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Molar Volume and Compressibility Studies of Some Alkaline Earth Metal Chlorides in 4% Fructose + 0.01 m Aqueous Sodium Chlorides

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ABSTRACT : Apparent molar volume (ϕ_v), limiting apparent molar volume (ϕ_v^0), limiting apparent molar volume expansibility (ϕ_E^0), adiabatic compressibility (β) intermolecular free length (L_f), relaxation time (τ) and Gibb's free energy of activation for relaxation process (ΔG^*) have been reported for magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$) and strontium chloride ($SrCl_2$) in 4% fructose in 0.01m aqueous NaCl at temperatures 303.15, 308.15, 313.15 and 318.15 K. The density and ultrasonic velocity measurements were employed to obtain these parameters. The measured parameters were then used to interpret ion-solvent, ion-ion interactions occurring in the system. Further structure making/breaking behaviour of $MgCl_2$, $CaCl_2$ and $SrCl_2$ has been discussed and structure breaking behaviour of these metal chlorides in 4% fructose in 0.01m aqueous NaCl has been reported.

Keywords : Molar volume, adiabatic compressibility, alkaline chloride, fructose.

I. INTRODUCTION

Molar volume and adiabatic compressibility can furnish useful information on the nature of ion-solvent, ion-ion interactions and structural changes occurring in the solutions. Interactions of electrolytes in solutions especially multi-component solutions, similar to bio-fluids are the work systems of current research [1-8]. The results obtained can be employed for better understanding of biological processes occurring in bio-systems.

We have studied $MgCl_2$, $CaCl_2$ and $SrCl_2$ in 4% fructose + 0.01m aqueous NaCl, by density and ultrasonic velocity method and the nature of ion-solvent and ion-ion interactions has been interpreted. The working system was selected by keeping in consideration the biological importance of these salts. Fructose and NaCl are constituents of our daily food items, calcium, magnesium and strontium ions are required in small quantities in our body. Magnesium ions are essential to the basic nucleic acid; calcium plays an important role in building bones and keeping bones strong and healthy, strontium is useful in reducing tooth sensitivity and is used for the treatment of bone cancer. The study was carried out at four different temperatures 303.15, 308.15, 313.15 and 318.15 K.

II. MATERIAL AND METHODS

For preparation of the solutions triply distilled water with specific conductance in the range of 0.1×10^{-6} to $1.0 \times 10^{-6}\Omega^{-1}cm^{-1}$ was used. Magnesium chloride, calcium chloride, strontium chloride, sodium chloride and fructose (Anala R) were dried under vacuum for 24h before use. All the solutions were prepared by weight and conversions of molality to molarity were done by using the standard expression [9]. The concentration range of $MgCl_2$, $CaCl_2$ and $SrCl_2$ was 0.01 m to 0.12 m. All these solutions were prepared in 4% fructose + 0.01m aqueous NaCl as solvent. The density and velocity of sound were measured with the help of DSA (Density and Sound Analyser) 5000, Antor Paar, GmbH, Garz, Austria. All measurements were made at 303.15, 308.15, 313.15 and 318.15 K with an accuracy of ±0.05 K. Accuracy in density and ultrasonic velocity measurements are $\pm 1.3 \times 10^{-5}$ gcm^{-3} and $\pm 1.1 \times 10^{-1}ms^{-1}$ respectively.

III. RESULTS AND DISCUSSION

Molar volume studies

The apparent molar volume of $MgCl_2$, $CaCl_2$ and $SrCl_2$ in 4% fructose + 0.01 m aqueous NaCl solution have been calculated from density data (Table 1) by using Eqation (1).

$$\phi_v = (M_2/\rho) - 1000(\rho - \rho^0)/m\rho\rho^0 \quad \text{... (1)}$$

where ρ^0 is the density of solvent, ρ is the density of solution, m the molality of solution and M_2 the molecular weight of electrolyte. Errors in ϕ_v were calculated from equation (2) [10].

$$\Delta\phi_v = (2\Delta\rho/\rho^2)(1000/m + M_2) \quad \text{... (2)}$$

Equation (2) assumes error to be associated with the density of solution (ρ) and solvent (ρ^0) and the errors were estimated to range from $\pm$ 0.07 cm^{-3} mol^{-1} at 0.01 m concentration to ± 0.19 cm^{-3} mol^{-1} at 0.12 m concentration.

The densities of various solutions of magnesium chloride, calcium chloride and strontium chloride in 4% fructose + 0.01m aqueous NaCl vary linearly with $\sqrt{C}$ obey Root's equation and justify the use of Masson's Equation (3) for the estimation of the limiting apparent molar volume.

$$\phi_v = \phi_v^0 + S_v\sqrt{C} \quad \text{... (3)}$$

where ϕ_v^0 and S_v are calculated from the intercept and slope from the extrapolation of the plots of ϕ_v versus $\sqrt{C}$. The values of limiting apparent molar volume (ϕ_v^0) and slopes (S_v) along with standard errors are reported in Table 2. The slope S_v in Masson's equation may be attributed to be as a measure of ion-ion or solute-solute interactions [11-13]. Low and positive values of Sv for $MgCl_2$, $CaCl_2$ and $SrCl_2$ account for weak ion-ion interactions. There is a decrease in inter ionic interactions with increase in temperature for Magnesium chloride, calcium chloride and barium chloride in 0.01 m aqueous ascorbic acid solutions which may be due to more solvation of electrolytic ions with rise in temperature.

The ϕ_v^0 is a measure of ion-solvent interactions [14]. The ϕ_v^0 values for $MgCl_2$, $CaCl_2$ and $SrCl_2$ increase with increase in temperature and it may be due to more solvation of electrolytic ions as a result of decrease in hydrogen bonding between solvent molecules with rise in temperature, thus making more free solvent molecules available for solvation of electrolytic ions.

The temperature dependence of for $MgCl_2$, $CaCl_2$ and $SrCl_2$ can be expressed as:

$$\phi_v^0 = -4699.6643 + 15.68T - 0.023T^2 \quad \text{... (4)}$$

(For $MgCl_2$ in 4% fructose + 0.01m aqueous NaCl system)

$$\phi_v^0 = -4572.057 + 27.34T - 0.040T^2 \quad \text{... (5)}$$

(For $CaCl_2$ in 4% fructose + 0.01m aqueous NaCl system)

$$\phi_v^0 = -23342.123 + 52.604T - 0.081T^2 \quad \text{... (6)}$$

(For $SrCl_2$ in 4% fructose + 0.01m aqueous NaCl system)

where 'T' is the temperature in Kelvin.

The limiting apparent molar volume expansibility, $\phi_E^0 = (\partial\phi_v^0/\partial T)p$ calculated for $MgCl_2$, $CaCl_2$ and $SrCl_2$ from Eqations (4)-(6) is given in Table 2. The values of decrease with the increase in temperature for $MgCl_2$, $CaCl_2$ and $SrCl_2$ which indicates the absence of "caging effect" and their behaviour is just like common electrolytes [15-17]. The structure making/breaking capacity of $MgCl_2$, $CaCl_2$ and $SrCl_2$ may be interpreted with the help of Hepler's reasoning, *i.e.*, on the basis of sign of $\left(\partial^2\phi_v^0/\partial T^2)_p\right)$ [18]. It has been shown from general thermodynamic Equation (7).

$$(\partial\overline{C_P^0}/\partial P)_T = -T(\partial^2\Phi_v^0/\partial T^2)_P \quad \text{... (7)}$$

where $\overline{C_P^0}$ is the partial molar heat capacity at infinite dilution. From Equation (7), it is clear that structure making electrolytes should have a positive value of $(\partial^2\phi_v^0/\partial T^2)_p$ and structure breaking electrolytes should have negative value of $(\partial^2\phi_v^0/\partial T^2)_p$. For $MgCl_2$, $CaCl_2$ and $SrCl_2$ the sign of $(\partial^2\phi_v^0/\partial T^2)_p$ has been found to be negative which suggests that $MgCl_2$, $CaCl_2$ and $SrCl_2$ act as structure-breaker in 4% fructose + 0.01m aqueous NaCl solution.

Ultrasonic Studies

Using ultrasonic velocity and density data (Table 1), various acoustic parameters have been obtained for $MgCl_2$, $CaCl_2$ and $SrCl_2$ in 4% fructose + 0.01m aqueous NaCl.

Adiabatic compressibility (β), defined as $\beta = (-1/V_m)(\partial V_m/\partial P)_S$ was obtained using the Newton-Laplace equation (8) [19].

$$\beta = 1/U^2\rho \quad \text{... (8)}$$

where ρ is the density U is the ultrasonic velocity of solutions. A gradual and almost linear decrease in adiabatic compressibility (Table 1) was observed as concentration of solute was increased [20]. This decrease in adiabatic compressibility shows presence of prominent ion-solvent interactions in the systems and these interactions increase with increase in solute concentration and with increase in temperature also.

Intermolecular free length (L_f) was obtained from adiabatic compressibility (β) using equation (9) [21].

$$L_f = K\beta^{1/2} \quad \text{... (9)}$$

where K is the temperature dependent constant $= (93.875 + 0.375T) \times 10^{-8}$) [22]. It is clear from Table 1 that ultrasonic velocity (U) increases and intermolecular free length (L_f) decreases with increase in concentration for all $MgCl_2$, $CaCl_2$ and $SrCl_2$ in 4% fructose + 0.01m aqueous NaCl system. In general U and L_f have been reported to vary as the inverse of each other as in the present systems [23, 24]. The decrease in the value of L_f with the increase in molality indicates the presence of significant ion-solvent interaction between solute and solvent molecules due to which the structural arrangement in the neighbourhood of constituent ions is considerably affected [25].

To obtain a firm impact of interactions in solutions, relative association (R_A) was calculated by following relation (10) [26].

$$R_A = (\rho/\rho_0)(U_0/U)^{1/3} \quad \text{... (10)}$$

where ρ_0 and U_0 are the density and ultrasonic velocity of solvent respectively. The values of R_A increase with increase in solute concentration as well as with increase in temperature showing significant ion-solvent interactions which increase with increase in solute concentration (Fig. 1) [27].

Specific acoustic impedance (Z), Rao's molar sound function (R) and Molar compressibility (W) were also calculated using relations (11), (12) and (13) [28- 30].

$$Z = U_{\rho} \quad \text{... (11)}$$

$$R = (M/\rho)U^{1/3} \quad \text{... (12)}$$

$$W = (M/\rho)\beta^{-1/7} \quad \text{... (13)}$$

where M is the apparent molecular weight of the solution and can be calculated according to the following equation:

$$M = M_1W_1 + M_2W_2 \quad \text{... (14)}$$

where W_1 and W_2 are weight fractions of solvent and solute, respectively. M_1 and M_2 are molecular weights of solvent and solute, respectively.

Specific acoustic impedance (Z) increases with increase in temperature as well as with increase in concentration (Fig. 2) suggesting presence of solvent-solute interactions in system [31]. The molar sound velocity (R) and molar compressibility (W) were increasing linearly with concentration (Fig. 3, Fig. 4) indicating the solute-solvent interactions in the system [31].

Another parameter studied was solvation number, obtained by relation (15) [32, 33].

$$SN = (n_1/n_2)(1-\beta/\beta_0) \quad \text{... (15)}$$

where n_1 and n_2 are the numbers of moles of the solvent and the solute, respectively; β and β_0 compressibility coefficients of the solution and the pure solvent, respectively. Solvation numbers decrease with increase in solute concentration as well as with increase in temperature for all three salts [34].

The dispersion of ultrasonic waves in system contains information about the characteristic time of relaxation process that causes the dispersion. The relaxation time was calculated as (16) [35-37].

$$\tau = (4\eta/3\rho U^2) \quad \text{... (16)}$$

where η is viscosity*.

The relaxation time decreases with increase in temperature and its temperature dependence is used to calculate Gibb's free energy of activation for relaxation process (17) [38].

$$\Delta G = kT \ln(kT\tau/h) \quad \text{... (17)}$$

where k is Boltzmann constant, T, the absolute temperature and h is the Planck's constant.

The relaxation time increases with increase in concentration of solute and decreases with increase in temperature (Table 1). The values of ΔG^* are almost constant with increase in temperature.

The constant values of ΔG^* suggest that the rearrangement of molecules in solution are characteristic of physical properties of solute only [37].

IV. CONCLUSION

Prominent ion-solvent interactions in $MgCl_2$, $CaCl_2$ and $SrCl_2$ with 4% fructose + 0.01m aqueous NaCl are found and the interactions increase with increase in temperature. Gibb's free energy of activation for relaxation process is reported. $MgCl_2$, $CaCl_2$ and $SrCl_2$ in 4% fructose + 0.01m aqueous NaCl show no 'caging effect', and acts as structure-breaker.

Table 1. Densities (ρ), apparent molar volumes (Qv) and ultrasonic velocities (U), adiabatic compressibility (τ), inter molecular free length (L_f), solvation number (S_N), relaxation time (τ) and Gibb's free energy of activation (ΔG*) for $MgCl_2$, $CaCl_2$ and $SrCl_2$ in 4% fructose + 0.01m aqueous NaCl at different temperatures.

$C \times 10^2$ / mol^{-1} $litre^{-1}$	r/g cm^{-3}	U/ms^{-1}	[illegible] / cm^3 mol^{-1}	$\beta \times 10^{-10}$ /Pa–1	Lf × 10^{-11} /m	S_N	$\tau \times 10^{-13}$/s	$\Delta G^* \times 10^{-21}$ /Jmol^{-1}
				$MgCl_2$				
Temperature = 303.15 K		ρ_0 = 1.010724 gcm^{-3}			U_0 = 1522.65 ms^{-1}		β_0 = 4.2712 Pa^{-1}	
1.0101	1.012201	1523.58	56.48	4.2560	4.2819	14.8535	5.0673	4.8652
2.0187	1.013475	1525.39	66.32	4.2406	4.2741	17.4557	5.0697	4.8671
4.0299	1.015662	1526.85	79.91	4.2234	4.2654	14.3233	5.0820	4.8773
6.0315	1.017512	1529.68	89.79	4.2001	4.2537	14.5884	5.0808	4.8763
8.0219	1.019045	1531.33	98.51	4.1847	4.2459	13.4354	5.0868	4.8812
10.0002	1.020354	1533.32	105.87	4.1685	4.2377	12.8553	5.0894	4.8833
11.9649	1.021401	1536.14	112.85	4.1490	4.2277	12.8301	5.0866	4.8811
Temperature = 308.15 K		ρ_0 = 1.00918gcm^{-3}			U_0 = 1532.85 ms^{-1}		β_0 = 4.2213 Pa^{-1}	
1.0085	1.010593	1533.72	63.41	4.2066	4.2954	13.9938	4.4820	4.4930
2.0154	1.011818	1535.52	72.14	4.1917	4.2878	16.8203	4.4829	4.4939
4.0229	1.013910	1536.93	85.14	4.1753	4.2794	13.7765	4.4929	4.5034
6.0206	1.015680	1539.66	94.60	4.1533	4.2681	14.0166	4.4923	4.5028
8.0068	1.017131	1541.19	103.12	4.1391	4.2609	12.8397	4.4986	4.5088

9.9811	1.018404	1543.12	109.96	4.1236	4.2528	12.3172	4.5013	4.5113
11.9420	1.019443	1545.03	116.36	4.1092	4.2454	11.8394	4.5048	4.5146
Temperature = 313.15 K		***ρ_0 = 1.007289gcm^{-3}***			***U_0 = 1541.56 ms^{-1}***		***β_0 = 4.1810 Pa^{-1}***	
1.0066	1.008643	1542.31	68.29	4.1679	4.3139	12.8321	3.9206	4.0571
2.0115	1.009824	1544.06	76.71	4.1536	4.3065	15.9132	3.9211	4.0577
4.0148	1.011855	1545.46	88.92	4.1378	4.2983	13.2158	3.9288	4.0662
6.0082	1.013573	1548.10	97.99	4.1167	4.2873	13.4776	3.9287	4.0661
7.9902	1.015018	1549.68	105.80	4.1024	4.2799	12.4714	3.9334	4.0713
9.9599	1.016243	1551.52	112.58	4.0878	4.2722	11.9233	3.9365	4.0746
11.9164	1.017256	1554.45	118.79	4.0683	4.2621	12.0883	3.9339	4.0719
Temperature = 318.15 K		***ρ_0 = 1.005154gcm^{-3}***			***U_0 = 1548.81 ms^{-1}***		***β_0 = 4.1535 Pa^{-1}***	
1.0044	1.006464	1549.47	72.50	4.1384	4.3368	11.9378	3.6138	3.8338
2.0070	1.007599	1551.15	81.06	4.1248	4.3296	15.0709	3.6142	3.8342
4.0057	1.009565	1552.59	92.70	4.1092	4.3214	12.7733	3.6211	3.8426
5.9944	1.011254	1555.13	101.02	4.0889	4.3107	13.0300	3.6215	3.8431
7.9716	1.012659	1556.73	108.59	4.0748	4.3033	12.1234	3.6261	3.8486
9.9369	1.013890	1558.46	114.79	4.0609	4.2959	11.5682	3.6307	3.8542
11.8886	1.014889	1561.44	120.79	4.0414	4.2856	11.8098	3.6289	3.8520
				$CaCl_2$				
Temperature = 303.15 K		***ρ_0 = 1.010724gcm^{-3}***			***U_0 = 1522.65 ms^{-1}***		***β_0 = 4.2734 Pa^{-1}***	
1.0109	1.012393	1524.45	-17.89	4.2503	4.2791	22.2137	5.0615	4.8604
2.0217	1.013834	1525.33	-6.74	4.2394	4.2735	18.2148	5.0695	4.8670
4.0414	1.016285	1527.35	9.32	4.2180	4.2627	16.0624	5.0766	4.8729
6.0563	1.018291	1529.03	21.84	4.2005	4.2539	14.5113	5.0835	4.8785
8.0647	1.019942	1530.69	32.37	4.1846	4.2458	13.4652	5.0890	4.8831
10.0651	1.021312	1532.74	41.38	4.1678	4.2373	12.9538	5.0923	4.8858
12.0563	1.022414	1534.58	49.53	4.1533	4.2299	12.3621	5.0963	4.8890
Temperature = 308.15 K		***ρ_0 = 1.009188gcm^{-3}***			***U_0 = 1532.85 ms^{-1}***		***β_0 = 4.2223 Pa^{-1}***	
1.0093	1.010761	1534.43	-8.75	4.2020	4.2931	20.0316	4.4778	4.4891
2.0183	1.012131	1535.27	1.19	4.1917	4.2878	16.7752	4.4844	4.4953
4.0341	1.014463	1537.23	16.11	4.1714	4.2774	15.0604	4.4912	4.5017
6.0453	1.016435	1538.85	26.89	4.1546	4.2688	13.7349	4.4970	4.5073
8.0495	1.018026	1540.50	36.89	4.1392	4.2609	12.8288	4.5027	4.5126
10.0457	1.019338	1542.50	45.56	4.1232	4.2526	12.3728	4.5050	4.5148
12.0343	1.020547	1544.29	52.15	4.1087	4.2452	11.8918	4.5091	4.5187
Temperature = 313.15 K		***ρ_0 = 1.007289gcm^{-3}***			***U_0 = 1541.56 ms^{-1}***		***β_0 = 4.1822 Pa^{-1}***	
1.0073	1.008785	1542.89	-1.48	4.1642	4.3120	17.7703	3.9173	4.0535
2.0142	1.010077	1543.69	8.54	4.1546	4.3070	15.2822	3.9226	4.0594
4.0256	1.012321	1545.63	21.86	4.1350	4.2968	14.1500	3.9279	4.0653
6.0320	1.014194	1547.18	32.31	4.1191	4.2886	12.9523	3.9334	4.0712
8.0319	1.015801	1548.81	40.75	4.1039	4.2807	12.2317	3.9378	4.0761
10.0240	1.017138	1550.77	48.41	4.0881	4.2724	11.8763	3.9403	4.0788
12.0073	1.018263	1552.55	55.22	4.0743	4.2652	11.4321	3.9436	4.0824
Temperature = 318.15 K		***ρ_0 = 1.005154gcm^{-3}***			***U_0 = 1548.81 ms^{-1}***		***β_0 = 4.1504 Pa^{-1}***	
1.0051	1.006584	1549.87	4.72	4.1358	4.3354	15.4539	3.6120	3.8315
2.0097	1.007827	1550.68	13.95	4.1264	4.3305	14.0229	3.6159	3.8363
4.0162	1.009965	1552.60	27.09	4.1075	4.3205	13.3351	3.6199	3.8412
6.0177	1.011803	1554.09	36.34	4.0922	4.3125	12.3049	3.6250	3.8473
8.0123	1.013315	1555.70	44.93	4.0776	4.3048	11.6626	3.6289	3.8521

9.9996	1.014666	1557.63	51.63	4.0621	4.2966	11.4050	3.6322	3.8561
11.9779	1.015769	1559.38	58.10	4.0486	4.2894	11.0103	3.6357	3.8603
				$SrCl_2$				
Temperature = 303.15 K		***ρ_0 = 1.010724gcm^{-3}***			***U_0 = 1522.65 ms^{-1}***		***β_0 = 4.2744 Pa^{-1} Pa^{-1}***	
1.0096	1.012323	1524.30	107.10	4.2515	4.2796	20.7443	5.0625	4.8612
2.0167	1.013711	1525.19	117.25	4.2407	4.2742	17.3746	5.0710	4.8682
4.0214	1.016073	1526.88	132.19	4.2215	4.2645	14.9324	5.0818	4.8771
6.0122	1.018068	1528.49	142.94	4.2043	4.2558	13.6687	5.0887	4.8828
7.9875	1.019737	1530.02	152.15	4.1891	4.2481	12.7328	5.0955	4.8884
9.9461	1.021127	1531.63	160.31	4.1746	4.2407	12.0700	5.1006	4.8926
11.8871	1.022286	1533.20	167.56	4.1613	4.2340	11.4955	5.1062	4.8971
Temperature = 308.15 K		***ρ_0 = 1.00918gcm^{-3}***			***U_0 = 1532.85 ms^{-1}***		***β_0 = 4.2232 Pa^{-1}***	
1.0080	1.010670	1534.20	118.50	4.2037	4.2939	17.8766	4.4792	4.4903
2.0132	1.011969	1535.07	127.31	4.1935	4.2887	15.6155	4.4855	4.4964
4.0140	1.014197	1536.69	140.54	4.1755	4.2795	13.7363	4.4943	4.5047
6.0006	1.016105	1538.27	149.97	4.1591	4.2711	12.7520	4.5004	4.5105
7.9718	1.017724	1539.76	158.09	4.1444	4.2636	11.9724	4.5070	4.5167
9.9260	1.019068	1541.32	165.56	4.1306	4.2564	11.3982	4.5119	4.5213
11.8639	1.020286	1542.81	171.50	4.1177	4.2498	10.9120	4.5178	4.5269
Temperature = 313.15 K		***ρ_0 = 1.007289gcm^{-3}***			***U_0 = 1541.5 ms^{-1}***		***β_0 = 4.1810 Pa^{-1}***	
1.0060	1.008699	1542.61	125.55	4.1661	4.3130	15.2914	3.9187	4.0551
2.0091	1.009931	1543.44	134.14	4.1565	4.3080	13.9898	3.9239	4.0608
4.0056	1.012086	1545.00	145.80	4.1393	4.2991	12.7115	3.9312	4.0688
5.9876	1.013903	1546.54	155.03	4.1236	4.2909	11.9359	3.9366	4.0748
7.9544	1.015513	1547.98	162.05	4.1095	4.2836	11.3077	3.9420	4.0807
9.9042	1.016831	1549.51	169.05	4.0960	4.2766	10.8290	3.9467	4.0858
11.8371	1.017983	1550.94	175.00	4.0838	4.2702	10.3714	3.9518	4.0914
Temperature = 318.15 K		***ρ_0 = 1.00515gcm^{-3}***			***U_0 = 1548.81 ms^{-1}***		***β_0 = 4.1543 Pa^{-1}***	
1.0038	1.006503	1549.58	131.56	4.1377	4.3364	12.9380	3.6131	3.8329
2.0047	1.007681	1550.37	139.84	4.1286	4.3316	12.5194	3.6178	3.8386
3.9964	1.009759	1551.90	150.62	4.1120	4.3229	11.8155	3.6241	3.8462
5.9733	1.011469	1553.42	160.07	4.0970	4.3150	11.2164	3.6292	3.8524
7.9342	1.012928	1554.79	167.77	4.0839	4.3081	10.6037	3.6343	3.8585
9.8786	1.014202	1556.28	174.13	4.0710	4.3013	10.2131	3.6392	3.8645
11.8061	1.015315	1557.66	179.63	4.0593	4.2951	9.8110	3.6443	3.8706

Table-2 Limiting apparent molar volume (ϕ_V^0), SV and apparent molar volume expansibility (ϕ_E^0), of $MgCl_2$, $CaCl_2$ and $SrCl_2$ in 4% fructose in 0.01m aqueous NaCl at different temperatures, standard errors are given in parenthesis.

Electrolyte	*T/K*	*ϕ_V^0 /cm^{3}mol^{-1}*	*Sv/cm^{3}l$^{1/2}$mol$^{-3/2}$*	*ϕ_E^0 /cm^{3}mol^{-1}K^{-1}*
$MgCl_2$	303.15	33.70 (±0.211)	2.287 (±0.008)	1.735
$MgCl_2$	308.15	41.57 (±0.197)	2.164 (±0.007)	1.505
$MgCl_2$	313.15	47.55 (±0.083)	2.057 (±0.003)	1.275
$MgCl_2$	318.15	53.11 (±0.253)	1.956 (±0.010)	1.045
$CaCl_2$	303.15	-45.60 (±0.149)	2.740 (±0.006)	3.088
$CaCl_2$	308.15	-30.01 (±0.411)	2.491 (±0.016)	2.688
$CaCl_2$	313.15	-24.26(±0.202)	2.291 (±0.008)	2.288
$CaCl_2$	318.15	-16.76(±0.314)	2.161 (±0.012)	1.888
$SrCl_2$	303.15	82.25 (±0.173)	2.475 (±0.007)	3.493
$SrCl_2$	308.15	96.57 (±0.242)	2.179 (±0.009)	2.683
$SrCl_2$	313.15	105.36 (±0.214)	2.017(±0.008)	1.873
$SrCl_2$	318.15	111.56 (±0.379)	1.978(±0.015)	1.063

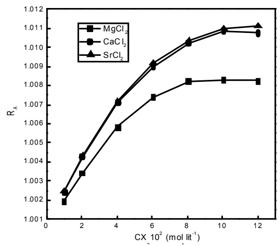

Fig. 1. Variation of relative association (R_A) with molar concentration (C) for magnesium chloride, calcium chloride and strontium chloride in 6% fructose + 0.01m aqueous NaCl at 303.15K.

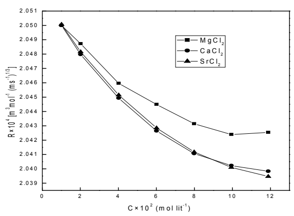

Fig. 2. Variation of molar sound velocity (R) with molar concentration (C) for magnesium chloride, calcium chloride and Strontium chloride in 6% fructose + 0.01m aqueous NaCl at 303.15K.

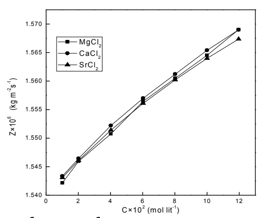

Fig. 3. Variation of specific acoustic impedance (Z) with molar concentration (C) for magnesium chloride, calcium chloride and Strontium chloride in 6% fructose + 0.01m aqueous NaCl at 303.15K.

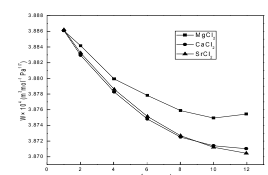

Fig. 4. Variation of molar compressibility (W) with molar concentration (C) for magnesium chloride, calcium chloride and Strontium chloride in 6% fructose + 0.01m aqueous NaCl at 303.15K.

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