Conductance Behaviour of some Transition Metal Halide Complexes in Methanol - Water System

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The conductance data of $[Co(en)_3]X_2$, $[Ni(en)_3]X_2$ and $[Cu(en)_2]X_2$ in aqueous methanol were analyzed using Fuoss-Edelson equation to obtain the equivalent condetance at infinite dilution (Λ_o) and the first association constant K_{a1} simultaneously. In all cases Λ_o value exhibits a minimum at 50 wt.% methanol corresponding to the maximum viscosity of mixed solvent. The calculated values of K_{a1} were found to be inversely proportional to the dielectric constant. The plots of the Walden product *vs* wt % of methanol in the solvent mixtures show maxima, the heights of which are in the order $[Co(en)_3]X_2$ > $[Ni(en)_3]X_2$ > $[Cu(en)_2]X_2$. The existence and the height of the maximum was explained on the basis of hydrophobic dehydration of cations due to the presence of cosolvent (MeOH) in water-rich region. The λ^{2+}_o for the above cations and the average values of $\lambda_o^{Cl^-}$ and $\lambda_o^{Br^-}$ were derived at all proportions of methanol.

The complexes of ethylenediamine with Co^{2+}, Ni^{2+} and Cu^{2+} were prepared for the first time by Werner, Steintzer and Rucker [1]. A series of octahedral nickel and cobalt complexes of the general formula $[M(en)_3]X_{1-2}$ and square planar complexes $[Cu(en)_2]X_{1-2}$ were reported where X is a univalent or divalent anion.

The aim of this work is to study the conductance behaviour of the complexes - $[Co(en)_3]X_2$, $[Ni(en)_3]X_2$ and $[Cu(en)_2]X_2$ (where X = Cl, Br or I) - in wide range of methanol - water mixtures at 25°C to observe the effect of dielectric constant on the mobility of the ions. Walden product for the above complexes are calculated and the results interpreted with respect to viscosity and dielectric properties of the solvent.

EXPERIMENTAL

Experimental details concerning the preparation and analysis of $[Co(en)_3]X_2$, $[Ni(en)_3]X_2$, and $[Cu(en)_2]X_2$ (where X = Cl, Br and I), purification of water and methanol, preparation of solvent mixtures etc., were described earlier [1,2 and 3]. The specific conductance (x_o) of the carbon dioxide - free conductivity water was found to be 2-5 X 10^{-7} Ω^{-1} cm^{-1}. The density (d) and viscosity (η) values for the purified methanol were found to be 0.78666 $g.ml^{-1}$ and 0.5439 cp respectively and are consistent with previous data [4]. The values for water was taken as 0.99704 $g.ml^{-1}$ and 0.8903 cp [5]. Density and viscosity values for methanol- water mixtures were obtained by interpolation from published data [4]. The required dielectric constants (D) were taken by interpolation from data of Bates and Robinson [5].

A Mettler microbalance with accuracy ±0.01 mg was used for weighing. All solutions were prepared by weight reduced to vacuum. Successive dilution was carried out inside an Erlenmeyer conductivity cell with bright platinium electrodes using a dispenser for siphoning the solvent. The temperature was adjusted at 25±0.02°C using an ultrathermostat - model MLW type U10. The cell constant (K) was 0.03565±045% cm^{-1} at 25°C [6].

An ac Beckman conductivity bridge - Model RC No 18A - was used for measuring the resistance of the solution at 3 kHz. The accuracy of measurements was ± 0.1 ohm for R < 1000 and ± 0.3 ohm for R>1000.

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RESULTS

It is observed that $[Co(en)_3]X_2$, $[Ni(en)_3]X_2$ and $[Cu(en)_2]X_2$ complexes (X = Cl, Br or I) are easily soluble in methanol - water mixtures at 25°C. Conductivity measurements were carried out covering the whole miscibility field. Only in case of $[Ni(en)_3]X_2$ measurements were carried out up to 93 wt% of methanol and in case of $[Co(en)_3]X_2$ (which has lower solubility) measurements were carried out only up to 75 wt% of methanol.

The equivalent conductance data of different concentrations of each of the complex in different aqueous methanol mixtures at 25°C are summarized in Table (1-3) respectively.

Table 1

Conductance Data of $[Co(en)_3]X_2$ in aqueous methanol mixtures

Temp 25° C; conc in eq.l^{-1} Equivalent conductance Λ in ohm^{-1}.eq^{-1}.cm^2

18.45 % MeOH		40.08 % MeOH		60.08 % MeOH		75.36 % MeOH	
10^4 C	Λ	10^4 C	Λ	10^4 C	Λ	10^4 C	Λ
X = Cl							
23.439	98.822	19.483	77.904	21.831	63.634	15.079	61.787
19.306	100.71	16.180	79.778	17.947	66.111	12.289	64.300
14.598	103.08	12.491	81.979	13.952	69.080	9.4336	67.634
10.993	105.08	9.6204	84.034	10.661	71.939	7.1738	71.036
8.3088	106.82	7.4903	85.763	8.3562	74.391	5.5148	74.104
6.4816	108.21	5.9292	87.101	6.6512	76.493	4.3038	76.995
5.1301	109.21	4.7272	88.475	5.2674	78.574	3.1729	80.497
3.9982	110.45	3.6833	89.675	4.0542	80.664		
18.59% MeOH		38.13% MeOH		56.58% MeOH		73.47% MeOH	
X = Br							
24.379	108.19	22.610	48.295	19.693	81.785	14.314	69.994
15.540	111.04	18.850	86.196	16.632	83.051	12.049	73.126
11.479	113.56	14.333	88.314	12.659	85.737	9.5564	77.123
8.7043	115.43	10.667	90.551	9.4854	87.226	7.3413	79.228
6.7065	116.78	8.0083	92.307	7.2279	89.110	5.7680	82.869
5.2920	118.05	6.2158	93.454	5.5923	90.574	4.4816	85.606
		4.7253	94.517	4.1963	92.210	3.4830	88.068
19.85% MeOH		40.32% MeOH		59.26% MeOH		75.71% MeOH	
X = I							
20.708	107.60	20.719	89.530	19.687	81.729	12.399	82.434
16.482	109.48	18.061	91.678	16.418	83.975	9.7387	84.116
12.917	111.84	10.757	95.054	13.011	86.119	7.6406	87.026
10.107	112.96	8.3892	96.469	9.8283	88.009	5.9430	90.247
7.7444	115.28	6.5233	97.742	7.1966	90.257	4.4925	92.984
6.0554	116.69	5.2811	98.529	5.6170	92.017	3.1301	95.687
4.1192	118.60	4.4347	99.405	4.2477	93.145		

Table 2

Conductance Data of $[Ni(en)_3]X_2$ in aqueous methanol mixtures

Temp 25° C; conc in eq.l^{-1}; Equivalent conductance Λ in ohm^{-1}.eq^{-1}.cm^2

10.58 % MeOH		29.46 % MeOH		53.74 % MeOH		73.02 % MeOH	
10^4 C	Λ	10^4 C	Λ	10^4 C	Λ	10^4 C	Λ
X = Cl							
19.638	83.858	20.234	71.172	22.777	56.543	22.075	63.399
15.632	86.317	16.885	72.301	18.561	57.827	17.713	65.871
11.733	89.457	13.147	75.114	13.512	59.954	13.840	68.843
8.9569	90.716	9.9508	76.186	10.055	62.427	10.849	71.183
6.8079	93.453	7.6116	80.472	7.7531	64.397	8.3080	73.807
5.2193	95.289			5.6918	67.040	6.5881	75.746
4.0034	97.405			3.4871	69.812		
3.2726	99.010						
20.07% MeOH		41.83% MeOH		63.38% MeOH		83.22% MeOH	
X = Br							
12.384	82.720	20.897	63.023	22.377	60.875	16.863	64.953
8.9277	84.771	16.552	64.935	18.490	62.515	12.831	67.828
6.7230	87.268	12.291	67.154	13.633	65.341	7.6115	75.602
5.2772	88.634	8.9030	70.602	9.9389	68.939	6.0373	78.519
4.2818	90.270	6.7317	72.417	7.4095	71.624	4.8852	80.864
3.3636	91.922	5.2132	74.015	5.8347	72.612	4.0499	82.396
		4.2142	75.323	4.6004	74.189		
		3.3748	76.541				
20.32% MeOH		43.52% MeOH		72.31% MeOH		92.18% MeOH	
X = I							
19.826	83.118	20.171	67.210	20.560	68.996	15.017	80.043
15.402	85.242	16.294	68.964	16.857	72.154	12.110	83.443
11.483	87.904	12.116	71.940	12.421	75.266	8.8725	87.945
8.4036	90.399	9.1479	74.125	9.2341	77.982	6.4658	92.214
6.2250	93.036	6.9423	77.703	7.0156	80.533	4.8117	96.178
4.7720	95.111	5.2995	79.170	5.4642	82.559	3.7535	99.470
3.7663	97.382	4.1213	81.011	4.2774	84.953	2.9592	102.78
				3.2592	87.255	2.3403	105.90

Equivalent Conductance at Infinite Dilution

The values of Λ_o and the first association constant K_{a1} for unsymmetrical 2:1 electrolytes can be successfully calculated using Fuoss-Edelson (F-E) method [7]. For an electrolyte MX_2, the association equilibria can be represented as:

$$M^{2+} + X^- \overset{K_{a1}}{\rightleftharpoons} MX^+$$

$$MX^+ + X^- \overset{K_{a2}}{\rightleftharpoons} MX_2$$

Table 3

Conductance Data of $[Cu(en)_2]X_2$ in aqueous methanol mixtures

Temp 25° C; conc in $eq.l^{-1}$; Equivalent conductance Λ in $ohm^{-1}.eq^{-1}.cm^2$

14.70 % MeOH		53.88 % MeOH		70.61 % MeOH		92.68 % MeOH	
10^4 C	Λ	10^4 C	Λ	10^4 C	Λ	10^4 C	Λ
X = Cl							
16.716	85.780	24.394	58.437	20.728	58.370	18.523	76.768
13.626	86.754	14.944	61.059	16.742	59.957	15.364	79.505
7.6753	88.539	10.846	62.854	13.429	61.013	11.613	82.376
5.8612	89.883	8.3184	63.780	9.9318	63.050	8.6983	84.968
3.5849	91.157	6.5555	64.590	7.6493	64.445	7.0416	86.617
		5.2258	65.280	5.8844	65.544	3.7784	91.110
		4.1348	65.780	3.1530	67.748		
9.43% MeOH		35.09% MeOH		56.69% MeOH		73.52% MeOH	
X = Br							
20.412	99.417	10.400	70.996	19.561	60.871	20.540	62.001
16.885	100.79	8.0604	71.968	16.048	61.827	17.195	63.542
12.656	102.04	6.4817	72.584	11.857	63.373	12.823	65.539
9.3204	103.04	5.2566	73.030	8.6225	64.842	9.5413	67.727
6.9053	104.43	4.1177	73.709	6.5764	65.922	7.3943	69.393
5.3585	105.20			5.1675	66.883	5.7168	70.807
4.2321	106.03			4.1657	67.583	4.5028	72.055
3.6446	106.50			3.1957	68.342	3.6497	73.055
10.01% MeOH		31.73% MeOH		61.01% MeOH		80.55% MeOH	
X = I							
22.208	96.794	20.155	73.972	21.055	66.521	20.806	68.624
17.423	98.540	16.243	75.134	16.708	67.788	16.284	72.108
10.408	102.91	8.1623	77.905	12.086	69.676	12.231	74.670
8.3472	104.10	5.9660	78.716	8.9038	70.852	9.0845	76.407
6.6866	105.02	4.5834	79.469	6.7306	72.024	6.8591	78.669
5.3666	105.82	3.5731	79.939	4.2467	73.535	5.3327	80.269
		2.8061	80.667	3.3524	74.114	3.3444	83.112

where K_{a1} and K_{a2} refer to the first and second association constants respectively. The F-E method assumes K_{a2} is negligible and the chelate cations (MX^+) are considerably larger than the anion (X^-). So M^{2+} can be thought to be hydrodynamically equivalent to MX^+ except in charge type; since the ratio of the charges equals that of the mobility, the mobility of M^{2+} can be taken as twice that of MX^+.

A plot of Λ *vs* x for the electrolyte MX_2 gives a straight line. From this plot, an initial value of Λ_o is obtained. More accurate value of Λ_o and also K_{a1} can be obtained from the plot of Λ' *vs* x

where $\Lambda' = \Lambda$ EXP(F)

Here F is a function of C and Λ_o and can be calculated for each concentration. EXP(F) corrects the conductance ratio Λ/Λ_o for the effect of interionic forces on the mobility : x = C f_b $^1\Lambda$ ($^1\Lambda$-1/2Λ_o)

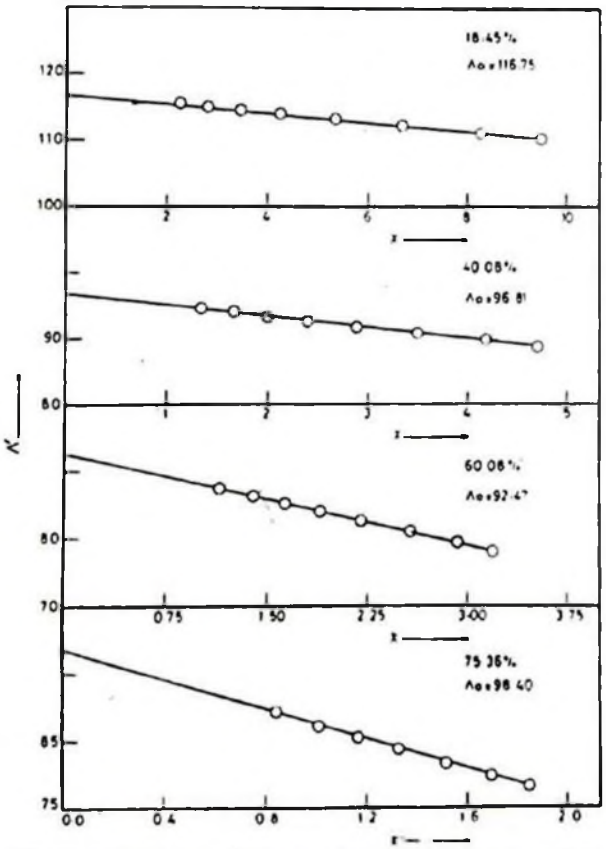


Fig.1 Fouss and Edelson Plots For $[Co(en)_3]Cl_2$ Methanol water Mixtures T = 25°C

f_b is the cationic activity coefficient and can be calculated by the Debye Huckel Limiting Law as follows:

$$-\log f_b = 250.3\ z^2\ B\ \sqrt{3\ C}\ /D^{2/3} \qquad ...(1)$$

F-E method relates Λ' and x as

$$\Lambda' = \Lambda_o - x\ K_{a1}\ \Lambda_o \qquad ....(2)$$

Fig. 1 represents typical straight lines obtained in F-E plots. Accurate values of Λ_o and K_{a1} are calculated from the F-E plots for the different salts and in different solvent mixtures. These values are included in Table 4. The related physical properties of the solvent mixtures used (d, and D) are also included in the same Table. The values of Λ_o and K_{a1} for $[Cu(en)_2]X_2$ and $(Ni(en)_3]X_2$ complexes (X=Cl, Br or I) in pure water are taken from published data [2a] while those in methanol are derived after recalculation of the published conductance data [2b]. The variation of both Λ_o and log K_{a1} with composition in typical cases are shown in fig.2 .

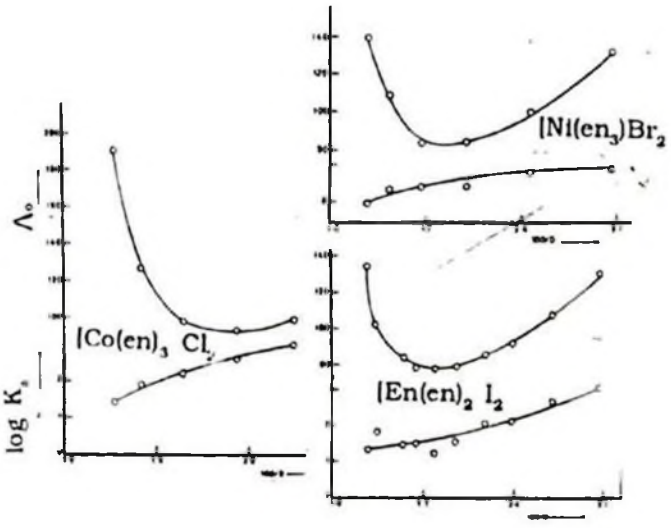


Fig.2 Variation of Λ_o and log K_a with 100/D in Methanol water Mixtures T = 25°C

Table 4

Physical Properties and constants derived from (F-E) Eq.

Solvent MeOH- H_2O Mixtures; Temp 25°C

Wt % of MeOH	d (g.ml^{-1})	η CP	D	Λ_o Ω^{-1} eq^{-1} cm^2	K_{ass} l mol^{-1}
$[Co(en)_3]Cl_3$					
0.000	0.99704	0.8903	78.30	190.38	26.540
18.45	0.95050	1.362	70.40	116.75	78.900
40.08	0.90275	1.590	60.75	96.81	164.88
60.08	0.86100	1.369	51.60	92.47	422.74
75.36	0.83075	1.079	44.50	98.40	1077.2
$[Ni(en)_3]Cl_2$					
0.000	0.99704	0.8903	78.30	138.09	95.257
10.58	0.96950	1.160	73.00	106.26	209.02
29.46	0.92600	1.547	65.55	89.98	213.06
53.84	0.87400	1.481	54.40	76.80	266.24
73.02	0.83600	1.124	45.55	90.08	328.82
100.0	0.78657	0.5445	32.70	130.61	813.70
$[Cu(en)_3]Cl_2$					
0.000	0.99704	0.8903	78.30	133.99	13.687
14.70	0.95900	1.264	72.05	94.84	24.455
53.88	0.87350	1.480	54.45	70.62	47.169
70.61	0.84250	1.170	46.70	73.49	80.347
92.68	0.80000	0.711	36.25	102.65	86.573
100.0	0.78657	0.5445	32.70	118.86	1716.0
$[Co(en)_3]Br_2$					
0.000	0.99704	0.8903	78.30	192.40	21.025
18.59	0.95050	1.363	70.35	124.55	55.044
38.13	0.90700	1.590	61.70	101.67	97.921
56.38	0.86800	1.438	53.20	99.36	112.53
73.47	0.83450	1.116	45.35	105.19	790.0
$[Ni(en)_3]Br_2$					
0.000	0.99704	0.8903	78.30	139.57	94.776
20.07	0.94700	1.401	69.70	99.40	227.16
41.83	0.89900	1.586	60.00	84.03	279.73
63.38	0.85450	1.307	50.05	85.10	313.90
83.22	0.81650	0.920	40.70	101.02	804.27
100.00	0.78657	0.5445	32.70	134.77	1264.0
$[Cu(en)_2]Br_2$					
0.000	0.99704	0.8903	78.30	135.61	43.722
9.430	0.97050	1.132	74.40	110.67	23.610
35.09	0.91400	1.582	63.10	77.37	25.416
56.69	0.86875	1.433	52.65	72.59	60.170
73.52	0.83450	1.115	45.35	80.02	126.27
100.0	0.78657	0.5445	32.70	123.26	2006.0
$[Co(en)_3]I_2$					
0.00	0.99704	0.8903	78.30	191.87	51.934
19.85	0.74850	1.388	69.75	125.46	82.929
40.32	0.90225	1.591	60.70	105.67	145.11
59.26	0.86275	1.383	51.95	101.80	147.34
75.71	0.82980	1.072	44.30	108.43	411.06
$[Ni(en)_3]I_2$					
0.000	0.99704	0.8903	78.30	138.52	59.841
20.32	0.94650	1.406	69.55	104.69	210.71
43.52	0.89550	1.579	59.20	90.59	325.34
53.20	0.87500	1.490	54.75	88.78	325.87
72.31	0.83700	1.138	45.90	97.16	343.18
80.19	0.82175	0.9860	42.20	103.87	416.18
92.18	0.80050	0.7240	36.45	121.52	747.94
$[Cu(en)_2]I_2$					
0.000	0.99704	0.8903	78.30	134.69	21.379
31.73	0.92375	1.564	64.55	83.97	30.489
40.29	0.90225	1.590	60.70	77.95	31.582
60.88	0.85450	1.353	51.20	79.08	35.361
72.29	0.83700	1.138	45.90	85.51	121.12
80.55	0.82100	0.9780	42.00	91.19	135.31
90.74	0.80300	0.7540	37.15	106.64	495.81
100.0	0.78657	0.5445	32.70	129.84	1288.0

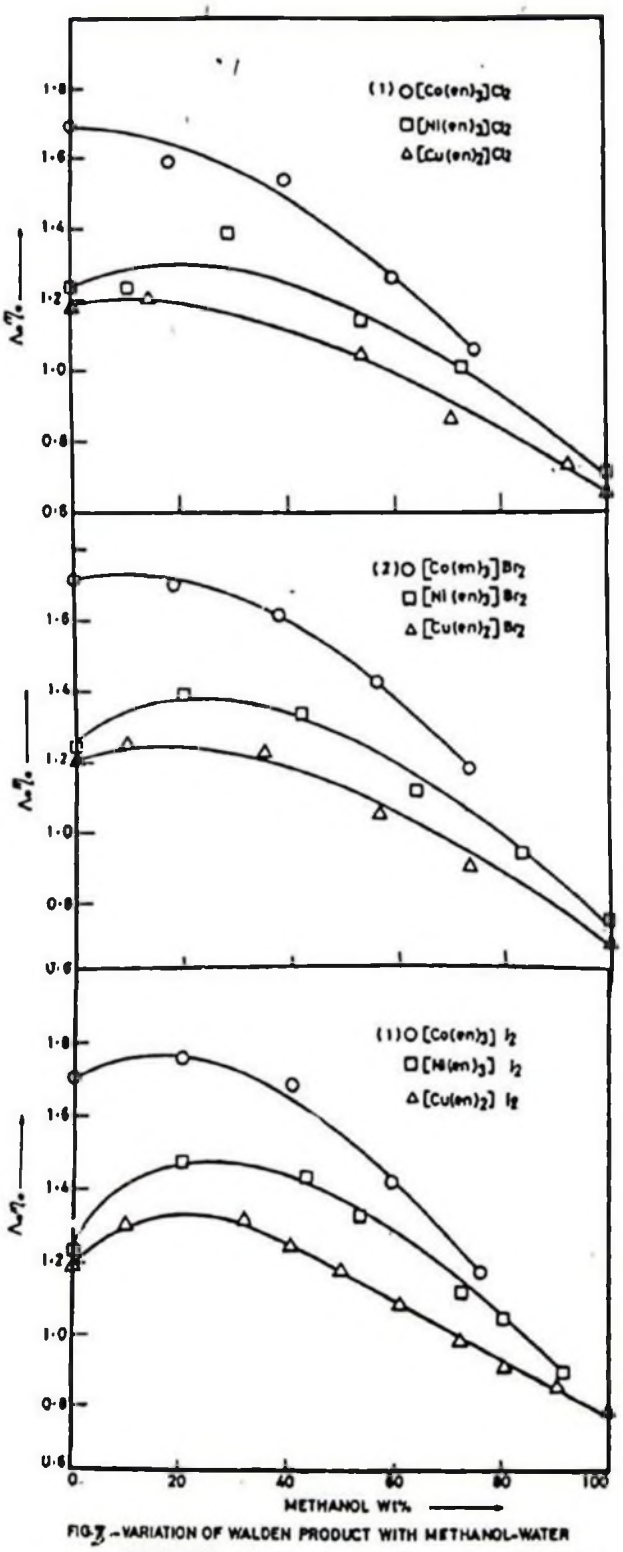


FIG.3 - VARIATION OF WALDEN PRODUCT WITH METHANOL-WATER COMPOSITION FOR (1) CHLORIDE (2) BROMIDE AND (3) IODIDE COMPLEXES.

The plot of Walden product $\Lambda_o\eta_o$ for the chloride, bromide and iodide complexes against wt% of MeOH are illustrated by fig.3. The value of λ^-_o for iodide ions in different aqueous methanol mixtures were obtained by interpolation of values published earlier [3,8,9]. The cation conductance λ^{2+}_o of $[Co(en)_3]^{2+}$, $[Ni(en)_2]^{2+}$ and $[Cu(en)_2]^{2+}$ in these mixtures were obtained from the experimental Λ_o values of the respective iodides and λ^{I-}_o. These values in different solvent mixtures are presented in Table 5. Using these cationic conductance and Λ_o of the chloride and bromide complexes, the values of λ^{Br-}_o and λ^{Cl-}_o in different media are calculated. Average values of these are also included in the Table 5.

DISCUSSION

Variation of Λ_o with 1/D for any complex of the present set shows pronounced minimum at about 50% of MeOH, i.e., 100/D=1.8 (Table 4, Fig.2). Kubota and Yokoi [10] obtained a minimum for Λ_o at about 50% wt. of MeOH when they measured the conductance of $[Fe(phen)_3]SO_4$ and $[Fe(phen)_3]Cl_2$ complexes in methanol-water mixtures at 25°C. Hafez et al. [3] obtained minimum values at the same wt% of MeOH (50 wt%) for S-n-alkylisothiouronium iodides (1:1 electrolyte) at 25°C. They discussed the results on the basis of viscosity variation and solvation process. The position of the minimum corresponds to a maximum viscosity of the mixtures. This means that electrophoretic effect reaches its maximum value at this percentage. The results can be interpreted on the basis that at this percentage the strucutre of the solvent around the ion is varied remarkably. In other words, it is due to variation of solvent clathrates and accordingly size of solvated ion.

Inspection of Table 5 shows that λ^{2+}_o values for Co or Ni complex cations are higher than those of Cu complex cation.

Table 5

Molar ionic conductance of $[Co(en)_3]^{2+}$, $[Ni(en)_2]^{2+}$ and $[Cu(en)_2]^{2+}$ and halide ions in methanol water mixtures

wt % of MeoH	Molar Conductance of Ions → Co ion	Ni ion	Cu ion	I^-	Cl^-	Br^-
0	114.06	61.68	57.93	76.90[6]	76.35[6] 76.26	78.17[6] 78.03
10	76.9	59.3	53.0	60.3	54.8	60.2
20	70.9	57.1	47.3	48.3	40.2	45.4
30	68.2	54.8	42.8	44.6	33.9	37.8
40	66.2	53.0	40.0	43.2	29.4	32.7
50	64.8	52.0	39.4	37.1	26.7	30.4
60	64.3	52.2	40.1	38.4	26.8	31.5
70	64.5	53.9	42.2	41.2	31.0	34.5
80	-	57.1	46.4	46.4	38.1	41.4
90	-	64.3	52.3	53.2	45.3	48.9
100	-	78.41	66.72	62.78[17]	52.38[17] 52.16[19]	56.25[17] 56.48[19]

References are indicated for published values.

This phenomena may be due to the ability of the square planar Cu(II) complexes to accomodate two more solvent molecules in their coordinate shell, which promotes solvation through hydrogen bond formation;hence their mobility must be less than those of the octahedral Co(II) and Ni(II) complexes.

A glance at Table 4 indicates that Λ_o for a series of salts with common cation decreases in the direction - bromides > Iodides >chlorides. This trend is in agreement with that obtained for the same complexes in pure water [2a]. This trend was attributed to the ionic solvation. However Nightingale [11] recorded the values 3.32, 3.30 and 3.31 A for the hydrated radii (r_h) of Cl^-, Br^- and I^- respectively.

It can also be seen from Table 4 that K_{a1} increases in general with decrease in dielectric constant of the mixture. This behaviour is quite expected on electrostatic basis. This observation also supports the role of the solvent in stabilizing the formed ion-pair through dipole-dipole interaction in case of electrolytes when at least one of its ions is large. Bjerrum [12] has shown a relation for the ion pair association constant K_A and dielectric constant D as

$$\ln K_A = \ln \frac{4\pi N a^3}{3000} + \frac{|Z_1 Z_2| e^2}{aDkT} \quad .....(4)$$

where k, N, a, Z_1 and Z_2 are the Boltzmann constant, Avogadro number, the closest distance of approach of the two opposite ions of charge Z_1 and Z_2. So a plot of log K_A *vs* 1/D should be a straight line.

Inspection of Fig.2 shows that log K_{a1} *vs* 1/D exhibit curvature; Equation 4 is not obeyed in the present case. This indicates the importnace of the added correction term U [13] which is given by the relation

$$U = \Delta S/k - E_a/kT \quad ...(5)$$

where $\Delta S/k$ (the entropy/Boltzmann constant ratio) illustrates the probability of the orientation of solvent molecules around the free ions and around pairs; E_s/kT is the difference in energy between solvent-ion and solvent ion pairs.

Sadek and Hafez studied the variation of log K_Λ with 1/D for S-n-alkyl-isothiouronium bromides in dioxan -water [6b] and for S-n-alkylisothiouronium iodides in methanol- water [3]. Hafez studied $[Ni(en)_3]X_2$ and $[Cu(en)_2]X_2$ in dioxan -water [2a]. They obtained minima in all cases at small proportions of dioxan or methanol. This unexpected behaviour was attributed not so much to changes in D, but to the modifications produced in the solvent structure by adding small amounts of the organic solvent to water. In this case, the organic solvent depolymerizes the water aggregates, hence the sharing of water in stabilizing the formed ion-pair is decreased. Further addition of organic solvent does not cause any sudden modification in water structure but D decreases. So structure and K_Λ increases as D decreases.

Fig.3 shows that Walden product for any complex passes through a maximum value in the order $[Co(en)_3]X_2$ > $[Ni(en)_3]X_2$ > $[Cu(en)_2]X_2$ [X = Cl, Br or I]. The existence of the maximum in Walden product can be explained on the basis of hydrophobic dehydration [14,15] of cations due to the presence of co-solvent (MeOH) in the water rich region. After the maximum in Walden product, cations and anions are solvated by the co-solvent MeOH which has a smaller dielectric constant. Accordingly, ion-solvent interaction increased and hence $\Lambda_o\eta$ decreases.

Hafez et al [2a] showed that Walden product of cations $[Ni(en)_3]^{2+}$ and $[Cu(en)_2]^{2+}$ in water - dioxan media has indefinite trend while in case of Cl^- and I^- anions, maxima were obtained approximately at 10 to 15 wt% of dioxan respectively. This variation was attributed to the variation of solvent structure as well as variation of ionic solvation.

It can be seen from Table 5 that the derived values of $\lambda_o^{Cl^-}$ and $\lambda_o^{Br^-}$ in pure methanol and water are in good agreement with those obtained by other methods [8,16]. This observation indicates the precision of the conductnace results obtained in this study.

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