[CONTRIBUTION FROM THE MALLINCKRODT CHEMICAL LABORATORY OF HARVARD UNIVERSITY]

The Viscosity of Aqueous Solutions as a Function of the Concentration. II. Potassium Bromide and Potassium Chloride

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Recent papers from this Laboratory[1] have pointed out the significance of viscosities in the development of the modern theory of electrolytic solutions and have recorded data obtained by an improved technique. The present paper contains new data on aqueous solutions of potassium bromide over a wide range of concentration (0.001 to 3.75 *N*) and an extension of the data already published for potassium chloride up to 3 *N*.

Our new method of timing by means of a photoelectric cell which has been described in detail in the third paper referred to was used. The salts were carefully purified and are believed to have contained no impurities in significant amounts. The data are recorded in Table I in which the headings have the same significance as in our earlier paper, except that instead of giving the absolute densities of the solutions, the relative apparent densities in air (*i. e.*, the weight of the solution divided by the weight of an equal volume of water at the same temperature with no vacuum corrections applied) are given because this is the figure needed for the present

TABLE I

RELATIVE VISCOSITY AT 25°

c	d_c/d_0	t_c	t_0	d_0t_c/d_ct_0	K. E. corr.	η obs.	η comp.	$\Delta\eta$ obs. − comp.
				Potassium Bromide				
0.001000	1.000089	618.55	618.54	1.00010	0.00000	1.00010	1.00010	0.00000
.002000	1.000160	618.60	618.64	1.00010	.00000	1.00010	1.00011	− .00001
.005000	1.000417	618.39	618.59	1.00009	.00000	1.00009	1.00009	.00000
.010005	1.000841	618.26	618.79	0.99998	.00000	0.99998	0.99998	+ .00000
.020001	1.001695	617.51	618.72	.99974	− .00002	.99972	.99969	+ .00003
.050001	1.004256	615.12	618.49	.99879	− .00005	.99874	.99864	+ .00010
.099899	1.008492	611.34	618.46	.99688	− .00010	.99678	.99672	+ .00006
.199882	1.016955	603.98	618.50	.99308	− .00021	.99287	.99281	+ .00006
.499927	1.042194	582.87	618.38	.98235	− .00055	.98180	.98189	− .00009
.959172	1.080449	555.29	618.59	.96989	− .00104	.96885	.96884	+ .00001
.998357	1.083718	553.06	618.50	.96906	− .00108	.96798	.96795	+ .00003
1.999826	1.166031	509.04	618.63	.95959	− .00203	.95756	.95747	+ .00009
2.003090	1.166167	508.96	618.53	.95947	− .00203	.95744	.95747	− .00003
3.030933	1.249592	481.41	618.68	.97234	− .00281	.96953	.97181	− .00228
3.749274	1.307264	470.81	618.58	.99498	− .00321	.99177	.99695	− .00518
				Potassium Chloride				
0.498450	1.023223	603.23	618.58	0.99783	−0.00023	0.99760	0.99764	−0.00004
.999718	1.045948	589.99	618.67	.99746	− .00044	.99702	.99716	− .00014
2.011510	1.090591	572.19	618.77	1.00849	− .00076	1.00773	1.00765	+ .00008
2.962076	1.131272	565.65	619.45	1.03302	− .00091	1.03211	1.03221	− .00010

(1) Grinnell Jones and Malcolm Dole, THIS JOURNAL, **51**, 2950 (1929); Grinnell Jones and S. K. Talley, *ibid.*, **55**, 624 (1933); Grinnell Jones and S. K. Talley, *Physics*, **4**, 213 (1933).

purpose. For the dilute solutions reported in the earlier paper the difference is insignificant. All measurements were made at 25.00°.

It will be noted that although all solutions of potassium bromide within the range of 0.01 to 3.75 normal have a viscosity less than that of water, nevertheless the 0.001, 0.002 and 0.005 normal solutions have a viscosity greater than that of water. This furnishes another case supporting the prediction of Jones and Dole that "At very low concentrations the viscosities of solutions of all strong electrolytes will be greater than that of water, including salts which at moderate concentrations show diminished viscosity."

The data recorded in this paper show that an equation of the form $\eta = 1 + A\sqrt{c} - Bc$, is only valid up to about 0.1 N for solutions of potassium bromide and up to about 0.2 N for solutions of potassium chloride. Both of these salts have a minimum viscosity (at about 0.8 normal for potassium chloride and at about 1.9 normal for potassium bromide). Other data in the literature indicate that salts which give solutions having a viscosity less than that of water will commonly have a minimum in their viscosity–concentration curves and again have a viscosity greater than that of water at high concentrations if they are sufficiently soluble. A more detailed discussion of the laws for the viscosity of concentrated solutions will be postponed until more extensive data are available. The results so far obtained, however, indicate that another term proportional to the square of the concentration must be added.

The viscosity of solutions of potassium bromide up to 2 N can be expressed approximately by the equation

$$\eta = 1 + 0.00474\sqrt{c} - 0.04904\,c + 0.01221\,c^2$$

The values computed by this equation are given in the table in the next to the last column. The greatest deviation up to 2 N is only 0.01%. The value of the coefficient of the square root term computed from the formula of Falkenhagen and Vernon[2] is 0.0049 which agrees satisfactorily with the value 0.00474 obtained from our experiments. For potassium chloride the equation

$$\eta = 1 + 0.0052\sqrt{c} - 0.01612\,c + 0.00808\,c^2$$

holds approximately up to 3 N. The greatest deviation between our experimental data and the values computed by this equation is only 0.016%.

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(2) H. Falkenhagen, *Physik. Z.*, **32**, 365, 745 (1931); H. Falkenhagen and E. L. Vernon, *ibid.*, **33**, 140 (1932); *Phil. Mag.*, [7] **14**, 537 (1932); L. Onsager and R. M. Fuoss, *J. Phys. Chem.* **36**, 2689 (1932).