by using these basic parameters various thermo-acoustical parameters have been computed. The results are used to explain the interaction between molecules.

MATERIALS AND METHODS

D(+)-Galactose, CAS-No. 59-23-4, AR grade (99.9% pure), molecular weight 180.16 g mol^{-1} was obtained from Sigma-Aldrich Ltd. The aqueous solution of D-Galactose of different concentrations was freshly prepared by using double distilled water. With the help of digital ultrasonic pulse–echo velocity meter operating at 2 MHz frequency, ultrasonic velocity of aqueous solution was measured. By using specific gravity bottle method, density of solution was determined. An Ostwald viscometer was used to determine the viscosity of solution. During the experiment, temperature controller was used to maintain the constant temperature.

Theoretical Calculations: Experimentally measured values of density, viscosity and ultrasonic velocity are used to calculate the following acoustical parameters:

Acoustic Impedance (Z): Acoustic impedance (Z) is given by,

$$Z = U \rho \qquad (\text{Kg}.m^{-2}s^{-1})$$

Where, U=ultrasonic velocity of solution, ρ=density of solution.

Adiabatic compressibility (β_{ad}): The adiabatic compressibility is defined as the fractional decrease of volume per unit increase of pressure and it is given by,

$$\beta_{ad} = 1 / U^2\rho (N^{-1}m^2)$$

Relaxation Time (τ):

$$\tau = \frac{4}{3\beta\eta} \text{ (sec)}$$

Where, η is the viscosity of solution.

Classical Absorption (α/f^2):

$$(\alpha/f^2) = \frac{8\eta\pi^2}{3\rho U^3} \quad (m^3\ mol)$$

Where, U=ultrasonic velocity of solution. ρ=density of solution. η=viscosity of solution.

Apparent molal compressibility (ϕ_k):

$$\phi_k = \left[\frac{10^3 \times (\beta_s\rho_0 - \beta_0\rho_s)}{m\rho_s\rho_0}\right] + \left[\frac{\beta_s M}{\rho_s}\right] (m^2\ N^{-1})$$

Where, βs=adiabatic compressibility of solution, β_0=adiabatic compressibility of pure solvent m=molar concentration, M=molecular weight of solute.

Apparent molal volume (ϕ_v):

$$\phi_v = \left[\frac{10^3 \times (\rho_0 - \rho_s)}{m\rho_s\rho_0}\right] + \left[\frac{M}{\rho_s}\right] (m^3\ mol^{-1})$$

Where, ρ_s=density of solution, ρ_0=density of solvent, m=molar concentration, M=molecular weight of solute.

Relative Association (R_A): It is the measure of non-ideality of solution. Relative association (R_A) has been calculated by using the following relation.

$$R_A = (\rho / \rho_0) \times (u_0 / u)^{1/3}$$

Where, ρ=density of solution, ρ_0=density of solvent, u_0=ultrasonic velocity of solvent, u=ultrasonic velocity of solution.

Surface Tension (σ): Surface tension (σ) is used to study the surface composition of aqueous solution of the mixture. The surface tension is given by,

$$\sigma = (6.3 \times 10^{-4})\ \rho\ U^{3/2} (Nm^{-1})$$

Where, ρ = density of solution.

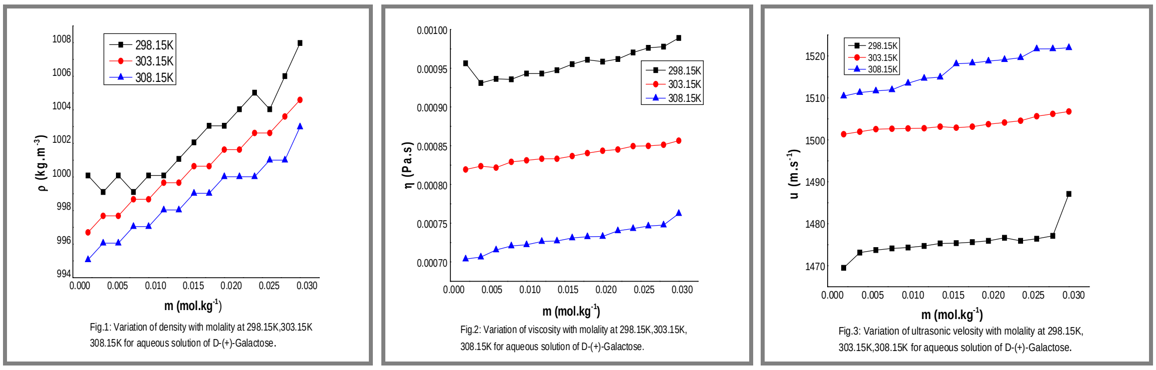
RESULTS AND DISCUSSION

The experimentally measured values of density(ρ), viscosity(η) and ultrasonic velocity(u) of aqueous solution of D(+)-Galactose of different concentration (mol kg^{-1}) at different temperature 298.15K, 303.15K and 308.15K are as given in table 1.The variation of experimentally measured parameters are as shown in figures 1-3, whereas derived parameters such as acoustic impedance (Z), adiabatic compressibility (β_{ad}), relaxation time (τ), classical absorption (α/f^2), apparent molal compressibility (ϕ_k), apparent molal volume (ϕ_v), relative association (R_A), and surface Tension(σ) at different concentration are as shown in figure 4-11 respectively. The density of solution of D(+)-Galactose increases with increase in the concentration at different temperatures, but decreases with increase in temperature (figure 1) for the same concentration presented in table 1. Density of solution under present investigation increases with concentration is mainly due to rise in number of solute particles in solvent double distilled water [6, 7]. The decrease in density values is due to increase in volume of the solution with rise in temperature. Also this decreasing trend in density might be due to weakening of inter molecular cohesive forces [8]. To understand the structure and interactions occurring in the solutions of D(+)-Galactose, viscosity is important parameter. It is seen that, the viscosity values increases with increase in the concentration at different temperatures, but decreases with increase in temperature (figure 2) for the same concentration presented in table 1. The linearly increase of viscosity with solute increases of cohesive forces due to strong molecular interactions and decrease of these parameters with temperature suggests that decrease of cohesive forces [9, 10]. From table 1, the ultrasonic velocity of solution increased linearly with concentration and temperature (figure 3). Increase in velocity is due to size enlargement of the component in the mixture, cohesion will increase and thus it may lead to solvent-solvent interaction [11, 12]. The linear variation of ultrasonic velocity with rise in temperature shows the molecular association in the sample [13].

Table 1. Density, viscosity and ultrasonic velocity of aqueous solution of D (+)-Galactose at different concentration and temperature range (298.15, 303.15 and 308.15) K.

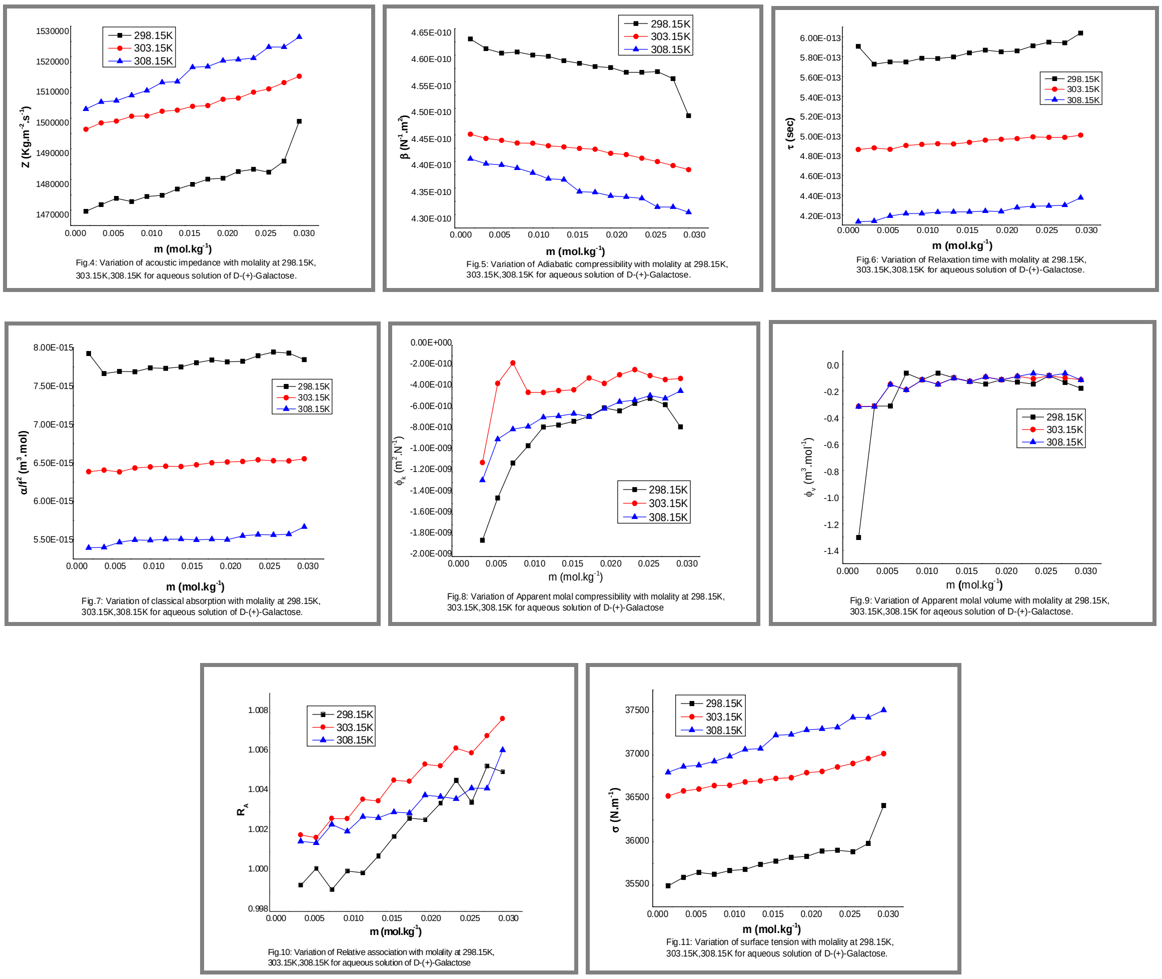
T(K)	Molality ($mol.kg^{-1}$)	ρ ($kg.m^{-3}$)	η (Pa.s)	U ($m.s^{-1}$)
298.15	0.002	1000.089	9.564E-04	1469.501
	0.004	999.103	9.309E-04	1473.136
	0.006	1000.089	9.363E-04	1473.736
	0.008	999.103	9.357E-04	1474.122
	0.01	1000.089	9.431E-04	1474.336
	0.012	1000.089	9.431E-04	1474.712
	0.014	1001.075	9.474E-04	1475.312
	0.016	1002.061	9.552E-04	1475.376
	0.018	1003.048	9.609E-04	1475.625
	0.02	1003.048	9.585E-04	1475.926
	0.022	1004.034	9.619E-04	1476.646
	0.024	1005.020	9.703E-04	1475.926
	0.026	1004.034	9.762E-04	1476.436
	0.028	1006.007	9.778E-04	1477.122
	0.03	1007.979	9.890E-04	1487.110
303.15	0.002	996.697	8.193E-04	1501.334
	0.004	997.684	8.236E-04	1501.937
	0.006	997.684	8.217E-04	1502.540
	0.008	998.670	8.292E-04	1502.636
	0.01	998.670	8.311E-04	1502.711
	0.012	999.657	8.332E-04	1502.767
	0.014	999.657	8.332E-04	1503.132
	0.016	1000.644	8.366E-04	1502.892
	0.018	1000.644	8.404E-04	1503.136
	0.02	1001.631	8.435E-04	1503.720
	0.022	1001.631	8.451E-04	1504.112
	0.024	1002.618	8.494E-04	1504.543
	0.026	1002.618	8.497E-04	1505.620
	0.028	1003.605	8.512E-04	1506.173
	0.03	1004.591	8.565E-04	1506.751
308.15	0.002	995.069	7.037E-04	1510.429
	0.004	996.058	7.063E-04	1511.261
	0.006	996.058	7.155E-04	1511.653
	0.008	997.047	7.206E-04	1511.921
	0.01	997.047	7.222E-04	1513.485
	0.012	998.037	7.264E-04	1514.650
	0.014	998.037	7.270E-04	1514.921
	0.016	999.026	7.309E-04	1518.110
	0.018	999.026	7.325E-04	1518.322
	0.02	1000.015	7.329E-04	1518.753
	0.022	1000.015	7.402E-04	1519.105
	0.024	1000.015	7.430E-04	1519.567
	0.026	1001.004	7.463E-04	1521.670
	0.028	1001.004	7.476E-04	1521.678
	0.03	1002.982	7.624E-04	1521.935

From figure 4, it is observed that acoustic impedance increases with concentration and also with temperature. This may be due to the variation of pressure from one particle to another particle, and the increase in acoustic impedance values with solute concentration can be attributed to the effective



Figures 1-3. Variation of Density (ρ), Viscosity (η) and Ultrasonic velocity (U) of aqueous solution of D(+)-Galactose at different concentration and temperature range (298.15, 303.15 and 308.15)K.

4.



Figures 4-11.

solute solvent interactions [14, 15]. The adiabatic compressibility (figure 5) decreases with increase in the concentrations also with temperature. The decrease in the compressibility shows that there are enhanced molecular associations in this system with increases in the solute content, as the new entities become compact and less compressible [16]. Relaxation time increases with increase in the concentration at different temperatures, but decreases with increase in temperature for the same concentration as shown in figure 6. This is due to the molecules of the medium are strongly held together, to overcome these forces more time is needed; hence relaxation time is more [17]. The relaxation time which is in the order of 10^{-13} second is due to the structural relaxation process [18]. It is seen that the value of classical absorption slightly increases with increase in the molal concentration (figure 7) indicating more stability of molecules. Molar concentration supports the presence of strong intermolecular interaction through bonding of hydrogen in the component molecules of this binary liquid system [**19**].

The apparent molal compressibility increases with increase in the concentration (figure 8). The increasing values of apparent molal compressibility indicate that strengthening of the solute-solvent interactions exists in these mixtures and negative values are indicative of ionic and hydrophilic interactions in this system [**20**]. The value of apparent molal volume decreases non-linearly with increase in the concentration (figure 9) at different temperatures and also decreased non-linearly with increasing temperature. Decrease in apparent molal volume is due to strong ion-solvent interaction and the negative values of apparent molal volume indicate electro-strictive solvation of ions [**21**].

Relative association is influenced by two factors (i) breaking up of the associated solvent molecules on addition of solute in it and (ii) the solvation of solute molecules. The former leads to decrease and later to increase of relative association, the values of Relative association increases with increase in solute concentration (figure 10) and it indicating significant ion-solvent interactions which increase with increase in solute concentration [**22**]. The values of surface tension increases with concentration and also with temperature (figure 11). The cause of the increase of the surface tension lies in the elevated free energy of cohesion between the electron acceptor and electron-donor sites of molecularly dissolved sugar molecule as a result of hydrogen bonding [**23**].

APPLICATION

The measured and derived physical parameters data obtained in the present investigation is helpful for not only understanding nature, type and strength of the molecular interactions but also physico-chemical and thermo dynamical properties of the aqueous solution under the study.

CONCLUSION

In this study, the measurement of density, viscosity, ultrasonic velocity and other acoustical parameters of aqueous solution of D(+)-Galactose was studied in different concentration (0.002-0.03) mol kg^{-1} at 298.15K, 303.15K and 308.15K. The variation in basic and physical parameters has shown the existence of molecular interactions. So the nature of solute and solvent and concentration play an important role in determining the interactions occurring in the aqueous solutions.

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