

Electrical Conductivity of Concentrated Aqueous Mixtures of HCl and KCl in a Wide Range of Compositions and Temperatures

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The electrical conductivity of the HCl + KCl + H₂O ternary system has been measured in a wide range of compositions ($0 \text{ mol}\cdot\text{dm}^{-3} < c_{\text{HCl}} < 6 \text{ mol}\cdot\text{dm}^{-3}$ and $0 \text{ mol}\cdot\text{dm}^{-3} < c_{\text{KCl}} < 1.2 \text{ mol}\cdot\text{dm}^{-3}$) and temperatures ($15 \text{ }^\circ\text{C} < t < 45 \text{ }^\circ\text{C}$) making use of an automated station for conductometric titration based on the “electrodeless conductivity” technique. The experimental data obtained have been fitted to a polynomial in the HCl molar concentration, the KCl molar concentration, and the temperature. As a result, an empirical model enabling the interpolation of the conductivity of the chemical system under study within the limits of the variables investigated has been proposed.

Introduction

Electrical conductivity is one of the transport properties more frequently requested by chemists and engineers dealing with electrolyte solutions (Lobo, 1986). Electrochemists have often used the very accurate conductivity data which can be obtained from diluted systems to gain insight into the structure of electrolyte solutions. In engineering applications, conductivity is mainly used in process control and design (Schuppan, 1984). It has also been applied to monitor the purity of solvents, to develop high-energy batteries (Barthel et al., 1983), and as an analytical detector after chromatographic separation techniques (Fritz et al., 1980; Okada and Kuwamoto, 1984; Wieisiolek and Bachmaa, 1994; Okada, 1995). In all these fields, the dependence of conductivity on concentration is of importance.

Considerable information on conductivity data in diluted solutions can be found in bibliographies, probably due to the fact that extremely accurate data can be obtained using very simple instrumentation. The measurement of high conductivities ($\kappa \geq 200 \text{ mS}\cdot\text{cm}^{-1}$) usually gives rise to polarization of the electrodes and, consequently, to not so accurate data. This may be the reason for the scarcity of bibliographic conductivity data corresponding to concentrated electrolyte solutions. The situation is even worse if we refer to mixed concentrated electrolytes. Only a few systems, for example, KCl + NaCl + H₂O, KBr + NaBr + H₂O, KI + NaI + H₂O (Stearn, 1922), MgCl₂ + HCl + H₂O (Berecz and Báder, 1973), NaCl + MgCl₂ + H₂O (Bianchi et al., 1989), CdCl₂ + HCl + H₂O (Török and Berecz, 1989), H₂SiF₆ + HF + H₂O (de Diego et al., 1997a), have been investigated.

The development of the “electrodeless conductivity” technique (Relis, 1947, 1951) eliminated the problem of polarization of the electrodes and provided an excellent method for measuring high conductivities in industrial environments (Foxboro, 1977; Shaw and Light, 1982; Stock, 1984) and laboratory conditions (de Diego, 1996; de Diego et al., 1994, 1997b).

The HCl + KCl + H₂O system is of considerable importance in the fluoride-derivative manufacturing in-

dustry, since it is frequently involved in the preparation of solid salts such as KBF₄ and K₂TiF₆ via precipitation processes. These compounds are manufactured by reaction of HBF₄ or H₂SiF₆ with an excess of KCl. The composition of the resulting saturated KCl + HCl aqueous mixture changes as the reaction takes place. The control of such processes via conductivity measurements is possible if the electrical behavior of the chemical system is previously available in the composition and temperature ranges of interest.

In process control and design, the use of mathematical models to interpolate properties such as conductivity in the widest possible range of chemical and physical conditions is very frequent. Empirical models such as the Casteel–Amis equation (Casteel and Amis, 1972) or polynomials in concentration and/or temperature (Sears and Dawson, 1968; Fedotov and Maksimova, 1971; Surova and Zhdanov, 1973; Maksimova and Sergeev, 1974; Valyashko and Ivanov, 1974 a,b) have been attempted to explain the conductivity behavior of chemical systems of variable origin.

In this work, the measurement of the electrical conductivity of the HCl + KCl + H₂O ternary system over nearly the whole dissolved part of the phase diagram ($0 < c_{\text{HCl}} < 6 \text{ mol}\cdot\text{dm}^{-3}$; $0 < c_{\text{KCl}} < 1.2 \text{ mol}\cdot\text{dm}^{-3}$) at four temperatures (15, 25, 35, and 45) °C is described. In addition, an empirical model enabling the interpolation of the electrical conductivity of the system within the limits of the conditions investigated is also proposed.

Experimental Section

Materials and Reagents. The measurement of the electrical conductivity was performed with an automated conductometric titration station fully controlled by the CONDUCTO program (Cazallas, 1997). Both the experimental setup and the controlling software have been developed in our laboratory. A full description of the system can be found elsewhere (de Diego et al., 1994; Cazallas et al., 1995), and it will be briefly summarized here. A Polymetron Monec 8921 conductimeter, making use of the electrodeless conductivity technique, and a Crison MicroBu 2031 autoburet are directly connected to a personal com-

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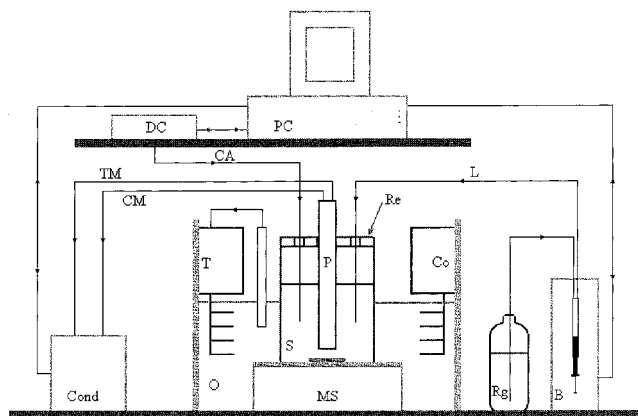


Figure 1. Scheme of the automated station for conductometric titration: DC, DC generator; PC, personal computer; Re, reactor; T, thermostat; Co, cooler; P, probe; S, solution; Cond, conductimeter; O, oil bath; MS, submersible magnetic stirrer; Rg, reagent; B, buret; CA, Coulometric additions; TM, temperature measurement; L, addition of liquid reagents; CM, conductivity measurement.

puter by RS-232-C interfaces. A Teflon-made reactor with four narrow entrances, allowing the introduction of different elements such as buret tips or thermometers, and another specific wider one for a Polymetron 8332 conductivity probe are immersed in a paraffin bath thermostated (± 0.1 °C) at the working temperature. The reactor is placed on the surface of an immersible magnetic stirrer. The experimental setup is schematically presented in Figure 1. CONDUCTO takes care of the monitorization of both conductivity and temperature, checks for chemical and thermal stabilization of the system, orders the addition of titrants to the reactor vessel, controls the steps of the titration throughout the experimentation, and stores data of interest in a file, everything according to a previously defined INPUT.

The experimental system was calibrated following the procedure described elsewhere (de Diego et al., 1996b). In a first step, experimental (κ , $100\omega_{\text{HCl}}$, t) data ($0 < 100\omega_{\text{HCl}} < 38.93$) at three temperatures, 15, 25, and 35 °C (Haase et al., 1965), were fitted to a fourth-grade polynomial in the HCl concentration, whose adjustable parameters linearly depend on the temperature (eq 1):

$$\kappa = \sum_{i=1}^4 (a_{i0} + a_{i1}t)c_1^i \quad i = 4 \quad (1)$$

The average relative standard deviation of the best fit was found to be 0.41%. In a second step, the conductivity of HCl solutions of known concentration was measured at known temperature with the system described above and the experimental conductivity was plotted against the corresponding values estimated using the model, eq 1. The calibration factor of the measuring system was calculated as the slope of the straight line obtained. HCl was selected in this alternative calibration methodology because (i) HCl solutions present very high values of conductivity ($\kappa_{\text{max}} \approx 850 \text{ mS}\cdot\text{cm}^{-1}$ at 25 °C), (ii) HCl is a relatively cheap and easy-to-handle reactive, (iii) high-quality HCl solutions are commercially available, (iv) further purification of commercial HCl solutions is easily attempted by well established procedures such as sub-boiling distillation (Mattison, 1972), and (v) fast analysis procedures are available to accurately determine the exact concentration of HCl solutions (Jeffery et al., 1989).

Table 1. Concentration of the Initial (HCl + KCl) Mixtures

mixture no.	$c_{\text{HCl}}/\text{mol}\cdot\text{dm}^{-3}$	$c_{\text{KCl}}/\text{mol}\cdot\text{dm}^{-3}$
1	6.0	7.50×10^{-2}
2	6.0	1.25×10^{-1}
3	6.0	2.50×10^{-1}
4	6.0	3.00×10^{-1}
5	4.8	4.50×10^{-1}
6	3.6	6.00×10^{-1}
7	2.4	9.00×10^{-1}
8	1.2	12.0×10^{-1}

Stock solutions of KCl ($\approx 1.2 \text{ mol}\cdot\text{dm}^{-3}$) and HCl ($\approx 6 \text{ mol}\cdot\text{dm}^{-3}$) were prepared by dissolving, respectively, the appropriate amounts of KCl (Merck, p.a.) and HCl (Fluka, p.a., $\geq 36.5\%$) in MilliQ water (Millipore water purification system, with $\kappa < 0.05 \mu\text{S}\cdot\text{cm}^{-1}$). The exact concentration of the KCl stock solution was determined by gravimetric analysis after reduction to dryness of a known volume. The HCl stock solution was analyzed by acid–base titration using Na_2CO_3 as the primary standard and methyl orange as the indicator.

All the glassware was thoroughly washed with tap water, immersed in a 10% HNO_3 bath overnight, again washed with tap water, and finally rinsed with MilliQ water before use.

Fitting of experimental data to mathematical models was carried out making use of NLREG (Sherrod, 1995), a nonlinear regression program which minimizes the sum of the squared absolute errors between calculated and experimental data.

Experimental Procedure. The experimentation was designed as a series of conductometric titrations. The term “conductometric titration” is not used here in its classical meaning. It is used to describe a process in which known volumes of a solution of known composition (“titrant”) are added to a known volume of another solution of known composition (“solution to be titrated”). After each addition, and not before chemical and thermal stabilization, the electrical conductivity of the system is measured. For the sake of brevity we will use the term “conductometric titration” when referring to the process described above.

Initial (HCl + KCl) mixtures were prepared by mixing appropriate volumes of stock HCl and KCl solutions. The exact composition of the eight initial mixtures is shown in Table 1. KCl solutions with the same KCl concentration as that of the initial mixtures were also prepared by appropriate dilution of the stock KCl solution. Three different conductometric titrations were performed per each initial mixture and temperature. In the first one, 300 mL of the initial (HCl + KCl) mixture was titrated with six additions (30 mL each) of the corresponding KCl solution (same concentration as that of the mixture). The resulting solution (300 mL) was again titrated using the same titrant solution, number of additions, and addition volume as those in the previous titration. The third titration consisted of the addition of six portions (30 mL each) of initial mixture onto 300 mL of the corresponding KCl solution. In this way 168 (8 mixtures \times 3 titration/mixture \times 7 composition/titration) different (HCl + KCl) compositions (constant KCl concentration and varying HCl concentration) were checked for their electrical conductivity at four different temperatures, (15, 25, 35, and 45) °C. The composition range covered in this study is provided in Figure 2. The range was selected in order to check the widest possible soluble area in the phase diagram of the HCl + KCl + H_2O system. The experimental procedure followed is schematized in Figure 3.

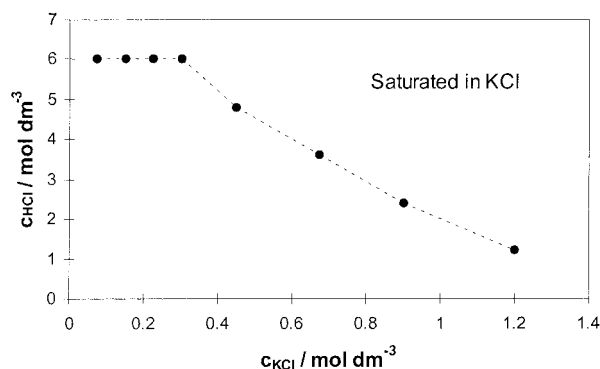


Figure 2. Composition of the initial (HCl + KCl) mixtures (black points). The surface below the dashed line approximately shows the applicability range of the model proposed to estimate the electrical conductivity of the chemical system.

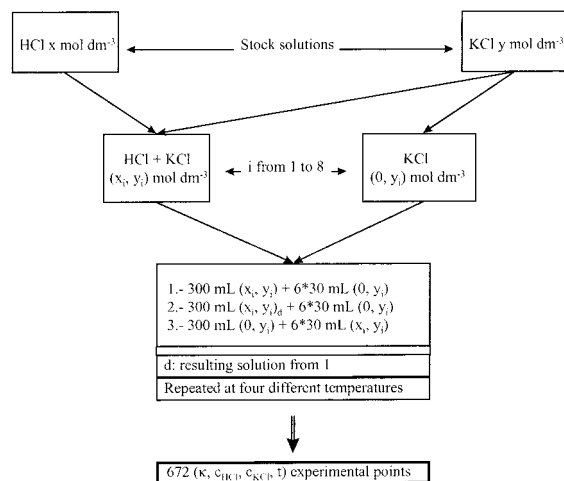


Figure 3. Scheme of the experimental procedure followed to generate conductivity data.

The same procedure was repeated in each titration: after cleaning and drying all the elements of the experimental setup, the Teflon-made titration vessel was located on the surface of the magnetic stirrer in the paraffin bath thermostated at the working temperature, and the measuring probe was inserted into the vessel through the corresponding hole. After thermal stabilization, the Pt100 included in the conductivity probe was calibrated against an external precalibrated thermometer and the zero measurement of conductivity was corrected. The solution to be titrated (300 mL) was added to the vessel. Both the conductivity and the temperature of the solution inside the vessel were monitored by means of CONTIE (Cazallas, 1997), a program written in QUICKBASIC. After chemical (constant κ) and thermal (constant t) stabilization of the system, the corresponding conductometric titration was automatically performed according to the parameters previously defined in the input file of CONDUCTO.

After each addition of titrant solution, 2 h elapsed before the first measurement of temperature. Temperature is then measured after every 5 min until the criterion for thermal stabilization of the system (working temperature ± 0.3 °C) was fulfilled. The program starts then to check the conductivity of the solution every 5 min. When the standard deviation of the last three conductivities is $<0.2\%$ of the mean, both the conductivity and the temperature are stored in a file and the next addition of titrant is ordered to the automatic buret. The solution inside the vessel is magnetically stirred throughout the conductometric titration.

Results and Data Treatment

As a result of the experimentation performed, a representative set of 672 (κ , c_{HCl} , c_{KCl} , t) data was obtained, covering all the composition range checked at four different temperatures. This data set has been fitted to an empirical mathematical model enabling the interpolation of conductivities within the limits of the investigated composition and temperature range.

Development of the Mathematical Model To Fit the Data. The procedure to develop the general model used in the data-fitting process was as follows: polynomials in the concentration have been frequently used to fit (κ , c) data of a single electrolyte solution at a fixed temperature (Fedotov and Maksimova, 1971; Maksimova and Sergeev, 1974):

$$\kappa_t = \sum_{i=0}^i a_i c_1^i \quad (2)$$

The effect of the temperature can be included in eq 2 by considering a linear relationship of the adjustable parameters a_i with the temperature:

$$\kappa = \sum_{i=0}^i (a_{i0} + a_{i1} t) c_1^i \quad (3)$$

A model derived from eq 3 has already been successfully applied to fit (κ , c , t) data of single-electrolyte aqueous solutions such as HBF_4 , H_2SiF_6 , and H_2TiF_6 (de Diego, 1996; de Diego et al., 1997b,c).

If it is assumed that, in general, the effect of a second electrolyte may be taken into account by considering a polynomial relationship of the adjustable parameters in eq 3, a_{i0} and a_{i1} , with the concentration of the second electrolyte, the following equation can be written:

$$\kappa = \sum_{i=0}^i \left[\sum_{j=0}^j (a_{ij0} + a_{ij1} t) c_2^j \right] c_1^i \quad (4)$$

The conductivity data of the ternary system $\text{H}_2\text{SiF}_6 + \text{HF} + \text{H}_2\text{O}$ have been recently fitted to an empirical model obtained by simplification of eq 4 (de Diego et al., 1997a).

Taking into account the round conditions of the chemical system to be investigated in this paper, the model can be simplified by previously fixing the values of several adjustable parameters. Thus, a_{000} and a_{001} parameters are null if the conductivity of MilliQ water is assumed to be negligible. The model should reduce to eq 3 when the concentration of KCl is zero or, in other words, when considering the HCl + H_2O binary system. The best fit of (κ , c_{HCl} , t) bibliographic data (Haase et al., 1965) to eq 3 leads to a fourth-grade polynomial in the concentration of HCl ($i = 4$) with the values of adjustable parameters (a_{100} , a_{101} , a_{200} , a_{201} , a_{300} , a_{301} , a_{400} , a_{401}) shown in Table 2. The assumption of these parameters as constants in the model to explain the variability of the (κ , c_{HCl} , c_{KCl} , t) experimental data set provides improved internal homogeneity to the model, since, as stated before, the experimental setup was calibrated using conductivity data of HCl solutions from Haase et al. (1965) as reference.

In the same way, when the concentration of HCl is zero, when the KCl + H_2O system is considered, eq 4 reduces to

$$\kappa = \sum_{j=0}^j (a_{j0} + a_{j1} t) c_2^j \quad (5)$$

Table 2. Set of Adjustable Parameters of Eq 4 Which Best Fits the (κ , c_{HCl} , c_{KCl} , t) Experimental Data, Together with Some Statistical Parameters of the Fit

parameter	value	method of estimation
a_{000}	0	by considering negligible the conductivity of water
a_{001}	0	
a_{100}	247.22 ± 0.83	
a_{101}	5.618 ± 0.029	
a_{200}	-37.84 ± 0.43	by fitting (κ , c_{HCl} , t) bibliographic data (Haase, 1965)
a_{201}	-0.903 ± 0.015	
a_{300}	2.317 ± 0.063	
a_{301}	0.0565 ± 0.0022	
a_{400}	-0.0535 ± 0.0028	
a_{401}	-0.00128 ± 0.00010	
a_{010}	63.8 ± 2.5	
a_{011}	2.444 ± 0.082	
a_{020}	-4.1 ± 3.9	by fitting (κ , c_{KCl} , t) bibliographic data (Isono, 1980)
a_{021}	-0.51 ± 0.13	
a_{030}	1.9 ± 1.9	
a_{031}	0.109 ± 0.063	
a_{040}	-0.34 ± 0.27	
a_{041}	-0.0119 ± 0.0092	
a_{110}	398 ± 24	
a_{111}	-15.92 ± 0.89	
a_{120}	-729 ± 54	
a_{121}	26.0 ± 1.9	
a_{130}	321 ± 29	
a_{131}	-11.8 ± 1.0	
a_{140}	0	by fitting the (κ , c_{HCl} , c_{KCl} , t) experimental data set
a_{141}	0	
a_{210}	-108.0 ± 9.5	
a_{211}	4.24 ± 0.36	
a_{220}	98 ± 11	
a_{221}	-4.40 ± 0.43	
a_{230}	0	
a_{231}	0.84 ± 0.15	
a_{240}	0	
a_{241}	0	
a_{310}	8.54 ± 0.90	
a_{311}	-0.338 ± 0.034	
a_{320} , a_{321} , a_{330} , a_{331} , a_{340} , a_{341} , a_{410} , a_{411} , a_{420} , a_{421} , a_{430} , a_{431} , a_{440} , a_{441}	0	
avg deviation ($\Delta\kappa_{\text{av}}$)	$4.34 \text{ mS}\cdot\text{cm}^{-1}$	
explained variance	99.94%	

Bibliographic (κ , c_{KCl} , t) data (Isono, 1984) were fitted to eq 5. The best result yielded a fourth-grade polynomial in the concentration of KCl ($j = 4$) with the values of adjustable parameters (a_{010} , a_{011} , a_{020} , a_{021} , a_{030} , a_{031} , a_{040} , a_{041}) shown in Table 2.

Thus, the experimental (κ , c_{HCl} , c_{KCl} , t) data set was consequently fitted to eq 4 with $i = 4$ and $j = 4$ and the parameters corresponding to the single solutions set constant at the values shown in Table 2.

Procedure to Fit Experimental Data. The whole (κ , c_{HCl} , c_{KCl} , t) data set was fitted to eq 4 ($i = 4$; $j = 4$) in a first step. Those points showing a residual value ($\Delta\kappa = |\kappa_{\text{exp}} - \kappa_{\text{calc}}|$) higher than three times the average deviation of the whole fit ($\Delta\kappa_{\text{av}} = |\kappa_{\text{exp}} - \kappa_{\text{calc}}|/N$; $N =$ amount of data) were considered as outliers and consequently removed from the data set. Outliers were removed one by one. When the criterion for outlier detection was fulfilled by the remaining data, the adjustable parameter in eq 4 with the highest probability to be zero (highest t parameter, $t = \sigma(a_{ijk})/a_{ijk}$) was removed from the model and the whole data set was again fitted to the new modified model. The process was repeated until all the adjustable parameters in the model showed a similar probability to be nonzero ($t \leq 0.0001$) and the residuals ($\Delta\kappa$) of all the experimental points considered were within the acceptable interval ($\Delta\kappa \leq 3\Delta\kappa_{\text{av}}$). These conditions were obtained after removing 19 adjustable parameters from the model. The set of parameters which best fits the remaining experimental data is provided in Table 2 together with several statistical parameters show-

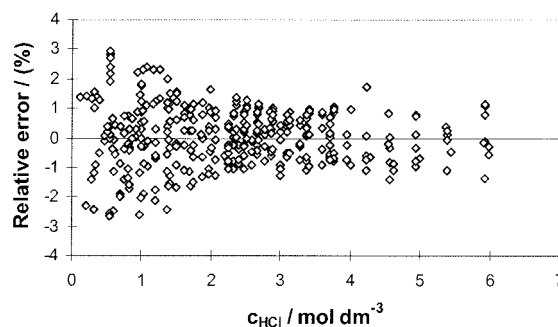


Figure 4. Relative errors ($\Delta\kappa/\kappa_{\text{exp}} \times 100$) of the experimental points used in the estimation of the adjustable parameters of the proposed model.

ing the quality of the fit. The residual values between experimental and calculated conductivities are plotted in Figure 4 as a function of the HCl molar concentration.

Interpolation of Conductivity Using the Proposed Model. The proposed model (eq 4 with the values of parameters shown in Table 2) has been used to interpolate the conductivity corresponding to the ternary system HCl + KCl + H₂O in the range of concentrations ($0 < c_{\text{HCl}} < 6 \text{ mol}\cdot\text{dm}^{-3}$ and $0 < c_{\text{KCl}} < 1.2 \text{ mol}\cdot\text{dm}^{-3}$) and temperature ($15^\circ\text{C} < t < 45^\circ\text{C}$) investigated. The accuracy of the estimate is always $>2\%$ in the $0.5 < c_{\text{HCl}} < 6 \text{ mol}\cdot\text{dm}^{-3}$ and $0.2 < c_{\text{KCl}} < 1.2 \text{ mol}\cdot\text{dm}^{-3}$ concentration ranges. Below those concentrations the error in the estimate is expected to be slightly higher. This effect is due to the fact that the

Table 3. Electrical Conductivities of the HCl + KCl + H₂O Ternary System at Round Compositions Calculated by the Proposed Model (Eq 4 + Table 2) for $t = 15\text{ }^\circ\text{C}$

$c_{\text{HCl}}/$ (mol·dm ⁻³)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)
0.0	0.15	14.8	0.30	29.2	0.60	56.7	0.90	83.1	1.20	108.7
0.5	0.15	175.1	0.30	190.6	0.60	209	0.90	222	1.20	242
1.0	0.15	309	0.30	324	0.60	334	0.90	338	1.20	362
1.5	0.15	420	0.30	434	0.60	435	0.90	435		
2.0	0.15	510	0.30	521	0.60	515	0.90	518		
2.5	0.15	582	0.30	589	0.60	577	0.90	590		
3.0	0.15	638	0.30	641	0.60	627				
3.5	0.15	679	0.30	680	0.60	666				
4.0	0.15	708	0.30	706	0.60	698				
4.5	0.15	728	0.30	724						
5.0	0.15	739	0.30	735						
5.5	0.15	744	0.30	742						
6.0	0.15	744	0.30	746						

Table 4. Electrical Conductivities of the HCl + KCl + H₂O Ternary System at Round Compositions Calculated by the Proposed Model (Eq 4 + Table 2) at $t = 25\text{ }^\circ\text{C}$

$c_{\text{HCl}}/$ (mol·dm ⁻³)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)
0.0	0.15	18.4	0.30	36.1	0.60	69.8	0.90	101.7	1.20	132.3
0.5	0.15	196.6	0.30	212	0.60	237	0.90	259	1.20	281
1.0	0.15	347	0.30	359	0.60	377	0.90	391	1.20	411
1.5	0.15	472	0.30	482	0.60	491	0.90	501		
2.0	0.15	575	0.30	581	0.60	583	0.90	590		
2.5	0.15	658	0.30	660	0.60	654	0.90	661		
3.0	0.15	722	0.30	721	0.60	707				
3.5	0.15	771	0.30	765	0.60	744				
4.0	0.15	805	0.30	795	0.60	767				
4.5	0.15	828	0.30	813						
5.0	0.15	840	0.30	820						
5.5	0.15	843	0.30	818						
6.0	0.15	839	0.30	809						

Table 5. Electrical Conductivities of the HCl + KCl + H₂O Ternary System at Round Compositions Calculated by the Proposed Model (Eq 4 + Table 2) at $t = 35\text{ }^\circ\text{C}$

$c_{\text{HCl}}/$ (mol·dm ⁻³)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)
0.0	0.15	21.9	0.30	43.0	0.60	82.8	0.90	120.3	1.20	155.9
0.5	0.15	218	0.30	233	0.60	265	0.90	296	1.20	320
1.0	0.15	385	0.30	394	0.60	420	0.90	445	1.20	460
1.5	0.15	525	0.30	530	0.60	548	0.90	566		
2.0	0.15	640	0.30	641	0.60	651	0.90	662		
2.5	0.15	733	0.30	731	0.60	730	0.90	731		
3.0	0.15	807	0.30	800	0.60	787				
3.5	0.15	862	0.30	850	0.60	822				
4.0	0.15	902	0.30	884	0.60	836				
4.5	0.15	928	0.30	902						
5.0	0.15	941	0.30	905						
5.5	0.15	942	0.30	895						
6.0	0.15	934	0.30	873						

Table 6. Electrical Conductivities of the HCl + KCl + H₂O Ternary System at Round Compositions Calculated by the Proposed Model (Eq 4 + Table 2) at $t = 45\text{ }^\circ\text{C}$

$c_{\text{HCl}}/$ (mol·dm ⁻³)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)	$c_{\text{KCl}}/$ (mol·dm ⁻³)	$\kappa/$ (mS·cm ⁻¹)
0.0	0.15	25.5	0.30	49.9	0.60	95.9	0.90	138.9	1.20	179.5
0.5	0.15	240	0.30	254	0.60	293	0.90	333	1.20	360
1.0	0.15	422	0.30	429	0.60	462	0.90	498	1.20	509
1.5	0.15	577	0.30	578	0.60	604	0.90	632		
2.0	0.15	705	0.30	702	0.60	719	0.90	733		
2.5	0.15	809	0.30	801	0.60	807	0.90	802		
3.0	0.15	891	0.30	879	0.60	867				
3.5	0.15	954	0.30	936	0.60	901				
4.0	0.15	999	0.30	973	0.60	906				
4.5	0.15	1028	0.30	990						
5.0	0.15	1041	0.30	990						
5.5	0.15	1042	0.30	972						
6.0	0.15	1030	0.30	936						

fit of the data has been performed minimizing the sum of the squares of the absolute errors, not those of the relative

ones. As a result, worse accuracy is necessarily obtained at lower values of conductivities.

Tables 3–6 summarize the proposed conductivity of HCl + KCl aqueous solutions at round concentrations calculated at four different selected temperatures.

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