Research Article

Acoustical Behaviour of Sodium Nitroprusside in Aquo-Organic Solvent Media at 308.15 K

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Density and ultrasonic velocity have been measured for sodium nitroprusside in aqueous solutions of CH_3OH , ethylene glycol, DMSO, and n-propanol solvents at 308.15 K. A quantitative relationship has been established among the acoustical properties like ultrasonic velocity (U), adiabatic compressibility (β), intermolecular free length (L_f), acoustic impedance (Z), apparent molar compressibility (K_ϕ), apparent molar volume (V_ϕ), limiting apparent molar compressibility (K_ϕ^0) limiting apparent molar volume (V_ϕ^0), and their constants (S_K, S_v). From the obtained values, molecular interaction study has been made successfully in the light of these acoustical properties through hydrogen bonding in solute and solvent mixture.

1. Introduction

In the recent years, ultrasonic velocity measurements are helpful to interpret solute-solvent, ion-solvent, and solvent-solvent interactions in aqueous and nonaqueous medium [1–4]. Recently, acoustic parameter studies of metal complexes have been carried out in our laboratory [5], and A. P. Mishra and D. K. Mishra have also reported a similar work [6]. The interaction helps in better understanding the types of solute and solvent, that is, whether the added solute modifies or distorts the structure of the solvent. Apparent molar volume gives valuable information about ion-ion and ion-solvent interactions in solution [7–11]. The addition of organic solvent to an aqueous solvent of electrolyte brings about a change in ion solvation that results in a large change in the reactivity of dissolved electrolyte [12, 13]. The transition metal plays a vital role in life system because of the natural presence in vitamins, proteins, and enzymes. Sodium nitroprusside (SNP), an Fe (II) ion complex, is an effective drug which rapidly lowers blood pressure and causes vascular smooth muscle relaxation. It is also used in a urine analysis test. In the presence of buffers, it is used as a reagent for ketone strips which test the ketone level in the urine of a diabetic. It is used by forensic chemists in Simons being fast for the identification of illicit substances [14]. Thus,

an attempt has been made to elucidate the ion-ion interaction between nitroprusside ions and ion-solvent interaction of SNP in aqueous solutions of methanol, ethylene glycol, n-propanol, and DMSO at 308.15 K through ultrasonic velocity and density measurement.

2. Experimental

The entire chemicals used in this present research work are spectroscopic reagents (SRs), analytical reagent (AR) grades of minimum assay of 99.9% obtained from E-Merck, Germany, and SD fine chemicals, India, which are used without further purification. Water used in these experiments was deionized and distilled. A synthetic method of preparation of SNP has been reported [15]. The required quantity of SNP was dissolved in binary mixture of aqueous methanol, ethylene glycol, DMSO, and n-propanol, and a similar procedure has been adopted for different molalities of SNP. The density was determined using a specific gravity bottle by a relative measurement method. The ultrasonic velocity was measured by ultrasonic interferometer having frequency 2 MHz (Mittal Enterprises, model no. F-81). The constant temperature is mentioned by circulatory water through the double wall measuring cell made up of steel.

3. Theory

Using the measured data, various acoustic parameters such as adiabatic compressibility, intermolecular free length, acoustic impedance, apparent molar compressibility, apparent molar volume, limiting apparent molar compressibility, limiting apparent molar volume, and the associated constants S_K and S_V are calculated.

Adiabatic compressibility (β) = $1/(U^2 d)$.

Relative association can be fitted to an equation of the form

$$R_A = \left(\frac{d}{d_0}\right) \times \left(\frac{U_0}{U}\right)^{1/3}. \quad (1)$$

Acoustic impedance, $Z = U \times d$.

Intermolecular free length can be determined by

$$L_f = K_j \beta^{1/2}, \quad (2)$$

where K_j is Jacobson constant = 2.0965×10^{-6} .

The apparent molar compressibility, K_ϕ , can be computed from

$$K_\phi = 100\beta m^{-1} - \beta^0 d^{-1} (1000m^{-1} - M_2). \quad (3)$$

From the density data, the apparent molar volume V_ϕ was calculated from the relation

$$V_\phi = 1000(md_0)^{-1} (d_0 - d) + M_2 d_0^{-1}. \quad (4)$$

The apparent molar compressibility (K_ϕ) and the apparent molar volume (V_ϕ) thus obtained are found to vary linearly with $m^{1/2}$. The K_ϕ and V_ϕ data were fitted by least squares method

$$\begin{aligned} K_\phi &= K_\phi^0 + S_K m^{1/2}, \\ V_\phi &= V_\phi^0 + S_V m^{1/2}, \end{aligned} \quad (5)$$

where K_ϕ^0 and V_ϕ^0 are limiting apparent molar compressibility and limiting apparent molar volume, respectively. S_K and S_V are the slopes.

4. Result and Discussion

The desired parameters such as adiabatic compressibility (β), intermolecular free length (L_f), acoustic impedance (Z), relative association (R_A), apparent molar compressibility (K_ϕ), apparent molar volume (V_ϕ), limiting apparent molar compressibility (K_ϕ^0), limiting apparent molar volume (V_ϕ^0) and their constants (S_K , S_V) have been studied at 308.15 K. The density increases with the increase in the concentration of sodium nitroprusside due to the increased electrostriction in the system. The density increases in case of CH_3OH + water, ethylene glycol + water, DMSO + water, and n-propanol + water with the increase in the concentration of sodium nitroprusside, but it decreases with mole fraction of CH_3OH and n-propanol and increases with the mole fraction

of ethylene glycol and DMSO for a particular concentration of sodium nitroprusside. The decrease in density in case of CH_3OH + water and n-propanol + water indicates the decrease in ion-solvent interaction or structure-breaking properties of sodium nitroprusside. But addition of ethylene glycol and DMSO to water has rigidified the three-dimensional structure of water forming a strong hydrogen bond between solvent molecules [16, 17]. It also indicates the structure-forming properties of sodium nitroprusside in ethylene glycol + water and DMSO + water.

Table 1 shows that ultrasonic velocity increases with the increase in the concentration of sodium nitroprusside in aqueous CH_3OH and DMSO, but it is found to be decreased in aqueous ethylene glycol and n-propanol. Molecular association is responsible for the observed increase in ultrasonic velocity in these mixtures. The increase in ultrasonic velocity in these solutions may be attributed to the cohesion brought about by the hydration [18].

The adiabatic compressibility (Table 1) decreased with increasing the concentration of solute in all aqueous solvent solutions except n-propanol + water. The decreasing adiabatic compressibility observed for sodium nitroprusside in CH_3OH + water, ethylene glycol + water, and DMSO + water confirms the calculation drawn from the velocity data. The increasing electrostrictive compression of water around the solute molecules results in a large decrease in the compressibility of solutions. The decrease in the compressibility implies that the molecular association is enhanced in these systems with the increase in the solute content as the new entities formed due to molecular association become compact and less compressible [19]. The compressibility appeared to decrease with increasing hydrogen bond strength between solute and solvent molecules. The larger decrease in compressibility of nitroprusside in DMSO + water indicates larger molecular association capacity than other solvents. But the increase of adiabatic compressibility with the increase in concentration of solution may be due to collection of solvent molecules around ion [20] supporting weak ion-solvent interaction. This indicates that there is significant ion-solvent interaction.

The intermolecular free length (L_f) is a predominant factor in solvation chemistry. Intermolecular free length depends on the intermolecular attractive and repulsive forces. In the present paper, the intermolecular free length is found to decrease with the increase in the concentration of nitroprusside as shown in Table 1, indicating a significant molecular association between solute and solvent molecules, suggesting a structure-promoting behaviors on addition of solute.

The character that determines the restriction/backward movement of sound wave is known as acoustic impedance (Z). It has been estimated for nitroprusside solution of CH_3OH + water, ethylene glycol + water, and DMSO + water which is found to increase with the increase in the concentration of sodium nitroprusside. But a reverse trend in the value of Z is observed for sodium nitroprusside solution of n-propanol + water. The higher impedance in DMSO + water indicates the presence of bulkier-solvated ion due to ion-solvent/solvent-solvent interaction which restrict the free flow of ultrasonic velocity.

TABLE 1: The values of density (d), ultrasonic velocity (U), adiabatic compressibility (β), intermolecular free length (L_f), acoustic impedance (Z), and relative association (R_A) of sodium nitroprusside in CH_3OH + water, ethylene glycol + water, DMSO + water, and n-propanol + water at 308.15 K.

Mole fraction (Xorg)	Concentration (m) mol dm^{-3}	Density (d) (10^3 kg/m^3)	Ultrasonic velocity (U) (m/sec)	Adiabatic compressibility (β) $\times 10^{-7} \text{ N}^{-1} \text{ m}^2$	Intermolecular free length (L_f) $\times 10^{-13} \text{ m}$	Acoustic impedance (Z) $\times 10^{-3} \text{ kg m}^{-2} \text{ s}^{-1}$	Relative association (R_A)
Sodium nitroprusside + CH_3OH + water							
0.047	0.01	0.9818	1532.4	4.3374	1.3807	1.5045	0.9824
	0.02	0.9827	1534.4	4.3221	1.3783	1.5078	0.9829
	0.03	0.9837	1536.6	4.3065	1.3758	1.5115	0.9834
	0.04	0.9846	1538.7	4.2897	1.3731	1.5147	0.9838
	0.05	0.9855	1540.4	4.2763	1.3710	1.5180	0.9844
0.099	0.01	0.9696	1552.3	4.2801	1.3716	1.5051	0.9660
	0.02	0.9705	1553.6	4.2690	1.3698	1.5077	0.9666
	0.03	0.9715	1554.8	4.2580	1.3680	1.5104	0.9674
	0.04	0.9724	1538.7	4.2470	1.3663	1.5131	0.9680
	0.05	0.9733	1540.4	4.2360	1.3645	1.5158	0.9686
0.160	0.01	0.9574	1573.3	4.2203	1.3620	1.5061	0.9496
	0.02	0.9583	1573.7	4.2136	1.3609	1.5080	0.9495
	0.03	0.9588	1574.3	4.2082	1.3600	1.5094	0.9508
	0.04	0.9597	1574.8	4.2016	1.3589	1.5113	0.9516
	0.05	0.9602	1575.5	4.1957	1.3580	1.5127	0.9519
0.228	0.01	0.9424	1556.3	4.3810	1.3800	1.4666	0.9381
	0.02	0.9433	1555.9	4.3791	1.3875	1.4676	0.9391
	0.03	0.9436	1555.6	4.3794	1.3874	1.4678	0.9394
	0.04	0.9442	1555.2	4.3789	1.3873	1.4684	0.9401
	0.05	0.9452	1554.9	4.3759	1.3868	1.4696	0.9412
0.307	0.01	0.9273	1537.7	4.5608	1.4158	1.4259	0.9268
	0.02	0.9276	1536.7	4.5652	1.4165	1.4257	0.9273
	0.03	0.9283	1535.6	4.5683	1.4170	1.4254	0.9282
	0.04	0.9286	1534.6	4.5728	1.4177	1.4250	0.9287
	0.05	0.9292	1533.5	4.5764	1.4183	1.4249	0.9295
Sodium nitroprusside + ethylene glycol + water							
0.035	0.01	1.0071	1542.0	4.1760	1.3548	1.5529	1.0056
	0.02	1.0081	1541.4	4.1751	1.3547	1.5538	1.0067
	0.03	1.0086	1540.8	4.1763	1.3548	1.5540	1.0074
	0.04	1.0093	1540.2	4.1766	1.3549	1.5544	1.0082
	0.05	1.0099	1539.6	4.1774	1.3550	1.5548	1.0089
0.075	0.01	1.0165	1572.3	3.9794	1.3225	1.5982	1.0184
	0.02	1.0175	1571.7	3.9786	1.3224	1.5992	1.0095
	0.03	1.0185	1571.0	3.9782	1.3223	1.6000	1.0107
	0.04	1.0193	1570.3	3.9786	1.3220	1.6006	1.0116
	0.05	1.0203	1569.6	3.9783	1.3198	1.6014	1.0128
0.121	0.01	1.0259	1610.8	3.7567	1.2850	1.6525	1.0096
	0.02	1.0274	1612.3	3.7443	1.2829	1.6564	1.0107
	0.03	1.0287	1613.7	3.7331	1.2809	1.6600	1.0117
	0.04	1.0301	1615.2	3.7211	1.2789	1.6638	1.0182
	0.05	1.0315	1617.5	3.7055	1.2762	1.6684	1.0137
0.177	0.01	1.0362	1636.5	3.6035	1.2585	1.6957	1.0143
	0.02	1.0381	1637.7	3.5916	1.2564	1.7000	1.0160
	0.03	1.0390	1638.8	3.5837	1.2550	1.7027	1.0166
	0.04	1.0409	1639.9	3.5724	1.2531	1.7069	1.0192
	0.05	1.0419	1641.4	3.5637	1.2515	1.7098	1.0190

TABLE 1: Continued.

Mole fraction (Xorg)	Concentration (m) mol dm ⁻³	Density (d) (10 ³ kg/m ³)	Ultrasonic velocity (U) (m/sec)	Adiabatic compressibility (β) $\times 10^{-7}$ N ⁻¹ m ²	Intermolecular free length (L _f) $\times 10^{-13}$ m	Acoustic impedance (Z) $\times 10^{-3}$ kg m ⁻² s ⁻¹	Relative association (R _A)
0.243	0.01	1.0475	1663.6	3.4494	1.2313	1.7457	1.0198
	0.02	1.0494	1664.0	3.4415	1.2299	1.7462	1.0216
	0.03	1.0503	1664.4	3.4369	1.2291	1.7481	1.0224
	0.04	1.0522	1664.8	3.4291	1.2277	1.7517	1.0241
	0.05	1.0541	1665.2	3.4213	1.2263	1.7552	1.0259
Sodium nitroprusside + DMSO + water							
0.027	0.01	1.0071	1553.5	4.1144	1.3448	1.5645	1.0031
	0.02	1.0087	1554.0	4.1052	1.3433	1.5675	1.0046
	0.03	1.0099	1554.4	4.0982	1.3421	1.5697	1.0057
	0.04	1.0109	1554.9	4.0915	1.3410	1.5718	1.0065
	0.05	1.0137	1555.4	4.0776	1.3387	1.5767	1.0093
0.059	0.01	1.0203	1590.2	3.8759	1.0352	1.6224	1.0084
	0.02	1.0212	1591.1	3.8676	1.3038	1.6248	1.0091
	0.03	1.0230	1592.0	3.8569	1.3020	1.6286	1.0107
	0.04	1.0240	1592.9	3.8488	1.3006	1.6311	1.0115
	0.05	1.0259	1593.8	3.8373	1.2987	1.6350	1.0132
0.097	0.01	1.0334	1628.1	3.6506	1.2667	1.6824	1.0133
	0.02	1.0344	1628.8	3.6440	1.2656	1.6848	1.0142
	0.03	1.0362	1629.6	3.6341	1.2638	1.6886	1.0158
	0.04	1.0372	1630.4	3.6270	1.2626	1.6910	1.0166
	0.05	1.0381	1631.1	3.6208	1.2615	1.6932	1.0173
0.144	0.01	1.0466	1656.1	3.4837	1.2374	1.7332	1.0205
	0.02	1.0475	1657.0	3.4379	1.2293	1.7351	1.0212
	0.03	1.0484	1658.0	3.4245	1.2269	1.7382	1.0218
	0.04	1.0503	1658.9	3.4179	1.2257	1.7423	1.0235
	0.05	1.0512	1659.8	3.4531	1.2320	1.7447	1.0242
0.307	0.01	1.0606	1683.3	3.3276	1.2094	1.7853	1.0285
	0.02	1.0613	1684.2	3.3218	1.2083	1.7874	1.0290
	0.03	1.0619	1685.0	3.3168	1.2074	1.7893	1.0294
	0.04	1.0625	1685.9	3.3114	1.2064	1.7912	1.0298
	0.05	1.0634	1686.8	3.3050	1.2053	1.7937	1.0305
Sodium nitroprusside + n-propanol + water							
0.206	0.01	0.9893	1681.3	3.5759	1.2537	1.6633	0.9598
	0.02	0.9902	1678.8	3.5833	1.2550	1.6623	0.9611
	0.03	0.9912	1676.1	3.5912	1.2564	1.6563	0.9626
	0.04	0.9921	1661.3	3.6521	1.2670	1.6482	0.9663
	0.05	0.9931	1658.1	3.6626	1.2688	1.6467	0.9679
0.057	0.01	0.9715	1627.2	3.8875	1.3071	1.5808	0.9528
	0.02	0.9724	1621.4	3.9118	1.3072	1.5766	0.9548
	0.03	0.9733	1625.8	3.8870	1.3112	1.5724	0.9549
	0.04	0.9743	1609.4	3.9626	1.3197	1.5680	0.9591
	0.05	0.9451	1605.3	3.9796	1.3226	1.5653	0.9607
0.094	0.01	0.9546	1573.5	4.2310	1.3637	1.5021	0.9468
	0.02	0.9555	1568.5	4.2540	1.3674	1.4987	0.9486
	0.03	0.9564	1563.4	4.2778	1.3712	1.4952	0.9506
	0.04	0.9578	1558.5	4.2984	1.3745	1.4927	0.9530
	0.05	0.9583	1553.0	4.3267	1.3790	1.4882	0.9546

TABLE 1: Continued.

Mole fraction (Xorg)	Concentration (m) mol dm ⁻³	Density (d) (10 ³ kg/m ³)	Ultrasonic velocity (U) (m/sec)	Adiabatic compressibility (β) $\times 10^{-7}$ N ⁻¹ m ²	Intermolecular free length (L _f) $\times 10^{-13}$ m	Acoustic impedance (Z) $\times 10^{-3}$ kg m ⁻² s ⁻¹	Relative association (R _A)
0.138	0.01	0.9367	1517.7	4.6368	1.4246	1.4216	0.9403
	0.02	0.9386	1515.3	4.6410	1.4281	1.4223	0.9427
	0.03	0.9396	1509.8	4.6689	1.4325	1.4186	0.9448
	0.04	0.9405	1504.3	4.6986	1.4371	1.4145	0.9469
	0.05	0.9424	1499.6	4.7186	1.4401	1.4132	0.9498
0.194	0.01	0.9198	1464.4	5.0698	1.4928	1.3469	0.9344
	0.02	0.9208	1461.1	5.0872	1.4953	1.3454	0.9361
	0.03	0.9227	1457.8	5.0997	1.4972	1.3451	0.9381
	0.04	0.9245	1457.8	5.1143	1.4993	1.3445	0.9413
	0.05	0.9264	1451.0	5.1270	1.5012	1.3442	0.9440

Xorg: mole fractions of the organic cosolvent, corresponding to Xorg, are 10, 20, 30, 40, and 50 v/V%, respectively.

TABLE 2: The data of concentration, apparent molar compressibility (K_ϕ), and apparent molar volume (V_ϕ) of sodium nitroprusside in CH₃OH + water, ethylene glycol + water, DMSO + water, and n-propanol + water at 308.15 K.

Concentration (m) mol dm ⁻³	Apparent molar compressibility $-(K_\phi) \times 10^{-3}$ m ² N ⁻¹					Apparent molar volume $(V_\phi) \times 10^{-3}$ m ³ mol ⁻¹				
Sodium nitroprusside + CH ₃ OH + water										
Xorg										
	0.047	0.099	0.160	0.228	0.307	0.047	0.099	0.160	0.228	0.307
0.01	0.8895	1.7665	1.8060	2.2354	1.5545	1.2153	1.8549	2.7133	3.4489	4.5363
0.02	0.4551	1.4259	1.3810	1.7833	1.0767	0.8676	1.6813	2.0950	2.9807	3.9907
0.03	0.3113	1.1368	0.9367	1.3445	0.7567	0.6448	1.3115	1.6218	1.9895	2.6502
0.04	0.2424	0.7206	0.6381	0.9238	0.4653	0.5359	1.1053	1.3798	1.5520	2.2165
0.05	0.1329	0.4721	0.3549	0.8459	0.3059	0.4705	0.8742	1.2162	1.2814	1.6033
Sodium nitroprusside + ethylene glycol + water										
Xorg										
	0.035	0.075	0.121	0.117	0.243	0.035	0.075	0.121	0.117	0.243
0.01	2.5035	4.4695	6.6966	8.2255	9.7695	-0.8102	-1.4964	-2.1054	-2.9105	-3.3467
0.02	2.0921	3.4918	5.0941	6.1076	7.8581	-0.4100	-1.1792	-1.5808	-2.3949	-2.7874
0.03	1.5133	2.4726	3.4826	4.8721	6.5100	-0.1901	-0.8122	-1.2352	-1.8191	-2.0885
0.04	0.5252	1.4043	1.6639	3.5932	5.3940	-0.0853	-0.5834	-1.0454	-1.5682	-1.8506
0.05	0.3920	0.7903	1.3359	1.6195	3.1943	-0.0204	-0.4296	-0.8642	-1.2096	-1.4241
Sodium nitroprusside + DMSO + water										
Xorg										
	0.027	0.059	0.097	0.144	0.201	0.027	0.059	0.097	0.144	0.201
0.01	3.1195	4.2045	5.4575	7.1265	8.2988	-1.0192	-1.7471	-2.3732	-3.4993	-3.8276
0.02	1.5396	2.7276	3.8456	4.8761	6.0566	-0.4402	-1.0689	-1.7329	-2.3919	-3.0861
0.03	1.0057	1.8100	2.5527	4.2513	4.8103	-0.2337	-0.6731	-1.1157	-1.5248	-1.9574
0.04	0.5917	1.3447	1.8991	2.4220	2.6882	-0.1255	-0.4550	-0.7870	-1.1165	-1.4233
0.05	0.3122	0.5718	1.5053	1.8407	2.1369	-0.0968	-0.3423	-0.5879	-0.8513	-1.0906
Sodium nitroprusside + n-propanol + water										
Xorg										
	0.026	0.057	0.094	0.138	0.194	0.026	0.057	0.094	0.138	0.194
0.01	5.9045	3.6885	2.5045	1.8966	1.2107	0.7716	2.3623	3.0625	3.4633	4.4763
0.02	4.1491	2.5066	1.7535	1.4344	0.7427	0.4903	1.6857	2.2358	2.7212	3.1981
0.03	3.1457	1.7097	1.5021	0.8798	0.3870	0.3933	1.2993	1.5603	2.0859	2.6904
0.04	1.8364	1.0602	0.6956	0.5131	0.2495	0.3473	0.7949	1.2099	1.6451	2.0475
0.05	1.4217	0.7279	0.4701	0.2432	0.1107	0.2176	0.7012	1.0178	1.3377	1.6597

FIGURE 1: Variation of apparent molar compressibility (K_ϕ) $C^{1/2}$ for sodium nitroprusside in different nitroprusside mole fraction of CH_3OH in water at 308.15 K. K_ϕ^0 corresponds to its value at zero concentration.

The decrease in relative association (R_A) is due to the breaking up of the solvent molecules on adding the solute, whereas the increase as R_A may be due to the solvation of solute [21]. In all the systems, R_A increases with the increase in the concentration due to the increase in electrostatic attraction. From this data, it can be said that ion-ion interaction between nitroprusside ions overcomes the ion-solvent interaction.

The following observations have been made on K_ϕ and V_ϕ of sodium nitroprusside in aqueous CH_3OH , ethylene glycol, DMSO, and n-propanol mixtures whose values are given in Table 2.

- (i) The values of K_ϕ are negative for all the systems over the entire range of concentration.
- (ii) The values of K_ϕ increase linearly with increasing the ion concentration.
- (iii) The values of V_ϕ are positive for CH_3OH and n-propanol whereas negative for ethylene glycol and DMSO.

Further, the negative values of V_ϕ indicated electrostatic solvation of ions [22]. In other words, the large negative value of K_ϕ may indicate the presence of packing or caging effect [23]. The decrease in the negative value indicates that with the increase in the mole fraction of aquo-organic solvents, ion-solvent interaction increases as the caging effect diminishes.

The limiting apparent molar compressibility K_ϕ^0 provides information regarding ion-solvent interaction. The values of limiting apparent molar compressibility K_ϕ^0 are negative in all the systems as the shown in Figures 1, 2, 3, and 4. It

FIGURE 2: Variation of apparent molar with compressibility (K_ϕ) with $C^{1/2}$ for sodium in different mole fraction of ethylene glycol in water at 308.15 K. K_ϕ^0 corresponds to its value at zero concentration.

FIGURE 3: Variation of apparent molar compressibility (K_ϕ) with $C^{1/2}$ for sodium nitroprusside in different nitroprusside in different mole fraction of DMSO in water at 308.15 K. K_ϕ^0 corresponds to its value at zero concentration.

TABLE 3: Results of limiting apparent molar compressibility (K_ϕ^0), limiting apparent molar volume (V_ϕ^0), and S_K and S_V .

Xorg	Limiting apparent molar compressibility (K_ϕ^0) m ² N ⁻¹	Limiting apparent molar volume (V_ϕ^0) m ³ mol ⁻¹	S_K m ³ mol ⁻² kg Pa ⁻¹	S_V m ³ kg ^{1/2} mol ^{-3/2}
Sodium nitroprusside + CH ₃ OH + water				
0.047	-0.94	1.1	0.291	-0.123
0.099	-1.86	1.85	0.383	-0.194
0.160	-1.72	2.75	0.404	-0.306
0.228	-2.26	3.5	0.424	-0.384
0.307	-1.58	4.6	0.383	-0.510
Sodium nitroprusside + ethylene glycol + water				
0.035	-3.0	-0.9	0.176	0.172
0.075	-4.1	-1.57	0.306	0.268
0.121	-7.4	-2.26	0.424	0.384
0.177	-8.8	-2.98	0.466	0.474
0.243	-10.2	-3.53	0.488	0.577
Sodium nitroprusside + DMSO + water				
0.027	-2.9	-0.95	0.249	0.176
0.059	-4.35	-1.8	0.344	0.268
0.097	-5.56	-2.6	0.404	0.364
0.144	-7.25	-3.7	0.488	0.445
0.201	-8.45	-3.85	0.554	0.532
Sodium nitroprusside + n-propanol + water				
0.026	-6.0	0.8	0.554	-0.466
0.057	-3.8	2.3	0.384	-0.404
0.094	-2.8	3.0	0.287	-0.344
0.138	-1.9	3.65	0.213	-0.268
0.194	-1.2	4.4	0.141	-0.105

decreases with the increase the in concentration of sodium nitroprusside solution for ethylene glycol and DMSO systems but increases in case of n-propanol system. The decrease is not regular in CH₃OH system. It implies that a little bit ion-ion interaction exists in CH₃OH and more ion-ion interaction in n-propanol systems. But the large negative values for ethylene glycol and DMSO systems indicate negligible ion-ion interaction and stronger ion-solvent interaction.

The volume behavior of solute at infinite dilution is satisfactorily represented by V_ϕ^0 which is independent of ion-ion interaction and provides information concerning ion-solvent interaction. The values of V_ϕ^0 are positive for CH₃OH and n-propanol shown in Figures 5 and 8, whereas these are negative for ethylene glycol and DMSO (Figures 6 and 7). Thus in ethylene glycol and DMSO solutions, predominance of ion-solvent interaction is again proved by negative K_ϕ^0 and V_ϕ^0 values. However, in CH₃OH and n-propanol solutions, positive values of V_ϕ^0 suggest that ion-ion interactions predominate.

The constant S_K provides information regarding ion-ion interaction. The values of S_K (Table 3) exhibit positive in all the systems. These values increase in ethylene glycol and DMSO systems, but this increase is not regular in CH₃OH confirming insignificant ion-ion interaction. It decreases in n-propanol system. The value of S_K in n-propanol system is higher at low mole fraction, indicating more ion-ion

interaction. In case of ethylene glycol and DMSO systems, ion-ion interactions are stronger because of having greater value of S_K . So ion-ion interaction is favoured at high mole fraction of ethylene glycol and DMSO, but it is favoured at low mole fraction of n-propanol. The S_V exhibits negative values in CH₃OH and n-propanol systems suggesting the presence of more ion-ion interactions and less complex formation occurring in the systems. The values of S_V which exhibit positive from Table 3 in ethylene glycol and DMSO systems reflect the existence of weak ion-ion interactions and predict the complex formation taking place in the systems.

Generally, the types of interactions occurring between sodium nitroprusside and aqueous solutions of solvents can be classified as follows:

- (i) ionic-hydrophilic interactions between the ions of sodium nitroprusside and polar group of solvents,
- (ii) hydrophilic-hydrophobic interactions between the ions of sodium nitroprusside and the nonpolar side group of solvents.

5. Conclusion

In summary, volume and compressibility data have been determined for sodium nitroprusside in aqueous CH₃OH,

FIGURE 4: Variation of apparent molar compressibility (K_ϕ) with $C^{1/2}$ for sodium nitroprusside in different mole fraction of n-propanol in water at 308.15 K. K_ϕ^0 corresponds to its value at zero concentration.

FIGURE 6: Variation of apparent molar volume (V_ϕ) with $C^{1/2}$ for sodium nitroprusside in different mole fraction of ethylene glycol in water at 308.15 K. V_ϕ^0 corresponds to its value at zero concentration.

FIGURE 5: Variation of apparent molar volume (V_ϕ) with $C^{1/2}$ for sodium nitroprusside in different mole fraction of CH_3OH in water at 308.15 K. V_ϕ^0 corresponds to its value at zero concentration.

FIGURE 7: Variation of apparent molar volume (V_ϕ) with $C^{1/2}$ for sodium nitroprusside in different mole fraction of DMSO in water at 308.15 K. V_ϕ^0 corresponds to its value at zero concentration.

FIGURE 8: Variation of apparent molar volume (V_ϕ) with $C^{1/2}$ for sodium nitroprusside in different mole fraction of n-propanol in water at 308.15 K. V_ϕ^0 corresponds to its value at zero concentration.

ethylene glycol, DMSO, and n-propanol at 308.15 K, and the results have been used to study the ion-solvent interactions present in the mixtures. From the magnitude of K_ϕ^0 , V_ϕ^0 , S_K and S_V , it can be concluded that a larger ion-solvent interaction will exist in ethylene glycol and DMSO solvents than other solvents. Thus, sodium nitroprusside is an effective structure maker in aqueous ethylene glycol and DMSO solutions over other two systems.

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