Molecular interactions analysis of some aluminium salts in binary aqueous solutions of tetrahydrofuran (THF): Acoustic and Conductometric approach

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Abstract: In the present investigation conductance and speed of sound of aluminium sulphate, aluminium nitrate, and aluminium chloride were experimentally determined in aqueous medium as well in binary aqueous mixtures of THF. Various conductance and acoustic parameters viz; molar conductance, limiting molar conductance, partial molar adiabatic compressibility, coefficient of adiabatic compressibility were also determined using Kohlrausch’s Law, Debye-Huckel theory and Masson’s equation at working temperatures and different compositions of THF. Analysis reveals that limiting molar conductivity ($\Lambda_m^0$) decreases with increase in composition of THF in water indicating the decrease in the ion-solvent interactions with increase in composition THF in water. Further it was found that with increase in temperature the $\Lambda_m^0$ values increase for all the three salts which support the increase in ion-solvent interactions with increase in temperature. The values of partial molar isentropic compression ($\phi_s^\text{iso}$) were found negative and these values further increase with increase in composition of THF indicating that on increase in composition, attractive interactions develop between THF and water which induces dehydration of aluminium salts which make the water molecules of aluminium salts more compressible than that of lower THF concentration resulting in decrease of ion solvent interactions with increase in THF composition in water. On the other hand with increase in temperature, the values of $\phi_s^\text{iso}$ further increase leading to increase in ion-solvent interactions of aluminium salts in water and 5% THF+ water. Walden product and its temperature coefficient i.e.$[d(\Lambda_m^0\eta_0)/dT]$ have also been calculated which confirms that aluminium salts act as structure breaker in different compositions of THF in water. 

Keywords: Partial molar compressibilities, limiting molar conductance, Walden product, structure breaker

Introduction: Physicochemical properties and conductivity measurements are used to interpret different types of interaction i.e. ion–ion, ion-solvent, proton-anion, proton-solvent interactions in aqueous solutions of aluminium salts as well in THF+H2O mixtures. These properties and measurements are very important in understanding various biochemical and physiological phenomenon in living cells [1].
In order to understand the behaviour of electrolyte solutions, studies on the thermodynamic and conductance properties of electrolytes in various solvent media are carried out which are proved very useful. For interpreting ion- ion and ion- solvent interactions, the mixed solvents [2] are taken which allows the variation of properties such as dielectric constant, conductance and viscosity. In the current study, an effort has been made to analyse the nature of ion–solvent and solvent-solvent interactions of aluminium salts viz; aluminium sulphate, aluminium nitrate, aluminium chloride in water as well as in tetrahydrofuran (THF) + water mixtures using conductometric studies as work has not been carried out on the above mentioned salts in the binary aqueous mixture of THF. Acoustic studies of electrolytic solutions is a subject of fundamental importance as these provide useful data about the nature of interactions in the solution. These studies have been carried out exclusively in aqueous solutions for the simple reason that water has favorable physical properties, such as a convenient liquid range, high dielectric constant, high dipole moment and high ionizing power for electrolytes [3-9].

**MATERIALS AND METHODS:**

**Reagents:** All the reagents viz; aluminium sulphate, aluminium nitrate, aluminium chloride and tetrahydrofuran [THF] used in the present study were of AR grade and procured from S.D Fine-Chem Limited. All the chemicals were dried over anhydrous CaCl₂ in a vacuum desiccator for more than 48 hours. Purity and method of purification of the chemicals used in the present work are given in table 1

| Chemical name       | Mass Fraction purity\# | Purification Method     |
|---------------------|-------------------------|-------------------------|
| Aluminium Sulphate  | >0.99                   | Vacuum drying           |
| Aluminium Nitrate   | >0.99                   | Vacuum drying           |
| Aluminium Chloride  | >0.99                   | Vacuum drying           |
| Tetrahydrofuran     | >0.99                   | Drying                  |

# As stated by supplier

The different compositions of THF-water and solutions of the electrolytes were prepared by weight. The molality (m) of electrolyte solution was then converted into molarity (c) by using the following expression [10].

\[
c = \frac{\text{molality} \times \text{density of solution}}{\text{molecular weight of electrolyte}}
\]

where, d is the density of electrolyte solution, and \(M_2\) is molecular weight of electrolyte. In the present study the conductivity meter was used to determine the conductance of the samples whereas the ultrasonic interferometer was used to find out the ultrasonic velocity in liquids for getting a high degree of accuracy.
The relationship between molar conductance ($A_m$) and specific conductance ($\kappa$) is given by [11-14]:

$$A_m = \frac{\kappa \times 1000}{N}$$  \hspace{1cm} (2)

Here, $N$ is the concentration (normality) of the solution.

The effect of temperature on conductance is given by [15]:

$$A_m = A_0 e^{-\frac{E_\lambda}{RT}}$$  \hspace{1cm} (3)

Here, $E_\lambda$ is the energy of activation for conduction, $R$ is the gas constant; $T$ is the temperature in Kelvin. The plot of $\log A_m$ and $1/T$ gives a straight line and from the plot, $E_\lambda$ can be determined by the slope of the straight line.

In case of acoustics properties [16-21], the partial molar isentropic compression ($\phi_{KS}$) and the apparent molar isentropic compression ($\phi_{KS}^0$) are determined by using:

$$\phi_{KS} = \frac{MK_s}{\rho} + \frac{1000(K_s \rho_0 - K_s^0 \rho)}{mp\rho_0}$$  \hspace{1cm} (4)

$$\phi_{KS}^0 = \phi_{KS} + S_K m$$  \hspace{1cm} (5)

where $m$ is the molal concentration of the solution, $M$ is the molar mass of the solute and $\rho_0, \rho, K_s$ and $K_s^0$ are the densities and coefficients of adiabatic compressibilities of the solvent and solution respectively.

The isentropic compressibility ($K_s$) is linked to speed of sound by:

$$K_s = \frac{1}{u^2 \rho}$$  \hspace{1cm} (6)

where $u$ is the speed of light and $\rho$ is the density of the solution.

**Results and Discussion:**

The specific conductance, molar conductance, limiting molar conductance and Walden product of all the salts are determined at 303.15K in water and different compositions of THF in water and values for aluminium sulphate are recorded in table 2 whereas the data for aluminium nitrate and aluminium chloride are given in supplementary data (table S1).

**Table 2. Conductance Parameters of Aluminium sulphate in water and different compositions of THF in water at 303.15K.**

| Concentration C X 10^2 (mol/L) | Specific Conductance $\kappa$ (Ω^(-1) cm^-1) | Molar Conductance $A_m$ (Ω^(-1) cm^2 mol^-1) | Limiting Molar Conductance $A_m^0$ (Ω^(-1) cm^2 mol^-1) | Walden product $A_m^0\eta_0$ (Ω^(-1) cm^2 mol^-1 cP) |
|-------------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| 0.298                         | 0.0010                                        | 335.5705                                      | 375.34                                          | 300.53                                      |
| 0.496                         | 0.0015                                        | 302.4194                                      |                                                 |                                              |
| 0.694                         | 0.0019                                        | 273.7752                                      |                                                 |                                              |
| 0.990                         | 0.0025                                        | 252.5253                                      |                                                 |                                              |
| 2.938                         | 0.0051                                        | 173.5875                                      |                                                 |                                              |
|       |       |       |       |
|-------|-------|-------|-------|
| 4.846 | 0.0073| 150.6397 |       |
| **5% THF+ Water** |       |       |       |
| 0.298 | 0.0006| 201.3423 |       |
| 0.496 | 0.0008| 181.4516 |       |
| 0.694 | 0.0012| 172.9107 |       |
| 0.990 | 0.0015| 151.5152 |       |
| 2.938 | 0.0041| 139.5507 |       |
| 4.846 | 0.0060| 123.8135 |       |
|       |       | 200.89 | 162.42|
| 0.298 | 0.0006| 200.6689 |       |
| 0.496 | 0.0008| 160.9658 |       |
| 0.694 | 0.0010| 143.8849 |       |
| 0.990 | 0.0013| 131.0489 |       |
| 2.938 | 0.0027| 91.71196|       |
| 4.846 | 0.0038| 78.25371|       |
|       |       | 210.36 | 171.80|
| 0.298 | 0.0004| 133.7793 |       |
| 0.496 | 0.0006| 120.7243 |       |
| 0.694 | 0.0007| 100.7149 |       |
| 0.990 | 0.0009| 90.72581 |       |
| 2.938 | 0.0022| 74.72861 |       |
| 4.846 | 0.0033| 67.95717 |       |
|       |       | 140.2  | 115.60|
| 0.298 | 0.0005| 167.2241 |       |
| 0.496 | 0.0006| 120.7243 |       |
| 0.694 | 0.0007| 100.7194 |       |
| 0.990 | 0.0009| 90.72581 |       |
| 2.938 | 0.0019| 64.53804 |       |
| 4.846 | 0.0027| 55.60132 |       |
FIG.1. Plot of Molar Conductance Vs square root of molar concentration for Aluminium sulphate in H2O and different compositions of THF in H2O at 303.15K

Limiting molar conductance ($\Lambda_m^0$) was obtained by plotting molar conductance ($\Lambda_m$) versus square root of concentration ($\sqrt{C}$) where intercept of the curve gives limiting molar conductance ($\Lambda_m^0$) and values of limiting molar conductance were found decreasing with increase in composition. This is because of the reason that the ionic mobility decrease with increase of THF composition in water. Limiting molar conductance ($\Lambda_m^0$) gives the information about ion-solvent interaction and these interactions were found decreasing with increase in composition of THF in water. Walden product ($\Lambda_m^0\eta_0$) has also been calculated and is helpful in determining the ion migration in solutions. It tells us about the contribution of the dielectric friction as well as the overall friction coefficient for moving ions. Using viscosity data from literature [9], the Walden Product values were calculated which were helpful in analysing the structure making/structure breaking capability of these salts. Temperature coefficient of Walden product can be calculated by plotting Walden Product against Temperature, and from the slope of the curve temperature coefficient of Walden product was calculated.

Table 3: Acoustic Parameters [Sound velocities (U), Coefficient of Adiabatic Compressibilities (Ks) and Apparent Molar Adiabatic Compressibilities ($\Phi_{KS}$), Partial Molar Adiabatic Compressibilities and their corresponding experimental Slopes] of Aluminium sulphate, Aluminium nitrate, Aluminium chloride in H2O and different compositions of THF in water At 303.15K.

| m (molKg⁻¹) | U (ms⁻¹) | $K_s \times 10^{10}$ (kg⁻¹ ms²) | $\Phi_{KS} \times 10^{15}$ (m³ mol⁻¹ GPa⁻¹) | $\Phi_{KS}^0$ (m³ mol⁻¹ GPa⁻¹) | $S_K^*$ (kg m³ mol⁻² GPa⁻¹) |
|-------------|--------|-------------------------------|---------------------------------|----------------------------|--------------------------|
| WATER       |        |                               |                                 |                            |                          |
| 5% THF      |        |                               |                                 |                            |                          |
| 10% THF     |        |                               |                                 |                            |                          |
| 15% THF     |        |                               |                                 |                            |                          |
| 20% THF     |        |                               |                                 |                            |                          |
|        | Aluminium Sulphate | Water | 5%THF+ Water |    | -43.79 | -5.86 | -43.29 | -6.57 | -43.16 | -6.57 | -42.44 | -5.93 | -42.51 | -5.93 |
|--------|--------------------|-------|--------------|----|--------|-------|--------|-------|--------|-------|--------|-------|--------|-------|
| 0.003  | 1510.05            | 4.409 |             | -43.76 |        |        |        |        |        |        |        |        |        |        |
| 0.005  | 1510.94            | 4.404 |             | -43.82 |        |        |        |        |        |        |        |        |        |        |
| 0.007  | 1511.23            | 4.398 |             | -43.85 |        |        |        |        |        |        |        |        |        |        |
| 0.01   | 1511.99            | 4.396 |             | -43.88 |        |        |        |        |        |        |        |        |        |        |
| 0.03   | 1513.29            | 4.390 |             | -43.98 |        |        |        |        |        |        |        |        |        |        |
| 0.05   | 1514.87            | 4.375 |             | -44.07 |        |        |        |        |        |        |        |        |        |        |
| 0.003  | 1518.12            | 4.374 |             | -43.26 |        |        |        |        |        |        |        |        |        |        |
| 0.005  | 1518.97            | 4.367 |             | -43.33 |        |        |        |        |        |        |        |        |        |        |
| 0.007  | 1519.65            | 4.362 |             | -43.36 |        |        |        |        |        |        |        |        |        |        |
| 0.01   | 1520.22            | 4.357 |             | -43.39 |        |        |        |        |        |        |        |        |        |        |
| 0.03   | 1520.95            | 4.353 |             | -43.50 |        |        |        |        |        |        |        |        |        |        |
| 0.05   | 1521.35            | 4.341 |             | -43.61 |        |        |        |        |        |        |        |        |        |        |
| 0.003  | 1507.05            | 4.440 |             | -43.13 |        |        |        |        |        |        |        |        |        |        |
| 0.005  | 1507.92            | 4.434 |             | -43.20 |        |        |        |        |        |        |        |        |        |        |
| 0.007  | 1508.81            | 4.428 |             | -43.23 |        |        |        |        |        |        |        |        |        |        |
| 0.01   | 1509.64            | 4.423 |             | -43.26 |        |        |        |        |        |        |        |        |        |        |
| 0.03   | 1510.85            | 4.407 |             | -43.37 |        |        |        |        |        |        |        |        |        |        |
| 0.05   | 1512.95            | 4.384 |             | -43.48 |        |        |        |        |        |        |        |        |        |        |
| 0.003  | 1673.99            | 3.607 |             | -42.42 |        |        |        |        |        |        |        |        |        |        |
| 0.005  | 1674.58            | 3.604 |             | -42.47 |        |        |        |        |        |        |        |        |        |        |
| 0.007  | 1675.09            | 3.602 |             | -42.50 |        |        |        |        |        |        |        |        |        |        |
| 0.01   | 1676.88            | 3.593 |             | -42.52 |        |        |        |        |        |        |        |        |        |        |
| 0.03   | 1677.33            | 3.585 |             | -42.62 |        |        |        |        |        |        |        |        |        |        |
| 0.05   | 1677.93            | 3.573 |             | -42.73 |        |        |        |        |        |        |        |        |        |        |
| 0.003  | 1720.00            | 3.427 |             | -42.50 |        |        |        |        |        |        |        |        |        |        |
| 0.005  | 1720.85            | 3.423 |             | -42.55 |        |        |        |        |        |        |        |        |        |        |
| 0.007  | 1721.45            | 3.420 |             | -42.58 |        |        |        |        |        |        |        |        |        |        |
| 0.01   | 1721.99            | 3.417 |             | -42.60 |        |        |        |        |        |        |        |        |        |        |
| 0.03   | 1722.68            | 3.409 |             | -42.70 |        |        |        |        |        |        |        |        |        |        |
| 0.05   | 1723.75            | 3.396 |             | -42.81 |        |        |        |        |        |        |        |        |        |        |
FIG. 2. Plot of Apparent Molar Isentropic Compressibility Vs Molality for Aluminium nitrate in H₂O and different compositions of THF in H₂O at 303.15K.

The sound velocity values are calculated using ultrasonic interferometer and in order to get the values of slope ($S_K'$) and partial molar isentropic compressibility ($\phi_{KS}^0$), values of apparent molar isentropic compressibility values are plotted against the molality ($m$). The obtained values of ($\phi_{KS}^0$) were found negative and reported for aluminium sulphate in table 3 (For other salts please refer supplementary table S2). These values further become less negative with increase in composition of THF in water which indicate that on increase in composition of THF in water, attractive interactions are developed between THF and water which induces dehydration of aluminium salts which make the water molecules of aluminium salts more compressible as compared to lower THF concentrations. These results ultimately lead to decrease in ion solvent interactions with increase in THF composition in water.

The specific conductance, molar conductance, limiting molar conductance, sound velocity, partial molar adiabatic compressibility of aluminium sulphate, aluminium nitrate and aluminium chloride were also determined at different temperatures i.e. 298.15K, 303.15K, 308.15K, 313.15K in water and 5% THF+ H₂O systems respectively. Specific conductance, molar conductivity, sound velocity, adiabatic compressibility of aluminium sulphate in water and 5% THF+ Water at different temperatures are reported in the table 4 where as for other salts values are given in supplementary table S3.
Table 4: Conductance Parameters and Walden Product of Aluminium Sulphate in H$_2$O and 5% THF + H$_2$O at different temperatures

| Concentration C X 10$^2$ (molL$^{-1}$) | Specific Conductance $\kappa$ (Ω$^{-1}$ cm$^{-1}$) | Molar Conductance $A_\infty$ (Ω$^{-1}$ cm$^2$ mol$^{-1}$) | Limiting Molar Conductance $A_0^0$ (Ω$^{-1}$ cm$^2$ mol$^{-1}$) | Walden product $A_\infty^0 \eta_0$ (Ω$^{-1}$ cm$^2$ mol$^{-1}$ cP) |
|-------------------------------------|------------------------------------------|-----------------------------|---------------------------------|-----------------------------|
| 298.15K                             |                                          |                             |                                 |                             |
| 0.298                               | 0.0009                                  | 301.0033                    | 343.80                          | 307.25                      |
| 0.496                               | 0.0014                                  | 281.6901                    |                                 |                             |
| 0.694                               | 0.0018                                  | 258.9928                    |                                 |                             |
| 0.990                               | 0.0023                                  | 231.8548                    |                                 |                             |
| 2.938                               | 0.0047                                  | 159.6467                    |                                 |                             |
| 4.846                               | 0.0069                                  | 142.0923                    |                                 |                             |
| 303.15K                             |                                          |                             |                                 |                             |
| 0.298                               | 0.001                                   | 335.5705                    | 375.34                          | 300.53                      |
| 0.496                               | 0.0015                                  | 302.4194                    |                                 |                             |
| 0.694                               | 0.0019                                  | 273.7752                    |                                 |                             |
| 0.990                               | 0.0025                                  | 252.5253                    |                                 |                             |
| 2.938                               | 0.0051                                  | 173.5875                    |                                 |                             |
| 4.846                               | 0.0073                                  | 150.6397                    |                                 |                             |
| 308.15K                             |                                          |                             |                                 |                             |
| 0.298                               | 0.0011                                  | 369.1275                    | 411.28                          | 297.15                      |
| 0.496                               | 0.0016                                  | 322.5806                    |                                 |                             |
| 0.694                               | 0.0021                                  | 303.0303                    |                                 |                             |
| 0.990                               | 0.0027                                  | 273.2794                    |                                 |                             |
| 2.938                               | 0.0055                                  | 187.5213                    |                                 |                             |
| 4.846                               | 0.0077                                  | 159.1238                    |                                 |                             |
| 313.15K                             |                                          |                             |                                 |                             |
| 0.298                               | 0.0012                                  | 404.0404                    | 444.8                           | 291.79                      |
| 0.496                               | 0.0017                                  | 343.4343                    |                                 |                             |
| 0.694                               | 0.0022                                  | 317.9191                    |                                 |                             |
| 0.990                               | 0.0029                                  | 293.8197                    |                                 |                             |
| 2.938                               | 0.0057                                  | 194.7386                    |                                 |                             |
| 4.846                               | 0.008                                   | 165.7001                    |                                 |                             |
| Temperature | Composition | Value 1 | Value 2 |
|-------------|-------------|---------|---------|
| 298.15K     | 5% THF+ Water | 0.298   | 0.0005  |
|             |              | 0.496   | 0.0008  |
|             |              | 0.694   | 0.0011  |
|             |              | 0.990   | 0.0014  |
|             |              | 2.938   | 0.0035  |
|             |              | 4.846   | 0.0055  |
|             |              |         | 167.2241|
|             |              |         | 160.9658|
|             |              |         | 158.2734|
|             |              |         | 141.1290|
|             |              |         | 118.8859|
|             |              |         | 113.2619|
| 303.15K     |              |         | 183.11  |
|             |              |         | 165.03  |
| 308.15K     |              |         | 200.89  |
|             |              |         | 162.42  |
| 313.15K     |              |         | 205.52  |
|             |              |         | 149.95  |
|             |              |         |         |
|             |              |         |         |
|             |              |         |         |
FIG. 3. Plot of Molar Conductance Vs ($\sqrt{C}$) for Aluminium sulphate in water at different temperatures
FIG.4. Plot of Molar Conductance vs ($\sqrt{c}$) for Aluminium chloride in 5% THF+ H₂O at different temperatures

Values of limiting molar conductance ($A_m^0$) are obtained by plotting graphs between molar conductance ($A_m$) versus square root of concentration ($\sqrt{c}$). Intercept of these curve give values of limiting molar conductance ($A_m^0$). The values of limiting molar conductance ($A_m^0$) increase with rise in temperature due to increase in ionic mobility with temperature. At infinite dilution, the motion of ions is retarded by its interaction with surrounding solvent molecules as there are no other ions within a finite distance. Values of limiting molar conductance ($A_m^0$) also give the information about ion-solvent interactions which are found further increasing with increase in temperature in this case.

Also, the Walden product ($A_m^0\eta_0$) data has been calculated which is helpful in determining the ion migration in solutions. When values of Walden product are plotted against the temperature, the temperature coefficient of Walden product i.e. slope was found negative. The negative values of temperature coefficient of Walden product confirms that the aluminium salts act as structure breaker in water as well as in 5% THF.

The activation energy of conductance ($E_\lambda$) are less than the activation energies obtained from the viscosity data $E_\eta$. The effect of temperature on viscosity is given by [22]:

$$\eta = Ae^{E_\eta/kT}$$  \hspace{1cm} (7)

The activation energy of conductance ($E_\lambda$) is calculated by plotting values of log($A_m$) and 1/T from equation (3) whereas ($E_\eta$) is obtained from the slope of linear plots of log $\eta$ versus 1/T using equation (7). The values of $E_\lambda$ and $E_\eta$ are given in table 5 for all the electrolytes in water:

**TABLE 5: Calculation of $E_\lambda$ (kJmol⁻¹) and $E_\eta$ (kJmol⁻¹) at different temperatures of all Aluminium Salts in water:**

| Concentration | $E_\lambda$ (kJ mol⁻¹) | $E_\eta$(kJ mol⁻¹) |
|---------------|------------------------|--------------------|
| **Aluminium Sulphate** | | |
| 0.003 | 15.20 | 16.85 |
| 0.005 | 10.23 | 16.80 |
| 0.007 | 11.12 | 17.03 |
| 0.01 | 12.26 | 17.23 |
| 0.03 | 10.47 | 17.72 |
| 0.05 | 8.01 | 17.63 |
| **Aluminium Chloride** | | |
| 0.003 | 12.43 | 16.52 |
| 0.005 | 9.17 | 16.85 |
| 0.007 | 8.12 | 17.08 |
| 0.01 | 7.18 | 17.03 |
The values of activation energy \((E_a)\) obtained from conductance is less than the activation energy of viscosity \((E_\eta)\) for all aluminium salts in water. It shows that activation energy obtained from the viscous flow for aluminium sulphate, aluminium nitrate and aluminium chloride is almost constant whereas activation energies obtained from conductance also do not follow a regular trend.

**TABLE 6: Acoustic Parameters of Aluminium Sulphate, Aluminium Nitrate, Aluminium Chloride in water and 5% THF at different temperatures.**

| \(M\) (molKg\(^{-1}\)) | \(U\) (ms\(^{-1}\)) | \(K_s \times 10^{10}\) (kg\(^{-1}\)ms\(^2\)) | \(\Phi_{KS} \times 10^{15}\) (m\(^3\)mol\(^{-1}\) GPa\(^{-1}\)) | \(\Phi_{KS}^0\) (m\(^3\)mol\(^{-1}\) GPa\(^{-1}\)) | \(S_k^*\) (kg m\(^3\)mol\(^{-2}\)GPa\(^{-1}\)) |
|------------------|------------------|------------------|------------------|------------------|------------------|
| **Aluminium Sulphate** | | | | | |
| **Water** | 298.15K | | | | |
| 0.003 | 1498.23 | 4.467 | -44.47 | -44.51 | -6.60 |
| 0.005 | 1499.12 | 4.461 | -44.54 |  | |
| 0.007 | 1499.69 | 4.457 | -44.57 | -44.51 | -6.60 |
| 0.01 | 1500.98 | 4.448 | -44.61 | -44.51 | -6.60 |
| 0.03 | 1501.9 | 4.434 | -44.72 | -44.51 | -6.60 |
| 0.05 | 1502.89 | 4.419 | -44.82 | -44.51 | -6.60 |
| **303.15K** | | | | | |
| 0.003 | 1510.05 | 4.409 | -43.76 | -43.79 | -5.86 |
| 0.005 | 1510.94 | 4.404 | -43.82 | -43.79 | -5.86 |
| 0.007 | 1511.23 | 4.398 | -43.85 | -43.79 | -5.86 |
| 0.01 | 1511.99 | 4.396 | -43.88 | -43.79 | -5.86 |
| 0.03 | 1513.29 | 4.390 | -43.98 | -43.79 | -5.86 |
| 0.05 | 1514.87 | 4.375 | -44.07 | -43.79 | -5.86 |
| Temperature  | Doping Concentration | 308.15K | 313.15K | 5% THF+ Water | 298.15K | 303.15K | 308.15K | 313.15K |
|-------------|----------------------|---------|---------|----------------|---------|---------|---------|---------|
| 308.15K     |                      |         |         | 0.003| 1520.63 | 4.354 | -43.14 | -43.18 | -5.94 |
| 308.15K     |                      |         |         | 0.005| 1521.82 | 4.350 | -43.21 |         |       |
| 308.15K     |                      |         |         | 0.007| 1521.97 | 4.342 | -43.24 |         |       |
| 308.15K     |                      |         |         | 0.01 | 1522.55 | 4.341 | -43.27 |         |       |
| 308.15K     |                      |         |         | 0.03 | 1523.66 | 4.336 | -43.37 |         |       |
| 308.15K     |                      |         |         | 0.05 | 1525.73 | 4.323 | -43.46 |         |       |
| 313.15K     |                      |         |         | 0.003| 1529.27 | 4.312 | -42.64 | -42.68 | -5.57 |
| 313.15K     |                      |         |         | 0.005| 1529.89 | 4.309 | -42.70 |         |       |
| 313.15K     |                      |         |         | 0.007| 1530.65 | 4.305 | -42.74 |         |       |
| 313.15K     |                      |         |         | 0.01 | 1531.05 | 4.300 | -42.77 |         |       |
| 313.15K     |                      |         |         | 0.03 | 1531.87 | 4.296 | -42.86 |         |       |
| 313.15K     |                      |         |         | 0.05 | 1532.61 | 4.286 | -42.94 |         |       |
| 5% THF+ Water | 298.15K         | 0.003   | 1511.73 | 4.411 | -43.92 |         |         |         |       |
| 5% THF+ Water | 298.15K         | 0.005   | 1512.35 | 4.401 | -43.99 |         |         |         |       |
| 5% THF+ Water | 298.15K         | 0.007   | 1512.99 | 4.397 | -44.02 | -43.95 | -6.76  |         |       |
| 5% THF+ Water | 298.15K         | 0.01    | 1513.65 | 4.393 | -44.05 |         |         |         |       |
| 5% THF+ Water | 298.15K         | 0.03    | 1514.06 | 4.388 | -44.16 |         |         |         |       |
| 5% THF+ Water | 298.15K         | 0.05    | 1515    | 4.377 | -44.28 |         |         |         |       |
| 303.15K     |                      |         |         | 0.003| 1518.12 | 4.374 | -43.26 | -43.29 | -6.57 |
| 303.15K     |                      |         |         | 0.005| 1518.97 | 4.367 | -43.33 |         |       |
| 303.15K     |                      |         |         | 0.007| 1519.65 | 4.362 | -43.36 |         |       |
| 303.15K     |                      |         |         | 0.01 | 1520.22 | 4.357 | -43.39 |         |       |
| 303.15K     |                      |         |         | 0.03 | 1520.95 | 4.353 | -43.50 |         |       |
| 303.15K     |                      |         |         | 0.05 | 1521.35 | 4.341 | -43.61 |         |       |
| 308.15K     |                      |         |         | 0.003| 1523.03 | 4.347 | -42.64 | -42.67 | -6.31 |
| 308.15K     |                      |         |         | 0.005| 1523.82 | 4.342 | -42.71 |         |       |
| 308.15K     |                      |         |         | 0.007| 1524.27 | 4.339 | -42.74 |         |       |
| 308.15K     |                      |         |         | 0.01 | 1524.88 | 4.334 | -42.77 |         |       |
| 308.15K     |                      |         |         | 0.03 | 1525.97 | 4.320 | -42.87 |         |       |
| 308.15K     |                      |         |         | 4.829| 1527.7  | 4.300 | -42.98 |         |       |
| 313.15K     |                      |         |         | 0.003| 1532.03 | 4.268 | -42.23 | -42.23 | -6.23 |
FIG. 5. Plots of apparent molar isentropic compressibility vs molality for aluminium sulphate in water at different temperatures.
FIG. 6. Plots of apparent molar isentropic compressibility vs molality for aluminium sulphate in 5% THF+ water at different temperatures

The values of $\phi_{KS}$ for aluminium sulphate and other salts (Please refer Supplementary Table S4), in water and 5% THF at different temperatures were found negative (Table 6) and with increase in temperature makes the water molecules of aluminium salts more compressible. Further with rise in temperature the $\phi_{KS}$ values become less negative which indicate the electrostriction of water molecules and 5% THF surrounding aluminium salts is removed.

CONCLUSION

In the present study different conductance and acoustic parameters including Walden Product and its temperature coefficient i.e. $[d(\Delta m\eta_0)/dT]$ have been determined for aluminium sulphate, aluminium nitrate, aluminium chloride in water and binary aqueous mixtures of THF and it has been found that all aluminum salts act as structure breaker in water and different compositions of THF in water.

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