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Acoustical and viscometric studies of Gentamicin sulphate in aqueous medium

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ABSTRACT

Ultrasonic velocity along with the density and viscosity are highly functional parameters to understand various interactions, like solute-solute, solute-solvent and solvent-solvent for the binary and/or ternary systems. This may define the reactivity and effectiveness of the system for particular applications. In the present paper, such measurements were carried on an Aminoglycoside antibiotic namely Gentamicin sulphate in aqueous solution for different concentrations varying from 0.001 to 0.1 mol.kg^{-1}at temperatures 298.15, 303.15 and 308.15K. The acoustic impedance (Z), adiabatic compressibility (β), free length (L_f), free volume (V_f), internal pressure (π_i), Relaxation time (τ), Absorption coefficient (α/f^2), Cohesive energy (C.E), Gibb's free energy (ΔG), Relative association (R_A), Rao's constant (R_α), Wada's constant (W), Van deer Waal's constant (b) were also calculated. It was found that there is a certain degree of variation in these parameters with the change in concentration and temperature. These variations have been interpreted in terms of solute –solvent interactions.

Keywords: Gentamicin sulphate, Ultrasonic velocity, Molecular interactions, drugs, Thermodynamic parameters,

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INTRODUCTION

Ultrasonics is an important field of research useful for understanding the physics and chemistry of the solute, solvent, and their mutual interactions [1]. It has been widely applied for various acoustical parameter measurements in biology, biochemistry, engineering, geography, geology, medical sciences and polymer industry [2, 3]. Ultrasonic velocity (U), density (ρ) and viscosity (η) are the main parameters from which information regarding the bulk intermolecular forces and bulk properties can be obtained [4]. Various thermodynamic parameters can also be derived from the above basic parameters which are helpful for the development of molecular models, chemical engineering process design and operation [5-7].

Pharmacological properties of drugs are highly dependent on solution behaviour [8, 9]. In our previous attempt we have investigated various parameters of drugs like streptomycin and neomycin [10, 11]. The effect of concentration at various temperatures on solute-solvent interactions has also been interpreted. In continuation this work in the present paper, ultrasonic investigation on Gentamicin solution in aqueous medium at 298.15K, 303.15K and 308.15K has been reported. The outcome seems to be highly important to analyse solute (drug) – solvent (distilled water) interaction.

MATERIALS AND METHODS

An aminoglycoside antibiotic- Gentamicin sulphate (CAS No. 1405-41-0, molecular weight -1506.8) was obtained from HIMEDIA Ltd. India. Aqueous solutions of the drug were prepared by using double distilled water. The solutions of different concentration were prepared on the molality basis. A monopan electric balance having accuracy 0.0001g was used for weighing purpose. The density of solvent (double distilled water) and the freshly

prepared aqueous solutions of different concentration at different temperatures T= (298.15, 303.15 and 308.15 K) were measured by using hydrostatic sinker method. During the measurement of density, the temperature of experimental liquid was maintained constant throughout by using thermostat U-10 having accuracy of 0.1K. The accuracy in the density measurements was managed as ± 0.0001 g/cm^3. A pulse echo overlap technique was employed for the measurement of ultrasonic velocity. A double-walled liquid cell resonating at 2MHz was used for the study. The interferometer was calibrated by using double distilled water.

Viscosity measurements of the solvent and aqueous Gentamicin solutions were carried out by using Ostwald's viscometer. The temperature of the viscometer was maintained at constant by water circulating arrangement provided with it. A constant current of water was maintained with the help of thermostat U-10. The jar was properly lagged by asbestos thread leaving a suitable window to illuminate and observe the viscometer marks. The time of falling of the liquid between the viscometer marks was counted by using an electronic digital timer ET-450A (ECIL) having least count 0.01s. The accuracy of viscosity measurements was maintained as ±0.1%.

3. Physical Parameters

The experimental data of density, viscosity and ultrasonic velocity of aqueous Gentamicin sulphate at different concentration and temperatures T= (298.15, 303.15 and 308.15) K is utilized for calculating various thermodynamic parameters using the following empirical relations.

Acoustic impedance (Z)

$$Z = u\rho_s \tag{1}$$

Adiabatic compressibility (β)

$$\beta = \frac{1}{\rho_s u^2} \tag{2}$$

Where u is ultrasonic velocity and ρ_s is the density of solution

Free length (L_f)

$$L_f = K_1\beta^{1/2} \tag{3}$$

Where K_1 is Jacobson, a temperature dependent constant (K_1= (93.875+0.375T) ×10^{-8}

Free Volume (V_f)

$$V_f = \left(M_{eff}u/k\eta\right)^{3/2} \tag{4}$$

Where, M_{eff} is effective molecular weight, η is viscosity and 'k' is constant equal to 4.28 × 10^9 independent of temperature for all types of liquids.

Internal pressure (π_i)

$$\pi_i = bRT\left(\frac{k\eta}{u}\right)^{\frac{1}{2}}\left(\frac{\rho_s^{\frac{2}{3}}}{M_{eff}^{\frac{7}{3}}}\right) \tag{5}$$

Where, b stands for the cubic packing factor which is assumed to be '2' for all liquids and solutions, k is temperature independent constant, R is gas constant and T is the absolute temperature.

Relaxation time (τ)

$$\tau = \frac{4\eta}{3\rho_s u^2} \tag{6}$$

Absorption coefficient (α/f^2)

$$(\alpha/f^2) = 8\pi^2\eta/3\rho_s u^3 \tag{7}$$

Cohesive energy

$$C.E. = \pi_i \times V_f \tag{8}$$

Gibb's free energy (ΔG)

$$\Delta G = -kTlog\left(\frac{h}{\tau kT}\right) \tag{9}$$

Where k is the Boltzmann's constant (1.23 × 10^{-23}J.K^{-1}) and h is the Planck's constant (6.62 ×10^{-34}J.s)

Relative association (R_A)

$$R_A = (\rho_s/\rho_0)\,(u_0/u)^{\frac{1}{3}} \tag{10}$$

Where, ρ_s, u and ρ_0, u_0 are respectively the density and ultrasonic velocity of the solution and solvent.
Rao's constant (R_α)

$$R_\alpha = (M_{eff}/\rho_s)\,(u)^{\frac{1}{3}} \tag{11}$$

Molar compressibility or Wada's constant (W)

$$W = \left(\frac{M_{eff}}{\rho_s}\right)\beta^{-1/7} \tag{12}$$

Van deer Waal's constant (b) (13)

RESULTS AND DISCUSSION

The basic experimental data of density, ultrasonic velocity and viscosity of aqueous solutions of aminoglycoside antibiotic (Gentamicin) with molar concentrations 0.001, 0.005, 0.010, 0.050 and 0.1molkg^{-1} measured at 298.15, 303.15 and 308.15 K is given in Table1. Their respective plots against concentration at different temperature are shown in Fig. 1(a-c).Fig.1a shows the density of solution increases with concentration of the solution, however it falls with the increase in temperature. This is natural as there is increase in solute particles in solution with the increase in concentration. Viscosity also follows the similar kinds of trend (Fig.1c), however, as far as ultrasonic velocity trend is concerned it increase with the concentration as well as temperature (Fig.1b).

The observed trend of viscosity will be attributed to the increase in solute-solvent interaction because of increase in solute particles in solutions. Similarly, decrease in viscosity of solution with the rise in temperature may be attributed to the increase in kinetic energy of molecules which in turn decrease the solute-solvent interaction [12].

Table 1: Measured parameters of Gentamicin aqueous solutions for five different concentrations at temperatures T= 298.15, 303.15 and 308.15 K

Parameter	Temperature (K)	Value of parameters measured for concentrations (mol.kg^{-1})				
		m=0.0010	0.0050	0.0100	0.0501	0.1003
Density a_s 10^3 (Kg.m^{-3})	298.15	0.9992	1.0019	1.0044	1.0290	1.0600
	303.15	0.9983	1.0011	1.0031	1.0282	1.0590
	308.15	0.9974	0.9985	1.0005	1.0259	1.0567
Ultrasonic velocity u (m.s^{-1})	298.15	1499.15	1503.19	1507.25	1531.15	1562.21
	303.15	1512.18	1515.61	1520.64	1544.59	1576.34
	308.15	1520.06	1524.91	1529.68	1554.34	1586.85
Viscosity η 10^{-3} (N.s.m^{-2})	298.15	0.905	0.939	0.987	1.159	1.379
	303.15	0.804	0.839	0.895	1.068	1.273
	308.15	0.705	0.741	0.788	0.934	1.122

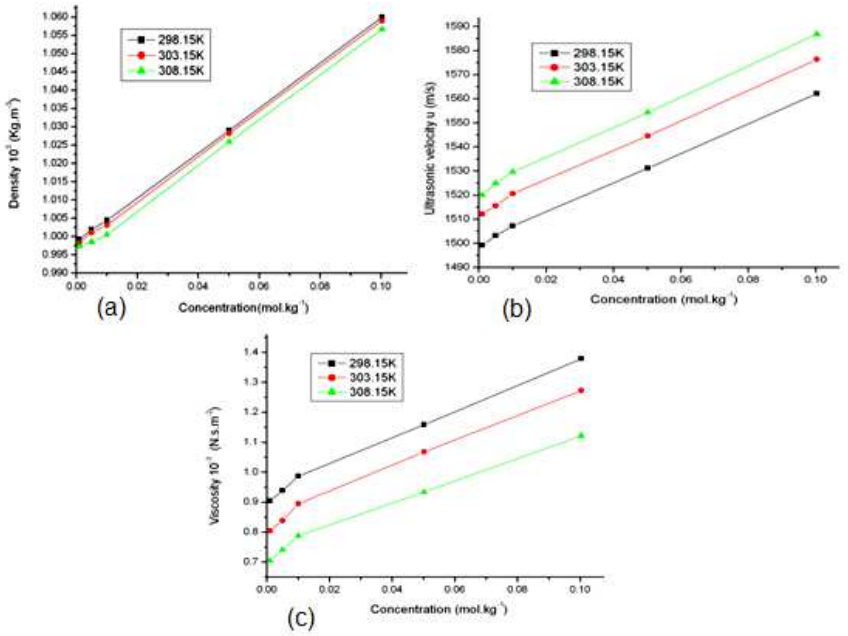

Fig. 1 Variations of (a) density, (b) ultrasonic velocity and (c) viscosity of Gentamicin sulphate with concentration and temperature

The ultrasonic velocity is however depends on making and breaking of hydrogen bonds. In fact, its linear variation with the concentration itself indicates the presence of solute-solvent interactions [13]. With the rise in concentration, the association among the solute and solvent molecules in solution becomes strong due to intermolecular hydrogen bonding [14, 15]. Thus, the increase in ultrasonic velocity with rise in concentration for the present drug confirms the greater molecular association. Similarly, with rise in temperature, breaking of hydrogen bonding increases, results in more and more number of monomeric water molecules. These molecules then enter in the cage-like water structure and get trapped, the consequence of which closed-packed water structure increases and forms the material medium for the propagation of ultrasonic wave. Thus ultrasonic velocity increases with the rise in temperature [16].
Beside ultrasonic velocity, density and viscosity various acoustical parameters also provide the useful information about the system. Therefore, parameters like Acoustic impedance (Z), Adiabatic compressibility (β), Free length (L_f), Free volume (V_f), Internal pressure π_i , Relaxation time (τ) , Absorption coefficient (α/f^2), Cohesive energy(C.E.) , Gibb's free Energy(ΔG) , Relative association(R_A) for Gentamicin sulphate have been calculated and are reported in Table 2. The variation of these parameters with change in concentration and temperature are given in Fig. 2 (a-h).

The impedance offered by the components of the solution is nothing but acoustic impedance. The increasing trend in acoustic impedance with the concentration (Fig.2a) suggests the strengthening of interaction among the components of the solution [17]. Acoustic impedance also increases with the rise in temperature which indicates the associative nature of the molecular interactions in Gentamicin sulphate [18, 19].

Table 1: Various acoustical parameters of Gentamicin aqueous solutions

Parameter	Temperature (K)	Value of parameters obtained for concentrations ($mol.kg^{-1}$)				
		m=0.0010	0.0050	0.0100	0.0501	0.1003
Acoustic impedance Z 10^6 ($Kg.\ m^{-2}.s^{-1}$)	298.15	1.498	1.506	1.514	1.576	1.656
	303.15	1.510	1.517	1.525	1.588	1.669
	308.15	1.516	1.523	1.530	1.595	1.677
Adiabatic compressibility β 10^{-10} ($N^{-1}m^2$)	298.15	4.453	4.417	4.383	4.145	3.866
	303.15	4.381	4.349	4.311	4.077	3.800
Free length L_f 10^{-11} (m)	308.15	4.339	4.307	4.272	4.035	3.758
	298.15	4.341	4.323	4.306	4.188	4.044
	303.15	4.345	4.329	4.311	4.192	4.047
Free volume V_f 10^{-8} ($m^3\ mol^{-1}$)	308.15	4.362	4.346	4.328	4.206	4.059
	298.15	1.843	1.767	1.664	1.459	1.283
	303.15	2.230	2.118	1.953	1.671	1.467
Internal pressure π_i 10^9 (Pa)	308.15	2.737	2.575	2.386	2.063	1.791
	298.15	2.729	2.761	2.807	2.870	2.920
	303.15	2.602	2.642	2.704	2.787	2.837
Relaxation time τ 10^{-13} (s)	308.15	2.469	2.511	2.567	2.637	2.694
	298.15	5.373	5.530	5.767	6.406	7.108
	303.15	4.696	4.865	5.145	5.805	6.450
Absorption coefficient α/f^2 10^{-15}	308.15	4.079	4.255	4.488	5.024	5.622
	298.15	7.068	7.255	7.545	8.250	8.972
	303.15	6.124	6.329	6.672	7.411	8.069
Cohesive energy ($J\ mol^{-1}$)	308.15	5.291	5.503	5.785	6.374	6.987
	298.15	50.288	48.781	46.729	41.871	37.463
	303.15	58.020	55.940	52.816	46.584	41.613
Gibb's free Energy 10^{-21}($J\ mol^{-1}$)	308.15	67.568	64.666	61.235	54.408	48.245
	298.15	4.001	4.107	4.261	4.646	5.027
	303.15	3.628	3.759	3.968	4.418	4.811
Relative Association(R_A)	308.15	3.215	3.376	3.578	4.006	4.432
	298.15	0.9990	1.0008	1.0024	1.0215	1.0453
	303.15	1.0020	1.0040	1.0049	1.0247	1.0483
	308.15	1.0031	1.0031	1.0041	1.0241	1.0476

Table 2: Important constants for Gentamicin aqueous solutions

Constants	Temperature (K)	Value of constants obtained for concentrations (mol.kg^{-1})				
		m=0.0010	0.0050	0.0100	0.0501	0.1003
Rao's constant R_a 10^{-4} (m^5 N^{-1})	298.15	2.065	2.073	2.086	2.167	2.267
	303.15	2.073	2.081	2.095	2.175	2.276
	308.15	2.078	2.090	2.104	2.185	2.286
Wada's constant W 10^{-4} (m^4 s^{-1})	298.15	3.910	3.927	3.951	4.116	4.320
	303.15	3.923	3.939	3.966	4.129	4.335
	308.15	3.932	3.955	3.982	4.145	4.353
Van deer Waal's constant 10^{-5} cm^3mole^{-1}	298.15	1.524	1.531	1.540	1.606	1.686
	303.15	1.525	1.532	1.543	1.608	1.688
	308.15	1.526	1.535	1.546	1.611	1.692

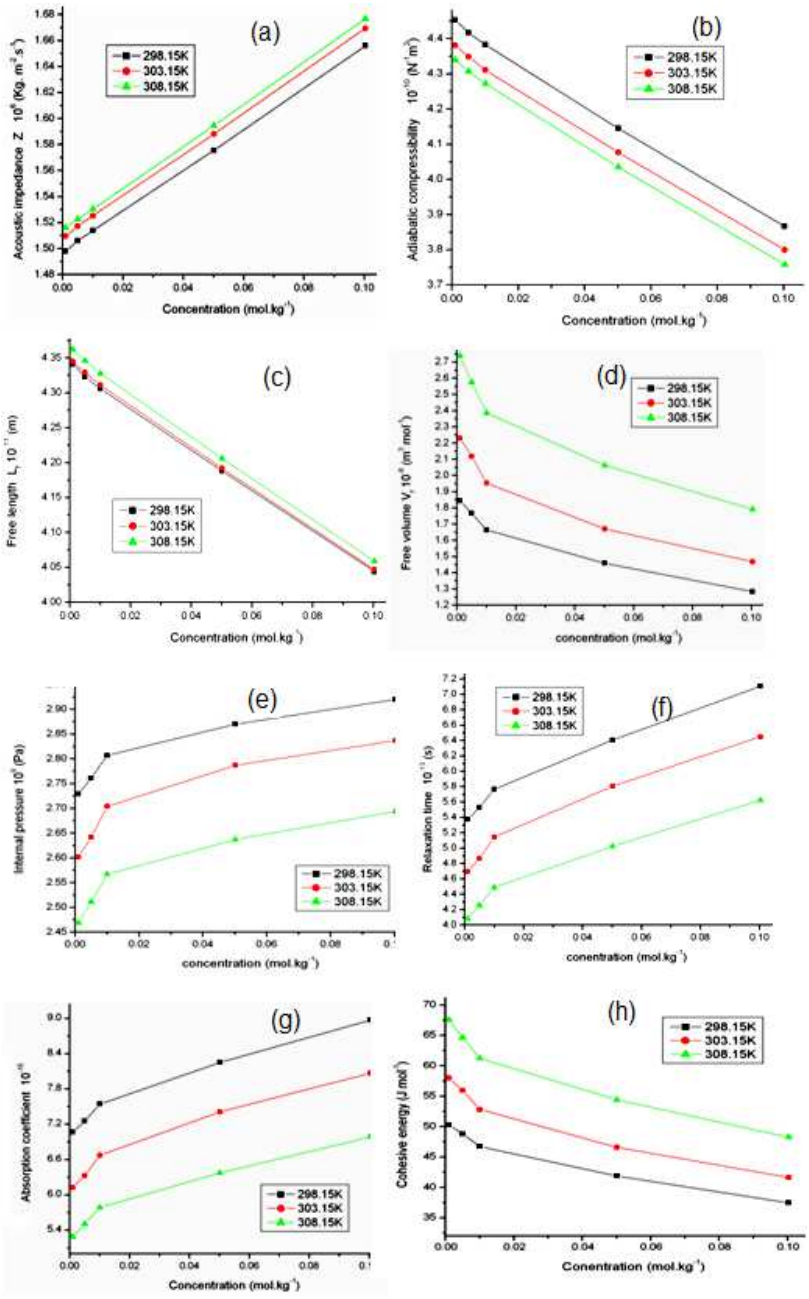

Fig. 2 Variation of various parameters of Gentamicin sulphate with the concentration and temperature: (a) acoustic impudence, (b) adiabatic compressibility, (c) free length, (d) free volume, (e) internal pressure, (f) relaxation time, (g) absorption coefficient and (h) cohesive force

The dependence of adiabatic compressibility of the aqueous Gentamicin sulphate solution on the concentration at 298.15K, 303.15K and 308.15K is as shown in Fig.2b. The higher compressibility values for higher temperature revels that the medium becomes loosely packed at higher temperature. The decrease in adiabatic compressibility values with the concentration indicates the aggregation of solvent molecule around the solute molecule and increasing solute-solvent interactions. In some liquid systems similar results were reported [20, 21].

Free length is distance between the surfaces of the molecules. From the Fig. 2c, it is observed that free length decreases with the rise in concentration, which suggests the solute-solvent interactions are more predominant. Initial maximum values of free length convey more available free space between the molecules of the solution which then decreases with the addition of solute in solvent. The higher values of free length for higher temperature are actually expected, as the intermolecular distance increases with the temperature.

The decrease in free volume with rise in concentration (Fig.2d) suggests the close packing of the molecules inside the shield, which may be brought about by the increasing magnitude of interactions [22]. It is observed that the free volume of Gentamicin sulphate solution decreases with rise in concentration but increases with the rise in temperature as expected.

The internal pressure is the resultant of intermolecular attractive and repulsive forces. Internal pressure depends on temperature, concentration force and external pressure in case of solutions [23]. This is an important parameter used to study nature of molecular interactions in liquids. Internal pressure decreases with rise in temperature (Fig.2e) because of thermal agitation of ions from each other due to increasing thermal energy, which reduces the possibility for interactions and reduces the cohesive forces and ultimately leads to decrease in internal pressure [24]. The increase in internal pressure with the concentration is due to increasing strength of molecular association through hydrogen bonding or dipolar association.

Relaxation time is the time taken for the excitation energy to appear as a translational energy which depends upon the temperature and impurities. At higher temperature, hydrogen bonds become weak due to thermal vibrations and structure breaking effect predominates over the formation of hydrogen bonding. As a result relaxation time value decreases in aqueous solution [15]. It is observed from the Fig.2f that the relaxation time increases with rise in concentration of the solution which indicates the structure making effect whereas adverse effect on relaxation time with rise in temperature shows structure breaking effect. Thus higher concentration is favorable for structure making effect whereas the higher temperature is likely unfavorable.

The absorption coefficient is the characteristics of medium depending on frequency and external conditions like pressure and temperature [25]. The strength of solute-solvent interaction in binary and ternary mixture can be assessed from the absorption coefficient values [26]. The variation of classical absorption coefficient with respect to concentration is as shown in Fig. 2g. The increase in classical absorption with concentration strongly supports the intermolecular association through hydrogen bonding between solute and solvent molecules in a solution [27].

Cohesive energy of the system gives the potential energy between the constituent particles [28].The variation of cohesive energy with concentration at different temperature of the Gentamicin aqueous solution is as shown in Fig. 2h. Similarly, by observing the Table 2 it is clear that the Gibb's free energy increases with the temperature. This suggests that the less time required for the cooperative process or the rearrangement of molecules in the solution decreases the energy leading to dissociation [29]. The increase in Gibb's free energy (Table-2) have been found with rise in concentration indicates the closer packing of the molecules in solution through hydrogen bonding. Relative association is measure of extent of association of constituents in medium.

The Physico-chemical behaviour of liquid and liquid mixture can be studied with the two important parameters Rao's constant and Wada's constant. Rao's constant. The increasing trend of both constants with increase in concentration by small value in the present investigation (Table 3) indicates the availability of more number of in a given region. Thus it leads to a tight packing of the medium and enhancement in molecular interactions.

CONCLUSION

Ultrasonic and viscometric measurements were carried on Gentamicin sulphate in aqueous solution for different concentrations varying from 0.001 to 0.1 mol.kg^{-1}at temperatures 298.15, 303.15 and 308.15K. The ultrasonic velocity data related acoustical parameters provide most valuable information regarding the molecular interactions in aqueous solutions. The increasing trend of ultrasonic velocity with concentration confirms the presence of solute-solvent interaction. The decrease in absorption coefficient and relaxation time with rise in temperature indicates that intermolecular forces weaken due to thermal agitations of the molecules at higher temperature.

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