The Viscosity of Aqueous $BaCl_2 + NaCl$ Solutions *

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Viscosities of the title solution were measured at 35, 40, 45 and 50 °C for 0.2, 0.3 and 0.4 M NaCl and 7BaCl$_2$ concentrations. Considering the NaCl solutions as the solvents for BaCl$_2$, the results were compared with the Jones-Dole equation, the Moulik equation and the Vand equation.

According to Jones and Dole [1, 2] the viscosity η of electrolyte solutions follows the empirical relation

$$\frac{\eta}{\eta_0} = 1 + A\sqrt{C} + B\,C\,, \qquad (1)$$

where C is the concentration of the solute and η_0 the viscosity of the solvent. The constant A is a theoretically justifiable ion – ion interaction parameter, and B is an empirical ion – solvent interaction constant which can not be calculated from a model [3]. Many single salts have been studied in aqueous medium [1, 2, 4, 5] and also in mixed solvents, but there are very few studies of mixed electrolytes in aqueous solution [6, 7].

In existing viscosity studies on mixed aqueous electrolytes the ratio of the concentrations of the electrolytes was kept constant [6, 7]. In the present study, sodium chloride-water mixtures were considered as solvents and the effect of BaCl$_2$ was studied. The solvents used were 0.2, 0.3 and 0.4 molar in NaCl.

Barium chloride (GR) and sodium chloride (AR) were from BDH, India, and were used without further purification. The water used was double distilled. An Ostwald viscometer with a flow time of 213 sec for water at 30 °C was used. The viscometer and the 10 ml pyknometer were cleaned with alkali, sulphuric acid and distilled water, in that order, before use. The temperature of the bath was controlled to ± 0.02 °C.

Tables 1 and 2 show the experimental results. On fitting (1) to these, in accordance with [8] very low positive values of A where found, showing that the solute – solute interactions are small. The B values obtained by fitting a straight line to the data are presented in Table 3. The B value for BaCl$_2$ in water at 35 °C was found to be 0.282 l/mole (literature value 0.285 [9, 10]).

Table 1. Viscosities (cp) of aqueous sodium chloride solutions at different temperatures.

Solvent	35 °C	40 °C	45 °C	50 °C
0.0 M	0.719	0.653	0.596	0.547
0.2 M	0.733	0.660	0.598	0.556
0.3 M	0.738	0.665	0.603	0.561
0.4 M	0.752	0.672	0.617	0.568

Table 2. Relative viscosities η/η_0 of solutions of BaCl$_2$ in aqueous NaCl at different temperatures.

C of BaCl$_2$ (moles/liter)	35 °C	40 °C	45 °C	50 °C
	0.2 M aqueous NaCl solution			
1.173	1.353	1.374	1.393	1.403
0.9385	1.280	1.299	1.309	1.318
0.7508	1.224	1.242	1.251	1.259
0.6006	1.177	1.191	1.201	1.205
0.4805	1.141	1.155	1.161	1.164
0.2803	1.085	1.091	1.097	1.101
0.1730	1.053	1.056	1.060	1.065
	0.3 M aqueous NaCl solution			
1.173	1.355	1.371	1.377	1.389
0.9385	1.274	1.278	1.305	1.314
0.7508	1.222	1.224	1.247	1.255
0.6006	1.178	1.177	1.197	1.203
0.4805	1.142	1.146	1.158	1.162
0.2803	1.084	1.086	1.093	1.098
0.1730	1.053	1.054	1.058	1.061
	0.4 M aqueous NaCl solution			
1.173	1.310	1.333	1.337	1.356
0.9385	1.257	1.274	1.276	1.285
0.7508	1.207	1.220	1.224	1.229
0.6006	1.164	1.177	1.175	1.180
0.4805	1.130	1.141	1.144	1.144
0.2803	1.077	1.085	1.086	1.092
0.1730	1.048	1.051	1.052	1.056

Table 3. B values (l/mole) for BaCl$_2$ solutions in aqueous NaCl at different temperatures.

Solvent	35 °C	40 °C	45 °C	50 °C
0.2 M NaCl	0.301	0.318	0.333	0.344
0.3 M NaCl	0.283	0.301	0.315	0.327
0.4 M NaCl	0.260	0.279	0.293	0.306

The results may be summarized qualitatively as follows:

(i) The viscosities increase with increasing NaCl and BaCl$_2$ concentrations, which implies $\eta > \eta_0$, and decrease with increasing temperature.
(ii) η/η_0 increases with increasing temperature.
(iii) The increase of η with increasing BaCl$_2$ concentration is the smaller the larger the NaCl concentration.

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Table 4. Parameters of (2) and (4) for aqueous $BaCl_2$-NaCl solutions.

Temp. °C	Moulik Eq. (2)		$\bar{V}$ and Eq. (4)
	I	M [(l/mole)^2]	$\bar{V}^0$ (extrapolated) [cm^3/mole]
	$BaCl_2$-0.2 M NaCl		
35	1.158	0.522	120.38
40	1.174	0.556	129.60
45	1.182	0.585	138.34
50	1.189	0.602	145.81
	$BaCl_2$-0.3 M NaCl		
35	1.160	0.506	121.01
40	1.160	0.522	123.15
45	1.181	0.560	134.15
50	1.189	0.579	140.55
	$BaCl_2$-0.4 M NaCl		
35	1.152	0.449	109.80
40	1.164	0.485	118.48
45	1.166	0.491	121.11
50	1.168	0.521	127.49

Possible explanation: The viscosity increases with increasing solvation of the ions. Then (ii) would show that the solvation of Ba^{2+} is less temperature dependent than the solvation of Na^+, and (iii) would show that the solvation of the ions decreases with increasing concentration of the ions.

According to Moulik [11], for concentrated solutions

$$(\eta/\eta_0)^2 = I + M C^2 , \tag{2}$$

where I and M are constants. Plots of η^2_r vs. C^2 were done, and the computed values of I and M are given in Table 4. The correlation coefficients (0.96 – 0.98) were found to be not as good as for η vs. C plots (0.992 – 0.996).

Vand [12] suggested the equation

$$\ln\left(\frac{\eta}{\eta_0}\right) = \frac{2.5\,\Phi}{1 - Q\Phi} , \tag{3}$$

where Q is a generalized particle interaction coefficient and Φ the volume fraction of the solute. A rearrangement of (3) gives

$$\frac{2.5\,C}{2.303\log(\eta/\eta_0)} = \frac{1}{\bar{V}} - Q\,C , \tag{4}$$

where $\bar{V}$ is the partial molar volume of the solute. On plotting the l.h.s. of (4) vs. C, reasonable straight lines were obtained (correlation coefficient 0.95 to 0.996). The intercepts with the ordinate gave the $\bar{V}^0$ values of Table 4. B values calculated with the equation

$$B\,[\text{l/mole}] = 2.5 \cdot 10^{-3}\,\bar{V}^0\,[\text{cm}^3/\text{mole}] \tag{5}$$

did not tally with the B values of Table 3 but were of the same order of magnitude, as has been found for other systems [14] too.

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