# Electrical Conductivity of Sodium Chloride and Potassium Chloride in Water Soluble Polymers at Different Temperatures

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**ABSTRACT**
The ionic conductivities of sodium chloride (NaCl) and potassium chloride (KCl) in water soluble polymer systems (aqueous polyvinyl alcohol and aqueous polyacrylamide) of 0.1, 0.5 and 1.0 g.dL$^{-1}$ were measured in various concentrations ($2 \times 10^{-3}$ to $10 \times 10^{-3}$ mol.dm$^{-3}$) and at different temperatures ranges from 298 to 318 K with interval of 5 K. The conductivity data were analyzed by various equations to evaluate limiting molar conductance ($\Lambda_m^\circ$), degree of dissociation ($\alpha$), dissociation constant ($K_d$), and energy of activation ($E_a$). The data obtained from conductometric studies used to investigate the ion-solvent interaction and ion-ion interactions of electrolytes in aqueous polymer system. Increased in the value of limiting molar conductance ($\Lambda_m^\circ$) with the increase in composition of solvents, showing strong solvent-solvent interaction. Thermodynamic parameters for dissociation processes such as free energy change of activation ($\Delta G^*$), enthalpy change of activation ($\Delta H^*$) and entropy change of activation ($\Delta S^*$) were also calculated.

**Keywords:** Molar conductance, Ionic interactions, Electrolytes, Polyvinylalcohol.

## 1. INTRODUCTION

Water-soluble polymers are showing their practical importance as viscosity-enhancing agents, flocculating agents, as well as food additives, etc[1]. Polyvinyl alcohol (PVOH) and polyacrylamide (PAM) are chiefly popular because of their low cost. The interactions of PAM with other synthetic water soluble polymers have also been studied[2]. Polyvinyl alcohol and polyacrylamide both are important synthetic polymers. PVOH a polyhydroxy polymer contains vinyl group as a monomer while PAM derived from acrylamide monomer. Because of their high stability over wide pH intervals as well as simplicity and widespread applications both PVOH and PAM become today the medium of choice in various processes[3]. PVOH is resistant to oil, grease and some solvents. These properties have led to its wide industrial use, in such areas as membrane, textile sizing and finishing, adhesive, coatings and paints[4]. An important use of polyvinyl alcohol is as the plastic interlayer for automotive and aircraft. PAM and its copolymers are used as coagulants and flocculants in waste and potable water treatment applications, as displacing fluids in the enhanced oil recovery (EOR), drag reduction agents (DRAs) in water and crude oil transportation pipelines, polymeric additive in water-based drilling fluids, and as water clarifier in industries such as mining and paper making[5,6].

The interaction of salts with solvents is used to study the solvent property like structural behavior of water. It is important to investigate the polymers and their interaction with the electrolytes in solution form. Realizing this important aspect, some researchers[7-12] has reported the solution properties of water soluble polymers. Conductometric studies of different electrolytes in aqueous[13,14], nonaqueous[15-19] and mixed solvent systems have been reported[20,21] in literature.

Transport properties have been observed in macromolecules, including electrical conductivity, dielectric permittivity and relaxation. A comparison of these transport properties in polymer-water

solutions can help to elucidate the effects of hydration on the transport properties[22]. Saeed et al.[23,24] worked on the ionic interaction of electrolytes ($ZnSO_4$. $7H_2O$ and KCl) in dilute solution of polyvinyl alcohol conductometrically and viscometrically respectively. It was found that association of polyvinyl alcohol is stronger with water as compared to solvent interaction with ion. Interaction of polyvinyl alcohol with various organic solvents at different temperatures was also discussed[25].

The effect of NaCl on the viscous flow of polyvinyl alcohol from dilute to extreme dilute concentration was discussed by Yang et al.[26]. The intermolecular H-bonding in extremely dilute aqueous polyvinyl alcohol solution was investigated by Liu et al.[27]. Ahmed et al.[28] evaluated the activation parameters of polyvinyl alcohol at different temperatures. Durrani and coworkers[29] studied the different solution properties like viscosity, conductance, surface tension and light scattering of polyethylene oxide dissolved in water, in the absence as well as presence of some salts (LiCl, NaCl and KCl). Ma et al.[30] studied nonionic (PBAM3) and ionic (PBAMS) hydrophobically associating polyacrylamide with and without the addition of NaCl.

Mixed water-organic solvents are a subject of very intensive investigation. The purpose of this work is to study the behavior of electrolyte in a different solvent medium for conductometric study like aqueous polymer systems. It is important to investigate the polymers and their interactions with the electrolytes in solution.

## 2. EXPERIMENTAL

Polyvinyl alcohol (E. Merck, average Mol. Wt = 72000 Da) and polyacrylamide (BDH, average Mol. Wt = 5,000,000 Da), sodium chloride (NaCl, Mol. Wt. = 58.44 $g.mol^{-1}$) and potassium chloride (KCl, Mol. Wt. = 74.55 $g.mol^{-1}$) were used without further purification. Structural formula of polyvinyl alcohol and polyacrylamide are shown in Fig. 1 and 2 respectively:
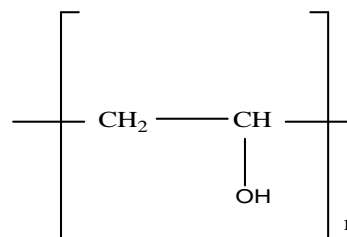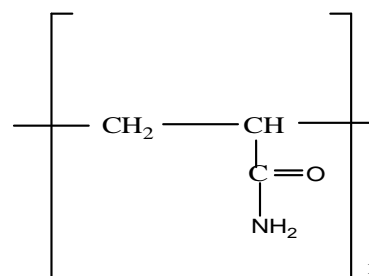


**Fig. 1: Structural formula of polyvinyl alcohol**



**Fig. 2: Structural formula of polyacrylamide**

All the weighing was done by an analytical balance, Model BL-150S, Sartorius having least count of ±0.001 g. Different compositions (0.1, 0.5 and 1.0 $g.dL^{-1}$) of aqueous polyvinyl alcohol (PVOH) were prepared in a known volume of hot (353±1K) deionized water. The solutions were constantly stirred by magnetic stirrer with hot plate 78HW-1 (made in Czechoslovakia) to make the solutions homogenized, resultant solutions were then cooled to room temperature and the volume was made up to the mark with deionized water. Aqueous polyacrylamide (PAM) of different compositions 0.1 0.5 and 1.0 g. $dL^{-1}$ were also prepared. Primary stock solutions of 0.01 $mol.dm^{-3}$ of sodium chloride (NaCl) and potassium chloride (KCl) were prepared by dissolving calculated amounts in aqueous polyvinyl alcohol and aqueous polyacrylamide (0.1, 0.5 and 1.0 $g.dL^{-1}$). Different solutions of the electrolytes (NaCl and KCl), ranging in concentration from $2\times10^{-3}$ to $8\times10^{-3}$±0.001 $mol.dm^{-3}$ were prepared from the primary stock solution. Conductivities were measured at various temperatures (298, 303, 308, 313 and 318 K) by a digital direct reading conductivity meter (Jenway 4510) having uncertainty of ±0.5 %, connected with a dip type probe having

cell constant of 0.99 cm$^{-1}$. The temperatures of desired level were attained and kept constant with the help of a thermostatic water bath, (Circulator Model YCM-01, made in Taiwan R.O.C).

An Ostwald viscometer type (Techniconomial constant 0.05 Cs.s$^{-1}$, capillary ASTMAD 445, made in England) was used to measure the viscosity. A relative density bottle (R.D bottle) having capacity 10.0 ml by volume was used. The densities of different compositions of aqueous polyvinyl alcohol and aqueous polyacrylamide (0.1, 0.3, 0.5, 0.7 and 0.9 g.dL$^{-1}$) solutions were measured at 303 K by the help of R.D bottle. The uncertainty in the experimental data for density was found to be ±0.0001 g.mL$^{-1}$.

For viscosity measurement viscometer was fixed vertically with clamp in a glass tube present in thermostatic bath having a constant circulation of water. A definite volume of solvent (aqueous polyvinyl alcohol and aqueous polyacrylamide i.e. 0.1, 0.3, 0.5, 0.7 and 0.9 g.dL$^{-1}$) under examination was taken into the viscometer kept for 15 to 20 minutes at 303 K in a water bath to attain the required temperature. Through a mouth suction rubber tube the solvent was drawn up into the upper bulb and time required for its meniscus to fall between the calibration marks was accurately measured. Each measurement was taken at least three times to attain the reliability in the results. The uncertainty in the experimental data for viscosity was found to be ±0.002 mPa.s.

## 3. RESULTS AND DISCUSSION

Conductivities (*L*) of various concentrations of electrolytes e.g., NaCl and KCl, ranging in concentration from $2 \times 10^{-3}$ to $10 \times 10^{-3}$ mol.dm$^{-3}$ in 0.1, 0.5 and 1.0 g.dL$^{-1}$ aqueous polyvinyl alcohol (PVOH) and aqueous polyacrylamide (PAM) at temperatures 298, 303, 308, 313, and 318 K were tabulated in Tables 1 and 2 respectively. These values were used to compute the molar conductance ($\Lambda_m$), reported in Tables 3 and 4.

$$\Lambda_m = \frac{1000L}{C} \quad (1)$$

where, $\Lambda_m$ is the molar coductance and *C* is the concentration of salt (NaCl and KCl). Results show that potassium chloride (KCl) has higher conducting capability than sodium chloride (NaCl) in both aqueous polyvinyl alcohol and aqueous polyacrylamide systems; this is due to the degree of solvation which is higher in sodium chloride (NaCl) than potassium chloride (KCl). The increase in molar conductance with temperature shows high mobility of ions of electrolytes, which is due to the reason that viscosity of the solvent (aqueous polymer solution) decreases with the rise of temperature, which enables the ions to move freely towards the electrodes. The tabulated results also show a decreasing pattern of molar conductance with the increase of concentration for sodium chloride (NaCl) and potassium chloride (KCl) in aqueous polyvinyl alcohol (PVOH) and aqueous polyacrylamide (PAM), as at low concentrations, ions are far part and hence inter ionic attraction is not as high as it would be in the case of solutions in which concentration of electrolyte is higher. This inter ionic forces are responsible for the retardation of movement of ions which actually causes molar conductance to descend as the concentration of the electrolyte increases. A direct relation of molar conductance with the increasing concentration of the aqueous polymer is also observed. Results tabulated in Table 3 and 4 also show an increase in molar conductance with the increase in concentration of aqueous PVOH and aqueous PAM. The solvent effects conductance primarily, through its viscosity, hydrogen bonding capability, dielectric constant, and its specific interaction with ions. The viscosity of the solvent actually resists the motions of ions and dielectric constant controls the effective field strength.

Ostwald dilution law was also employed to obtain molar conductance at infinite dilution.

$$\Lambda_m = \Lambda_m^\circ - [\mathrm{A} + \mathrm{B}\Lambda_m^\circ]C^{1/2} \quad (2)$$

where, $\Lambda_m^\circ$ is the molar conductance at infinite dilution. The result of molar conductance at infinite dilution ($\Lambda_m^\circ$) for

NaCl and KCl in aqueous PVOH and aqueous PAM tabulated in Table 5, have been calculated from the intercept of linear regression plot of $\Lambda_m$ and $C^{1/2}$, representative plot is shown in Fig. 3. Molar conductance at infinite dilution has been regarded as a measure of solute-solvent interaction, greater the magnitude of molar conductance at infinite dilution, the lesser would be the solute-solute interaction. In view of the fact that in the state of infinite dilution, the mobility of an ion is limited exclusively by its interaction with surrounding solvent molecules, there are no other ions with in a finite distance. The results show that molar conductance at infinite dilution increased with the increase in composition of solvent, which shows that polymer interaction increased with the increase in concentration of solvent through H-bonding between water molecules with hydroxyl group or carbonyl group which decreased the solvation around ions in aqueous PVOH and in aqueous PAM systems. The data is in good comparison with the literature values of limiting molar conductance reported for NaCl and KCl in aqueous medium 126.59 and 149.95 $S.cm^2.mol^{-1}$ respectively by Boruń et. al.[21].

Results show that molar conductance data for particular electrolyte (NaCl and KCl) in aqueous PAM was higher than aqueous PVOH.

**NaCl aqueous PVOH < NaCl aqueous PAM**
**KCl aqueous PVOH < KCl aqueous PAM**

Higher value of molar conductance for NaCl and KCl in aqueous PAM as compare to aqueous PVOH is due to structural differences between these two polymers as shown in Fig. 1 and 2. PAM has two hydrogen atoms on the amino group of each repeat unit, while PVOH has only single hydrogen atom in the form of hydroxyl group. Due to difference in primary structure which is responsible for different solubility and conformation in water. In aqueous medium, polymer chain forms intramolecular hydrogen bonding through hydrogen atoms of amino groups and the oxygen atoms in carboxyl groups. Tanaka et al.[31] reported hydrogen-

bonding-stabilized conformation of PAM in water was not the regular helical structure but the normal one.

As shown in Fig. 4, intramolecular hydrogen bonding in polyvinyl alcohol via a six-membered ring.
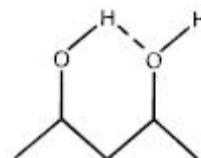


**Fig. 4: Repeating units in polyvinyl alcohol demonstrating the capability to form intramolecular hydrogen bonds**

Therefore it was observed that higher value of molar conductance for NaCl and KCl in aqueous PAM as compare to aqueous PVOH as PAM form strong H-bonding with water molecules allows the ions to migrate freely. Another reason for this difference in value of molar conductance for NaCl and KCl is that polymer chain becomes stiffer when larger substituent groups (as hydroxyl groupin PVOH) exist and the internal steric effects of polymer chain will affect the whole properties of polymers. Three types of hydrogen bonding were observed by Tanaka et al.[31] in $D_2O$ system as shown in Fig. 5.
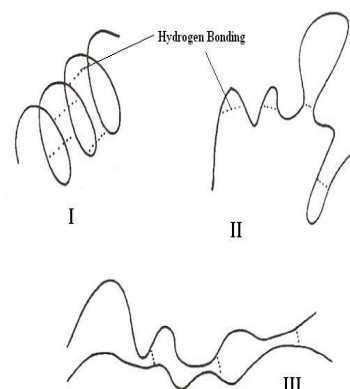


**Fig. 5: Schematic diagram showing three types of hydrogen bonding expected in $D_2O$ solution of polyacrylamide: (I) intramolecular hydrogen bonding in the helical structure; (II) intramolecular hydrogen bonding in extended segments; (III) intermolecular hydrogen bonding**

In aqueous polyvinyl alcohol, the hydroxyl group becomes ready acceptor for hydrogen bonding, not only increased its interaction with the water molecules but also allows the polyvinyl alcohol molecules to interact slightly with each other, such that at higher concentrations, a polyvinyl alcohol solution becomes slightly viscous. The polymer matrix surrounding the water molecule is firmly held together by hydrogen bonds and that the jump of the water molecule from one place to another requires breakage of hydrogen bonds. The long life of the polymer-polymer hydrogen bonds must be a major factor that retards the jump rate. This behavior of aqueous PVOH may also be responsible for lower values of conductivity of NaCl and KCl as compare to in aqueous PAM systems.

The values of degree of dissociation (α) and dissociation constant were tabulated in Table 6, show the inverse relation of temperature with the degree of dissociation. Values of degree of dissociation for NaCl and KCl in aqueous PVOH were higher than aqueous PAM which also confirms the higher value of conductance.

It was also found that the values of degree of dissociation for sodium chloride (NaCl) were greater than for potassium chloride (KCl).

This variation represents the electrostatic ion-solvent interaction in aqueous polymer systems. The smaller the ion, the strongest is the electrostatic interaction, and hence greater is the size of solvation. Therefore solvation size of NaCl is greater than KCl which also confirms its low value of conductivity as degree of dissociation of NaCl is higher than KCl. With the increase in concentration of solvent, the values of dielectric constant decreased resulted decrease in degree of dissociation.

A state of equilibrium between ionized and unionized molecule in solution explained in terms of dissociation constant ($K_d$).

$$K_d = \frac{\alpha^2 C}{(1-\alpha)} \quad (3)$$

where, α is the degree of dissociation and ( 1- α ) is the remaining fraction of an electrolyte in undissociated form. The values of dissociation constant for sodium chloride (NaCl) and potassium chloride (KCl) are also tabulated in Table 6. Results show that with the increase of solvents' composition and temperature, decreasing values of dissociation constant with same variation was observed. The variation of dissociation constant with composition of the solvent was due to the selective solvation of the ions with the solvent. It is also observed that in most cases the dissociation constant has followed a decreasing trend with the increase in concentration of the electrolyte. This is because of inter ionic attraction between ions increased with the increase in concentration of the electrolyte, favoring ion association phenomenon.

Since the conductance of an ion depends on its rate of movement, it seems reasonably to treat conductance in a manner analogous to that employed for other processes taking place at a defined rate which increases with temperature. The activation energy was determined by using the relation between conductance and temperature.

$$\log \Lambda_m^0 = \log A - \frac{E_a}{2.303RT} \quad (4)$$

where, R is the molar gas constant, $E_a$ is the energy of activation, which determines the rate of movement of ions, A is the frequence factor, and T is the absolute temperature. The results of energy of activation ($E_a$) for sodium chloride (NaCl) and potassium chloride (KCl) tabulated in Table 7 have been calculated from the slope of plots between $\log \Lambda_m^0$ and $1/T$, as shown in Fig. 6. The results show the descending pattern of energy of activation with the increase in the composition of the polymer solvent, it is due to the rate of movement of ions which was low in the solutions in which concentration of aqueous polymer system (solvent) was lower than the solutions in which solvent's concentration were of higher degree. Results tabulated in Table 7, show higher values of $E_a$ for NaCl and KCl in aqueous PVOH as compare to in aqueous PAM

system and also higher values were observed for NaCl than KCl . The increase in values of activation energy of the transfer process indicates more energy consumed for transfer process. This increase in values of activation energy is due to viscosity, dielectric constant and increase in association process of electrolytes. This increase in value of $E_a$ for NaCl and KCl in aqueous PVOH system as compare to aqueous PAM also confirms conductivity data, because increased in the value of energy of activation led to the decrease in the value of $\Lambda_m^{\circ}$.

With the help of free energy change, it is possible to predict whether the reaction will proceed spontaneously or not. Free energy change of activation for dissociation process is represented by a symbol "$\Delta G^*$" and can be calculated by using the relation:

$$\Delta G^* = -2.303\, RT \log K_d \quad (5)$$

The results tabulated in Table 8, show the values of free energy change of activation are positive which indicate the endothermic nature of the electrolytes, i.e., sodium chloride (NaCl) and potassium chloride (KCl), in polymer systems.

The positive values of $\Delta G^*$ show the lower stability of the electrolytes in solvent media which also indicate that the dissociation processes in aqueous polymer solvent system were nonspontaneous. Higher value of $\Delta G^*$ for NaCl and KCl was observed in aqueous PAM system as compared to aqueous PVOH solvent system. It was also observed that the free energy change of activation of electrolytes increased with the rise in temperature for aqueous polymer system show endothermic nature. The enthalpy change of activation for dissociation "$\Delta H^{*}$" is calculated by plotting log $K_d$ as a function of 1/ T, representative plot is shown in Fig. 7. Entropy change of activation ($\Delta S^*$) was calculated by the relation.

$$\Delta S^* = \frac{\Delta H^* - \Delta G^*}{T} \quad (6)$$

Entropy is significantly connected with the solvent structure perturbation brought about by the disordered ions. Entropy change of activation was reported in Table 9. The increased in values of entropy change of activation with the rise in temperature showed that randomness increased. The higher value of $\Delta S^*$ was observed for aqueous PAM as compare to aqueous PVOH system indicate that by the addition of the NaCl and KCl the structure of PAM disturb more strongly than aqueous PVOH.

## 4.  CONCLUSIONS

On the basis of obtained results, it is concluded that, potassium chloride (KCl) showed more conducting capability than sodium chloride (NaCl) also in aqueous polymer system as in aqueous medium. Conducting capability for NaCl and KCl in aqueous PAM is higher than in aqueous PVOH due to difference in hydrogen bonding. Thermodynamic parameters also confirmed same behavior in aqueous polymer solvent systems.

**Table 1: Conductivity ($L$) of NaCl and KCl in aqueous Polyvinyl alcohol systems at different temperatures**

| $10^3$ [Salt] (mol dm$^{-3}$) | $L$ (mS cm$^{-1}$) at temperatures (K) | | | | |
|---|---|---|---|---|---|
| | 298 | 303 | 308 | 313 | 318 |
| **NaCl** | | | | | |
| **0.1  (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 0.25 | 0.26 | 0.29 | 0.31 | 0.33 |
| 4.0 | 0.45 | 0.47 | 0.50 | 0.52 | 0.53 |
| 6.0 | 0.66 | 0.70 | 0.73 | 0.74 | 0.76 |
| 8.0 | 0.87 | 0.90 | 0.92 | 0.95 | 0.96 |
| 10 | 1.06 | 1.08 | 1.11 | 1.14 | 1.16 |
| **0.5 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 0.29 | 0.31 | 0.32 | 0.35 | 0.37 |
| 4.0 | 0.49 | 0.50 | 0.52 | 0.55 | 0.57 |
| 6.0 | 0.71 | 0.73 | 0.74 | 0.76 | 0.78 |
| 8.0 | 0.89 | 0.90 | 0.92 | 0.95 | 0.97 |
| 10 | 1.10 | 1.12 | 1.14 | 1.17 | 1.20 |
| **1.0  (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 0.34 | 0.36 | 0.38 | 0.41 | 0.43 |
| 4.0 | 0.54 | 0.57 | 0.60 | 0.62 | 0.63 |
| 6.0 | 0.75 | 0.77 | 0.78 | 0.80 | 0.83 |
| 8.0 | 0.95 | 0.96 | 0.98 | 1.01 | 1.02 |
| 10 | 1.15 | 1.18 | 1.20 | 1.22 | 1.23 |
| **KCl** | | | | | |
| **0.1  (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 0.30 | 0.32 | 0.33 | 0.35 | 0.38 |
| 4.0 | 0.49 | 0.51 | 0.52 | 0.55 | 0.58 |
| 6.0 | 0.70 | 0.73 | 0.75 | 0.77 | 0.80 |
| 8.0 | 0.90 | 0.92 | 0.95 | 0.97 | 1.00 |
| 10 | 1.12 | 1.14 | 1.16 | 1.17 | 1.20 |
| **0.5 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 0.36 | 0.37 | 0.40 | 0.42 | 0.43 |
| 4.0 | 0.54 | 0.57 | 0.60 | 0.61 | 0.63 |
| 6.0 | 0.76 | 0.78 | 0.81 | 0.82 | 0.84 |
| 8.0 | 1.01 | 1.02 | 1.04 | 1.05 | 1.07 |
| 10 | 1.20 | 1.23 | 1.25 | 1.27 | 1.30 |
| **1.0 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 0.39 | 0.42 | 0.43 | 0.45 | 0.48 |
| 4.0 | 0.60 | 0.63 | 0.65 | 0.67 | 0.70 |
| 6.0 | 0.78 | 0.80 | 0.81 | 0.82 | 0.84 |
| 8.0 | 1.03 | 1.06 | 1.07 | 1.09 | 1.12 |
| 10 | 1.25 | 1.27 | 1.29 | 1.33 | 1.35 |

**Table 2:** **Conductivity ($L$) of NaCl and KCl in aqueous Polyacrylamide systems at different temperatures**

| $10^3$ [Salt] (mol dm$^{-3}$) | $L$ (mS cm$^{-1}$) at temperatures (K) | | | | |
|---|---|---|---|---|---|
| | 298 | 303 | 308 | 313 | 318 |
| **NaCl** | | | | | |
| **0.1 (g.dL$^{-1}$) Aqueous PAM System** | | | | | |
| 2.0 | 0.35 | 0.37 | 0.38 | 0.39 | 0.42 |
| 4.0 | 0.58 | 0.61 | 0.63 | 0.64 | 0.67 |
| 6.0 | 0.80 | 0.82 | 0.85 | 0.86 | 0.88 |
| 8.0 | 1.01 | 1.04 | 1.06 | 1.07 | 1.10 |
| 10 | 1.21 | 1.23 | 1.24 | 1.25 | 1.27 |
| **0.5 (g.dL$^{-1}$) Aqueous PAM System** | | | | | |
| 2.0 | 0.40 | 0.41 | 0.43 | 0.44 | 0.46 |
| 4.0 | 0.63 | 0.65 | 0.66 | 0.67 | 0.69 |
| 6.0 | 0.90 | 0.91 | 0.92 | 0.94 | 0.95 |
| 8.0 | 1.16 | 1.18 | 1.19 | 1.20 | 1.23 |
| 10 | 1.40 | 1.42 | 1.43 | 1.45 | 1.48 |
| **1.0 (g.dL$^{-1}$) Aqueous PAM System** | | | | | |
| 2.0 | 0.44 | 0.46 | 0.48 | 0.49 | 0.50 |
| 4.0 | 0.72 | 0.74 | 0.76 | 0.77 | 0.80 |
| 6.0 | 0.95 | 0.97 | 0.98 | 1.01 | 1.02 |
| 8.0 | 1.21 | 1.23 | 1.24 | 1.25 | 1.27 |
| 10 | 1.48 | 1.51 | 1.52 | 1.54 | 1.56 |
| **KCl** | | | | | |
| **0.1 (g.dL$^{-1}$) Aqueous PAM System** | | | | | |
| 2.0 | 0.39 | 0.42 | 0.45 | 0.48 | 0.52 |
| 4.0 | 0.60 | 0.63 | 0.65 | 0.66 | 0.76 |
| 6.0 | 0.83 | 0.86 | 0.88 | 0.89 | 1.00 |
| 8.0 | 1.05 | 1.08 | 1.10 | 1.27 | 1.29 |
| 10 | 1.30 | 1.32 | 1.33 | 1.50 | 1.52 |
| **0.5 (g.dL$^{-1}$) Aqueous PAM System** | | | | | |
| 2.0 | 0.45 | 0.48 | 0.49 | 0.51 | 0.52 |
| 4.0 | 0.69 | 0.71 | 0.73 | 0.74 | 0.76 |
| 6.0 | 0.92 | 0.95 | 0.97 | 0.98 | 1.00 |
| 8.0 | 1.19 | 1.21 | 1.24 | 1.27 | 1.29 |
| 10 | 1.46 | 1.48 | 1.49 | 1.50 | 1.52 |
| **1.0 (g.dL$^{-1}$) Aqueous PAM System** | | | | | |
| 2.0 | 0.47 | 0.48 | 0.51 | 0.54 | 0.56 |
| 4.0 | 0.76 | 0.79 | 0.82 | 0.82 | 0.83 |
| 6.0 | 0.99 | 1.01 | 1.04 | 1.04 | 1.06 |
| 8.0 | 1.25 | 1.27 | 1.30 | 1.30 | 1.31 |
| 10 | 1.50 | 1.54 | 1.57 | 1.58 | 1.60 |

**Table 3:   Molar Conductance ($\Lambda_m$) of NaCl and KCl in aqueous Polyvinyl alcohol systems at different temperatures**

| $10^3$ [Salt] (mol dm$^{-3}$) | $\Lambda_m$ (S cm$^2$ mol$^{-1}$) at temperatures (K) | | | | |
|---|---|---|---|---|---|
| | 298 | 303 | 308 | 313 | 318 |
| **NaCl** | | | | | |
| 0.1     (g.dL$^{-1}$) Aqueous PVOH System | | | | | |
| 2.0 | 125 | 130 | 145 | 155 | 165 |
| 4.0 | 112 | 118 | 125 | 130 | 132 |
| 6.0 | 110 | 117 | 121 | 123 | 127 |
| 8.0 | 109 | 112 | 115 | 119 | 120 |
| 10 | 106 | 108 | 111 | 114 | 116 |
| 0.5 (g.dL$^{-1}$) Aqueous PVOH System | | | | | |
| 2.0 | 145 | 155 | 160 | 175 | 185 |
| 4.0 | 122 | 125 | 130 | 138 | 142 |
| 6.0 | 118 | 122 | 123 | 127 | 130 |
| 8.0 | 111 | 112 | 115 | 119 | 121 |
| 10 | 110 | 112 | 114 | 117 | 120 |
| 1.0 (g.dL$^{-1}$) Aqueous PVOH System | | | | | |
| 2.0 | 170 | 180 | 190 | 205 | 215 |
| 4.0 | 135 | 142 | 150 | 155 | 157 |
| 6.0 | 125 | 128 | 130 | 133 | 138 |
| 8.0 | 119 | 120 | 125 | 126 | 128 |
| 10 | 115 | 118 | 120 | 122 | 123 |
| **KCl** | | | | | |
| 0.1 (g.dL$^{-1}$) Aqueous PVOH System | | | | | |
| 2.0 | 150 | 160 | 165 | 175 | 190 |
| 4.0 | 122 | 128 | 130 | 138 | 145 |
| 6.0 | 117 | 122 | 125 | 128 | 133 |
| 8.0 | 112 | 115 | 119 | 121 | 125 |
| 10 | 112 | 114 | 116 | 117 | 120 |
| 0.5 (g.dL$^{-1}$) Aqueous PVOH System | | | | | |
| 2.0 | 180 | 185 | 200 | 210 | 215 |
| 4.0 | 135 | 142 | 150 | 152 | 157 |
| 6.0 | 127 | 130 | 135 | 137 | 140 |
| 8.0 | 126 | 128 | 130 | 131 | 134 |
| 10 | 120 | 123 | 125 | 127 | 130 |
| 1.0 (g.dL$^{-1}$) Aqueous PVOH System | | | | | |
| 2.0 | 195 | 210 | 215 | 225 | 240 |
| 4.0 | 150 | 158 | 162 | 168 | 175 |
| 6.0 | 130 | 133 | 135 | 137 | 140 |
| 8.0 | 129 | 132 | 134 | 136 | 140 |
| 10 | 125 | 127 | 129 | 133 | 135 |

**Table 4:   Molar Conductance ($\Lambda_m$) of NaCl and KCl in aqueous Polyacrylamide systems at different temperatures**

| $10^3$ [Salt] (mol dm$^{-3}$) | $\Lambda_m$ (S cm$^2$ mol$^{-1}$) at temperatures (K) | | | | |
|---|---|---|---|---|---|
| | 298 | 303 | 308 | 313 | 318 |
| **NaCl** | | | | | |
| **0.1 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 175 | 185 | 190 | 195 | 210 |
| 4.0 | 145 | 152 | 158 | 160 | 168 |
| 6.0 | 133 | 137 | 142 | 143 | 147 |
| 8.0 | 126 | 130 | 132 | 134 | 138 |
| 10 | 121 | 123 | 124 | 126 | 127 |
| **0.5 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 200 | 205 | 215 | 220 | 230 |
| 4.0 | 158 | 162 | 165 | 168 | 172 |
| 6.0 | 150 | 152 | 153 | 157 | 158 |
| 8.0 | 145 | 148 | 149 | 150 | 154 |
| 10 | 140 | 142 | 143 | 145 | 148 |
| **1.0 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 220 | 230 | 240 | 245 | 250 |
| 4.0 | 180 | 185 | 190 | 192 | 200 |
| 6.0 | 158 | 162 | 163 | 168 | 170 |
| 8.0 | 151 | 154 | 155 | 156 | 159 |
| 10 | 148 | 151 | 152 | 154 | 156 |
| **KCl** | | | | | |
| **0.1 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 195 | 210 | 225 | 240 | 245 |
| 4.0 | 150 | 158 | 162 | 165 | 172 |
| 6.0 | 138 | 143 | 147 | 148 | 155 |
| 8.0 | 131 | 135 | 137 | 138 | 142 |
| 10 | 130 | 132 | 133 | 134 | 137 |
| **0.5 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 225 | 240 | 245 | 255 | 260 |
| 4.0 | 172 | 178 | 182 | 185 | 190 |
| 6.0 | 153 | 158 | 162 | 163 | 167 |
| 8.0 | 149 | 151 | 155 | 159 | 161 |
| 10 | 146 | 148 | 149 | 150 | 152 |
| **1.0 (g.dL$^{-1}$) Aqueous PVOH System** | | | | | |
| 2.0 | 235 | 240 | 255 | 270 | 280 |
| 4.0 | 190 | 198 | 202 | 205 | 208 |
| 6.0 | 165 | 168 | 172 | 173 | 177 |
| 8.0 | 156 | 159 | 161 | 162 | 164 |
| 10 | 150 | 154 | 157 | 158 | 160 |

**Table 5:  Limiting molar conductance ($\Lambda_m^\circ$) for NaCl and KCl in aqueous polymer systems at different temperatures**

| Temperature (K) | $\Lambda_m^\circ$ (S.cm$^2$.mol$^{-1}$) in different solvent systems | | | | | |
|---|---|---|---|---|---|---|
| | **Aqueous PVOH Systems** | | | | | |
| | **0.1 (g.dL$^{-1}$)** | | **0.5 (g.dL$^{-1}$)** | | **1.0 (g.dL$^{-1}$)** | |
| | **NaCl** | **KCl** | **NaCl** | **KCl** | **NaCl** | **KCl** |
| **298** | 136.27 (±0.03) | 172.32 (±0.08) | 167.62 (±0.08) | 212.09 (±0.01) | 204.79 (±0.01) | 238.48 (±0.02) |
| **303** | 144.34 (±0.06) | 187.63 (±0.09) | 181.53 (±0.09) | 221.59 (±0.01) | 221.24 (±0.06) | 261.79 (±0.01) |
| **308** | 167.49 (±0.01) | 193.65 (±0.05) | 189.50 (±0.05) | 245.54 (±0.06) | 237.86 (±0.04) | 270.22 (±0.08) |
| **313** | 181.15 (±0.05) | 211.27 (±0.03) | 212.00 (±0.04) | 259.26 (±0.04) | 259.49 (±0.01) | 283.54 (±0.06) |
| **318** | 195.06 (±0.04) | 233.95 (±0.05) | 226.32 (±0.08) | 266.61 (±0.09) | 274.39 (±0.01) | 306.85 (±0.05) |
| | **Aqueous PAM Systems** | | | | | |
| | **0.1 (g.dL$^{-1}$)** | | **0.5 (g.dL$^{-1}$)** | | **1.0 (g.dL$^{-1}$)** | |
| | **NaCl** | **KCl** | **NaCl** | **KCl** | **NaCl** | **KCl** |
| **298** | 211.79 (±0.01) | 234.45 (±0.05) | 234.61 (±0.09) | 273.65 (±0.05) | 269.75 (±0.05) | 294.65 (±0.05) |
| **303** | 228.14 (±0.06) | 257.91 (±0.09) | 242.58 (±0.02) | 295.93 (±0.07) | 284.07 (±0.03) | 302.88 (±0.02) |
| **308** | 237.29 (±0.01) | 280.84 (±0.06) | 257.11 (±0.09) | 304.44 (±0.06) | 300.27 (±0.03) | 324.16 (±0.04) |
| **313** | 244.04 (±0.06) | 302.42 (±0.08) | 264.05 (±0.05) | 318.04 (±0.06) | 307.40 (±0.02) | 345.65 (±0.05) |
| **318** | 263.56 (±0.04) | 309.71 (±0.09) | 277.72 (±0.08) | 324.33 (±0.07) | 317.06 (±0.04) | 357.50 (±0.03) |

(±Standard deviations)

**Table 6:  Values of degree of dissociation (*α*), dissociation constant ($K_d$) and Walden product for 4x10$^{-3}$ mol.dm$^{-3}$ NaCl and KCl in different solvent systems at different temperatures**

| Temperature (K) | 10$^2$ *α* | 10$^4$ $K_d$ (mol dm$^{-3}$) |
|---|---|---|
| **NaCl** | | |
| **0.5 (g.dL$^{-1}$) Aqueous PVOH System** | | |
| 298 | 73.08 | 79.35 |
| 308 | 68.60 | 59.94 |
| 318 | 62.96 | 42.80 |
| **0.5 (g.dL$^{-1}$) Aqueous PAM System** | | |
| 298 | 67.13 | 54.84 |
| 308 | 64.17 | 45.96 |
| 318 | 62.11 | 40.72 |
| **KCl** | | |
| **0.5 (g.dL$^{-1}$) Aqueous PVOH System** | | |
| 298 | 63.65 | 44.58 |
| 308 | 61.09 | 38.36 |
| 318 | 59.08 | 34.12 |
| **0.5 (g.dL$^{-1}$) Aqueous PAM System** | | |
| 298 | 63.04 | 43.00 |
| 308 | 59.95 | 35.89 |
| 318 | 58.58 | 33.13 |

**Table 7: Energy of activation ($E_a$) for NaCl and KCl in different solvent systems**

| Solvent Systems (g.dL$^{-1}$) | 10 $E_a$ (kJ mol$^{-1}$) | |
|---|---|---|
| | Aqueous PVOH Systems | |
| | NaCl | KCl |
| 0.1 | 1.424 | 1.086 |
| 0.5 | 1.144 | 0.928 |
| 1.0 | 1.126 | 0.883 |
| | Aqueous PAM Systems | |
| | NaCl | KCl |
| 0.1 | 1.400 | 1.080 |
| 0.5 | 0.636 | 0.626 |
| 1.0 | 0.607 | 0.783 |

**Table 8: Free energy change of activation ($\Delta G^*$) for $4 \times 10^{-3}$ mol.dm$^{-3}$ NaCl and KCl in different solvent systems**

| Temperature (K) | 10 $\Delta G^*$ (kJ mol$^{-1}$) | |
|---|---|---|
| | 0.5 (g.dL$^{-1}$) Aqueous PVOH Systems | |
| | NaCl | KCl |
| 298 | 1.218 | 1.363 |
| 308 | 1.289 | 1.401 |
| 318 | 1.374 | 1.431 |
| | 0.5 (g.dL$^{-1}$) Aqueous PAM Systems | |
| | NaCl | KCl |
| 298 | 1.311 | 1.372 |
| 308 | 1.356 | 1.418 |
| 318 | 1.386 | 1.438 |

**Table 9: Entropy change of activation ($\Delta S^*$) for $4 \times 10^{-3}$ mol.dm$^{-3}$ NaCl and KCl in different solvent systems**

| Temperature (K) | 10 $\Delta S^*$ (kJ mol$^{-1}$K$^{-1}$) | |
|---|---|---|
| | 0.5 (g.dL$^{-1}$) Aqueous PVOH Systems | |
| | NaCl | KCl |
| 298 | 1.161 | 0.890 |
| 308 | 1.146 | 0.874 |
| 318 | 1.137 | 0.856 |
| | 0.5 (g.dL$^{-1}$) Aqueous PAM Systems | |
| | NaCl | KCl |
| 298 | 0.847 | 0.655 |
| 308 | 0.834 | 0.633 |
| 318 | 0.817 | 0.618 |

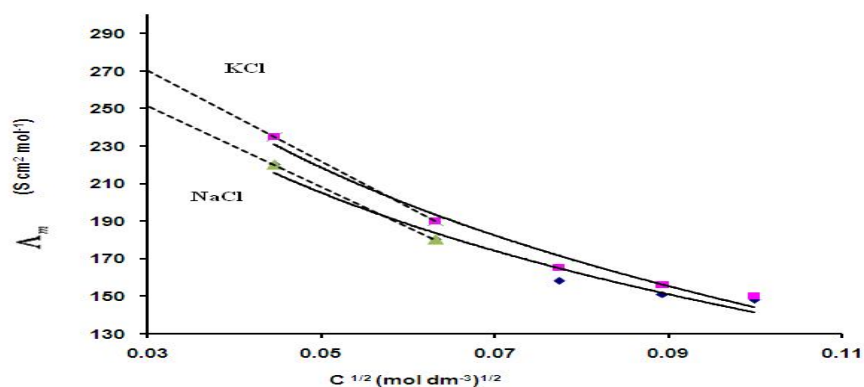**Fig. 3: Plots of $\Lambda_m$ vs $C^{1/2}$ for sodium chloride (NaCl) and potassium chloride (KCl) in 1.0 g.dL$^{-1}$ aqueous PAM at 298 K**

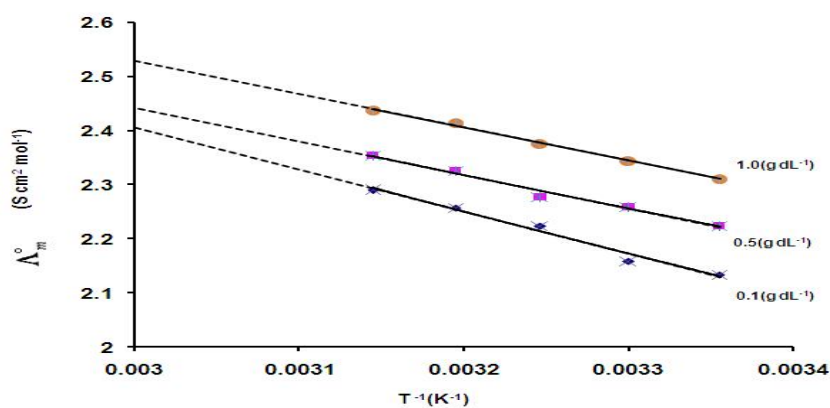

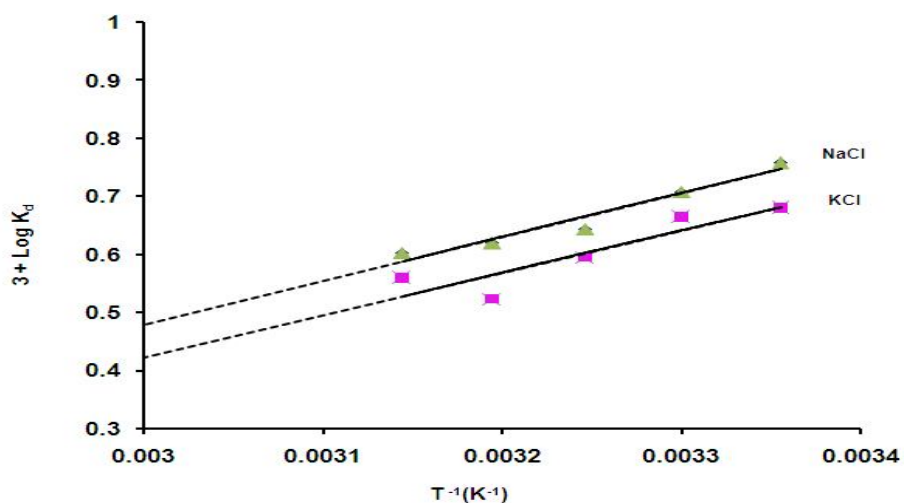**Fig. 6: Plots of log $\Lambda_m^o$ vs 1/ T for NaCl in 0.1, 0.5 and 1.0 g.dL$^{-1}$ aqueous PVOH**



**Fig. 7: Plot of log $K_d$ vs 1/ T for 8x10$^{-3}$ mol.dm$^{-3}$ NaCl and KCl in 1.0 g.dL$^{-1}$ aqueous PAM**

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