Volume 10, Issue 4, 2020, 5741 - 5746

Biointerface Research in Applied Chemistry

www.BiointerfaceResearch.com

https://doi.org/10.33263/BRIAC104.741746

Original Research Article

Open Access Journal

ISSN 2069-5837

Received: 19.10.2020 / Revised: 14.03.2020 / Accepted: 18.03.2020 / Published on-line: 29.03.2020

Evaluation of the physical parameters of nano-sized tetrachlorosilane as an inorganic material a mixed solvent using Fuoss-Shedlovsky and Fuoss-Hsia-Fernández-Prini

techniques

Enas Aljuhani ¹, Zehba A. Al-Ahmed ^{2,*}

¹Department of Chemistry, Faculty of Applied Science, Umm Al-Qura University, MakkahAlmukaramah, Mecca, Saudi Arabia ²Department of Chemistry, College of art and sciences, King Khalid University, Abba, Saudi Arabia

*corresponding author e-mail address: zehba_1234@yahoo.com | Scopus ID 57205471831

ABSTRACT

The electrical conductance of nano-sized tetrachlorosilane is measured in 50% mixed solvent of (absolute ethanol-H₂O) at various temperatures. The Λ_0 (limiting molar conductance) and the K_A (association constant) are evaluated *via* using Fuoss-Shedlovsky (F-SH) and Fuoss-Hsia-Fernández-Prini (FHFP) theories. The standard thermodynamic parameters for association (ΔS°_A , $\Delta H^{\circ}_A \& \Delta G^{\circ}_A$), energy of activation (Ea), hydrodynamic radii (RH) and Walden product ($\Lambda_0 \eta_0$) are calculated for tetrachlorosilane. These various physical parameters for tetrachlorosilane are evaluated and discussed.

Keywords: Electrical conductance; nano-sized tetrachlorosilane; TEM; F-SH; FHFP.

1. INTRODUCTION

There are various techniques, which used in synthesis nanomaterials and these techniques can be classified into bottomup and top-down approaches. The challenge in a synthesis of nanomaterials is to obtain materials in nano-sized by a simple method, high yield, and low cost[1-3]. The high-energy ball mill method is one of an inexpensive and easy method used to prepare nano-sized materials. It considered as a type of grinder used to grind bulk materials into a fine powder at the nanoscale. The ball mill consists of stainless steel balls in a container of the doublewalled tube from stainless steel and there is a magnet, which is placed outside the container to increase the milling energy during rotation of balls by increasing the pulling force to the material [4-6].

Tetrachlorosilane is an important inorganic compound used as an intermediate in the production of polysilicon [7]. Also, it is reduced to trichlorosilane in a hydrogenation reactor *via* hydrogen gas, and also, it is used in the Siemens process and injected into

2. MATERIALS AND METHODS

2.1. Preparation of solutions.

The binary mixed solvents of (EtOH-H₂O) 50% are prepared by mixing water with absolute ethanol (with error \pm 0.01%). The percentage of absolute EtOH is calculated from equation 1:

 $(V_1d_1)100 / (V_1d_1 + V_2d_2) \longrightarrow (1)$ d_1 : The densities of absolute ethanol d_2 : The densities of H₂O V_1 : The volumes of absolute ethanol V_2 : The volumes of H₂O

The conductance measurements of SiCl₄ are determined by using Germany conductivity meter LF 191 with accuracy±0.01% and cell constant 1±10% cm⁻¹ in mixed solvents. The solution of dry KCl used to detect the cell constant of the electrode. The MLW3230 ultra-thermostat with an accuracy of ±0.006 °C is used

a fluidized bed reactor. Moreover, the optical fibers are made by using OFD and MCVD processes where tetrachlorosilane is oxidized in the presence of oxygen to pure silica [8-10].

The physicochemical and thermodynamic parameters of tetrachlorosilane solutions give information about geometrical effects and intermolecular interactions in the systems used in several branches [11]. The study of viscosity, conductance, and ionic mobility of electrolytes in a partially aqueous & aqueous system are helpful not only to explain ion-solvent and ion-ion interactions, but also the favoured salvation of these ions in solutions [12]. The FHFP and F-SH [14] are good mathematic conductivity theories that effectively used to investigate electrolytes in different solutions [15].

In this article, the outcomes data of conductivity are investigated by using the modern (FHFP) and the classical (F-SH) conductivity equations.

to keep the mixtures temperature in the practical study was constant. The mixed solvent is prepared by using deionized water at 25 °C that has specific conductivity $\approx 0.07 \ \mu S \ cm^{-1}$. The chemicals used are supplied from Sigma-Aldrich such as (SiCl₄, 99.99 %), (EtOH, 99.99 %), and (KCl, 99.00 %).

2.2. Preparation of nano-sized tetrachlorosilane.

The Retsch MM2000 swing mill that consists of double-walled tube, two stainless steel balls (12 mm diameter and 7 gm weight) and a container filled with 10 cm³ stainless steel, is used to prepare nano-sized SiCl₄. Ball-milling is used at room temperature for half an hour and 20225 Hz, 100 HZ, (without circulating liquid). Powder sample is collected characterized by TEM.

3. RESULTS

3.1. Description of materials via SEM, TEM, XRD and Raman spectra.

SEM and TEM images (Figure 1) indicated that the prepared nano-SiCl₄has polycrystalline nano-particles with size ranging from 10-100 nm. Also, the TEM image indicated that the nano-SiCl₄was composed of interconnected silicon grains.



Figure 1. (a) SEM and (b) TEM photograph of nano-sized SiCl₄.

The XRD pattern of nano-SiCl₄ has five peaks that indicated to the diffraction peaks of cubic silicon (Figure 2a). As said by Sherrer's equation, the size of the nanoparticles silicon was evaluated to be 30 nm. In addition, the Raman spectrum has a sharp peak at 513 cm⁻¹, in proportion to first-order of Raman scattering from optic phonons of (Si–Si) stretching motions of nano-sized silicon (Figure 2b).



Figure 2.(a) XRD patterns and (b) Raman spectrum of nano-sized SiCl₄.

3.2. Conductometry of nano-sized tetrachlorosilane.

3.2.1. Ion-pair association parameters of SiCl₄.

The modern (FHFP) and the classical (FS) are mathematic conductivity theories that applied to determine the conductivity parameters. The Λ_0 (limiting molar conductance) is detected for nano-sized tetrachlorosilane solutions in pure water and (EtOH-H₂O) at various temperatures *via* extrapolating the linear Onsager plot [16] between (Λ_m) & (C)^½(Figure 3). The magnitude of (Λ_0) was used to determine the Onsager slope (S) by applying this equation (2)

- $S = a\Lambda_{o} + b \rightarrow (1)$ $a = 82 \times 10^{4} / (\epsilon T)^{3/2} \rightarrow (2)$ $b = 82.4/ \eta((\epsilon T)^{1/2} \rightarrow (3))$
- T: The temperature;

 η : The viscosity of the solvent;

ε: The relative permittivity of the solvent



Figure 3. The plot of (Λ) vs. (C^{1/2}, mol^{1/2} .L^{-1/2}) for nano-sized tetrachlorosilane at various temperatures in w₁ = 0.00 (- \bullet -), w₁ = 0.30 (- \bullet -), w₁ = 0.50 (- \bullet -) of (EtOH–H₂O) mixed solvents.

The Walden product $(\Lambda_o \eta_o \text{ or } \lambda_o \eta_o)$ is an essential point of view of ion-solvent interaction [17, 18]. The Walden product $(\Lambda_o \eta_o)$ is constant for the used electrolyte in different mixed solvent that the ion–solvent interactions are identical owing to the Walden product that considered the product of ion conductance by the viscosity of the medium depending on mobility of ions only and independent on the nature of the solvent and the molar conductance of ion at unlimited dilution. The Walden rule is written as in Equation (5).

$$\Lambda_0 \eta_0 = 0.82 \left[\frac{1}{r_s^+} + \frac{1}{r_s^-} \right] \rightarrow (4)$$

The (**R**_H) of the ions is a measure of $(\frac{1}{[1/r_s^+ + 1/r_s^-]})$ factor, where (**r**) is a radius that diffuses with the same speed as the

where (**r**) is a radius that diffuses with the same speed as the particle in this study of a hypothetical sphere. Practically, in solution the solute molecules are dynamic and solvated. Therefore, the ($\mathbf{R}_{\mathbf{H}}$) included the effect of both hydro solvent and dynamic shape. The $\mathbf{R}_{\mathbf{H}}$ and Walden product magnitude for nano-sized tetrachlorosilaneiscalculated as shown in Table 1, 2.

3.2.2. Applying Fuoss-Shedlovsky equation.

The outcomes data of conductance are discussed by using (F-SH) conductivity equation:

$$\frac{1}{\Lambda_{\rm m}S(Z)} = \frac{1}{\Lambda_{\rm o}} + \left(\frac{K_{\rm A}}{\Lambda_{\rm o}^2}\right) \left(C\Lambda_{\rm m}\gamma_{\pm}^2 S(Z)\right) \rightarrow (5)$$

$$S(Z) = I + Z + Z^2/2 + Z^3/8 + \dots \text{ etc.} \rightarrow (6)$$

$$Z = \frac{S(\Lambda_{\rm m}C)^{1/2}}{\Lambda_{o}^{3/2}} \rightarrow (7)$$

The degree of dissociation (α) magnitude is determined *via* the values of (Λ_o), (Λ_m) & S (z) through the following equation:

$$(\alpha) = \frac{\Lambda_{\rm m} \, {\rm S}({\rm Z})}{\Lambda_{\rm o}} \rightarrow (8)$$

The mean activity coefficients (γ_{\pm}) are calculated *via* the values of (ε) and (α) through this equation:

$$\log \gamma_{\pm} = -\frac{Z_{\pm}Z_{-}A\sqrt{I}}{I + Br^{o}\sqrt{I}} \quad \Rightarrow (9)$$

A & B: The Debye-Hückel constant $A = 1.824 \times 10^{6} (\varepsilon T)^{-3/2} \longrightarrow (10)$ $B = 50.29 \times 10^{8} (\varepsilon T)^{-1/2} \longrightarrow (11)$ Z.& Z₊: The charges of ions in solutions

Evaluation the physical parameters of nano-sized tetrachlorosilane as an inorganic material in mixed solvent using Fuoss-Shedlovsky and Fuoss-Hsia-Fernández-Prini techniques

 $\mathbf{r}^{\mathbf{o}}$: The distance of the closest approach

3.2.3. Applying the Fuoss-Hsia-Fernández-Prini equation.

The outcomes data are analyzed by applying (FHFP) conductivity equation:

$$\Lambda = \alpha \left[\Lambda_0 - S(\alpha C)^{\frac{1}{2}} + E\alpha C \ln(\alpha C) - J_1 \alpha C + J_2 \alpha C^{3/2} \right] \rightarrow (12)$$

 γ_{\pm} : The activity coefficients

S: The Onsager limiting slope

 α : The degree of dissociation

The terms J_1 , J_2 , S, & E are based on Λ_o while, the (J) term based on the distance of closest approach (r^o)

 K_A : The ion-pair association constant, calculated *via* applying this equation:

$$K_A = \frac{1-\alpha}{\alpha^2 C \gamma \pm^2} \rightarrow (13)$$

The degree of dissociation (α) is determined by applying this equation:

$$(\alpha) = \frac{\Lambda_{\rm m}}{\Lambda_{\rm o}} \rightarrow (14)$$

Also, the mean activity $coefficients(\gamma_{\pm})$ are calculated *via* using the values of (α) and (ϵ), through the Debye-Hückel limiting law equation:

$$\ln \gamma_{\pm} = -\frac{k q \alpha^{1/2}}{1 + k r^{0} \alpha^{1/2}} \rightarrow (15)$$

Where, $k = \left(\frac{16000 N_{A} Z^{2} e^{2} \alpha C}{\epsilon_{0} \epsilon K T}\right)^{1/2} \rightarrow (16)$

 ε_0 : The permittivity of vacuum

q: The Bjerrum distance

r^o: The distance of the closest approach set equal to **q** according to the recommendation of Justice [19]

k: The reciprocal radius of the ionic atmosphere

e: The electronic charge

 N_A : Avogadro's number (6.022140857 x 10²³)

z: is the ionic charge

K: Boltzmann constant (1.38065 x 10^{-23} J/K)

The outcomes data presented in Tables 1, 2 shown that the limiting molar conductance of $SiCl_4$ in pure water is more than that in binary mixed (EtOH-H₂O) at different temperatures [20]. This is because of the increasing of ethanol content in mixed solvent than in pure water alone leads to a decrease in the conductivity due to the formation of intramolecular hydrogen bonding or intermolecular attraction force which causes the association of water and ethanol to make difficulty in the ions mobility.

Moreover, as a temperature increase, the Λ_0 for SiCl₄ is increased in all solvents used owing to the increasing kinetic energies and mobility of ions, which leads to breaking of bond, rotational, variation in translational, and vibrational energy of molecules that cause the high mobility and frequency of the ions. This fact is confirmed by ionization degree (α) that decreased by rising the temperature.

The outcomes data of Walden product indicated to as a temperature increase, the Walden product values decrease that confirm the dehydration of ions by rising temperature [21]. As general, the Walden product influenced by two factors, viscosity(η) and limiting molar conductance (Λ_0), where the η is inversely proportional with temperature and Λ_0 is directly proportional with temperature. We can conclude that from the previous results, the value of viscosity is affected on the inverse proportional manners of the Walden product with the temperature.

The Walden product values decrease with increasing the percentage of absolute ethanol in the order: (0% > 30% > 50%) due to the increase of organic solvent that leads to a greater size of solvation shells around cation and this reduce its mobility in addition to Walden product [22]. The (**R**_H) values of the ions increase with increasing temperature, where the increasein temperature leads to break of the hydrogen bond between water molecules; this leads to a numeral of solvent molecules becomes ready for ion salvation [23, 24].

It is noted that as a temperature increase, the ion-pair association constant (K_A) increases for SiCl₄ which refers to the endothermic association process (Table 1, 2). This fact discussed from the relation between association and desolvation of ions where, as the temperature increases, the ions desolvation process takes place. Therefore the ions will be nearer than previous, so the association of ions increases [24].

In this study, the (K_A) increase as the percentage of organic solvent increases except in the case of 30% mixed solvent (EtOH- H_2O) at the same temperature. The increase in the valuesof(K_A) is due to the decreasing in relative permittivity by increasing the percentage of organic solvent and decreasing in the ions mobility that giving possibility for ions to associate.

The outcomes data of (K_A) values for nano-sized tetrachlorosilane in 30% mixed solvent of (EtOH-H₂O) are lesser than (K_A) values in water. This is due to the interaction between water and ethanol at a low concentration of ethanol that isaffected by the formation of cage-like structures, commonly known as (icebergs) around the hydrophobic ends of the absolute ethanol that effect on the ions mobility and decrease association constant [25, 26].

3.3. Thermodynamics of association and the activation energy of the transfer process of nano-sized tetrachlorosilane

The ΔG_A° is estimated *via* this equation for nano-sized tetrachlorosilane in mixed solvent at all selected temperatures as shown in Table 3.

 $\Delta G_{A}^{\circ} = -RT \ln K_{A} \text{ where, } R: \text{the gas constant } (8.314 \text{ J.mol}^{-1} \text{.K}^{-1}) \text{------}$ ---> (17)

Also, $\Delta S_A^{\circ} \& \Delta H_A^{\circ}$ values of association process are calculated by applying Van't Hoff equation:

$$\left(\frac{\mathrm{dlnK}}{\mathrm{d}T}\right) = \left(\frac{\Delta H_A^\circ}{\mathrm{R}T^2}\right)$$

By drawing (log K_A) against (1/T) as shown in Figure 4, where slope = $(-\Delta H_{A}^{\circ}/2.303R)$ but, (ΔS_{A}°) are determined by applying in Gibbs–Helmohltz equation as follow:

 $\Delta G_{A}^{\circ} = \Delta H_{A}^{\circ} - T\Delta S_{A}^{\circ} \quad \dots \rightarrow \quad (18)$

In all systems under studied, the associating free energy becomes more negative as the temperature increase and so the association processes are spontaneous. This indicated that the ionpair association is preferred at low dielectric constant medium.

The (+) ve magnitude of $\Delta S_A^{\circ} \& \Delta H_A^{\circ}$ for association may be ascribed to counter balance of the enthalpy *via* a favourable entropy change that resulting from the short- to long-range desolvation ions [27].

Ion mobility is highly sensible to treat the rating process that occurs with the change in temperature as shown in this equation:

$$\Lambda_0 = Ae^{-E_a/RT} \quad \dots \rightarrow (19)$$

Enas Aljuhani, Zehba A. Al-Ahmed

 E_a : is the Arrhenius activation energy of the transfer process **R**: The gas constant

A: The frequency factor

 E_a : The Arrhenius activation energy of the transfer process

Where, the values calculated by plotting (log Λ_0) against (1/T), and presented in Table 3. The activation energy is inversely proportioned with Λ_0 as reported by many authors [28, 29].

Table 1. The limiting, the	e molar conductance, and so	me different solvation pa	arameters ($\Lambda_o \eta$, R_H , S_H	, K_A , K_D , α , and γ_{\pm})	for nano-sized SiCl ₄ in (EtOF	ł-
	H_2O) mixtu	res at various temperatur	es by applying (F-SH)) equation.		

Mass fraction of	Т	Λ_{o}	$\Lambda_{\rm m}$	$\Lambda_{o}\eta$	R _H	S	K _A	$10^{3} K_{D}$	α	γ
$(EtOH-H_2O)(w_1)$	K	S cm ² mol ⁻¹	S cm ⁻² mol ⁻¹	S. mol ⁻¹ cm ² Pa.s	A		dm ³ mol ⁻¹			
$w_1 = 0.00$	298.15	257	171	229	0.0036	119	1034	0.967	0.674	0.892
	303.15	266	177	212	0.0039	129	1044	0.956	0.673	0.891
	308.15	271	178	195	0.0042	139	1095	0.913	0.665	0.899
	313.15	284	184	176	0.0046	156	1163	0.859	0.656	0.889
$w_1 = 0.30$	298.15	121	85.56	110.77	0.0074	90.42	812	1.230	0.717	0.881
	303.15	130	88.89	106.19	0.0077	100.75	941	1.062	0.693	0.882
	308.15	135	91.19	100.48	0.0082	113.32	1009	0.990	0.685	0.874
	313.15	140	93.26	91.66	0.0089	125.87	1041	0.959	0.680	0.872
$w_1 = 0.50$	298.15	75	38.18	70.09	0.0117	80.97	2587	0.386	0.519	0.890
	303.15	82	40.36	68.07	0.0120	91.25	2873	0.348	0.501	0.891
	308.15	91	43.24	69.14	0.0119	106.88	3263	0.306	0.485	0.877
	313.15	95	44.85	62.10	0.0132	119.90	3268	0.3059	0.4845	0.879

Table 2. The limiting, the molar conductance, and some different solvation parameters ($\Lambda_0\eta$, R_H, S, K_A, K_D, α , and γ_{\pm}) for nano-sized SiCl₄ in (EtOH-H₂O) mixtures at various temperatures by applying (FHFP) equation

Mass fraction of	Т	Λ_{o}	Λ_{m}	Λ₀η	R _H	S	K _A	$10^3 \text{ K}_{\text{D}}$	α	γ
$(EtOH-H_2O)(w_1)$	K	S cm ² mol ⁻¹	S cm ² mol ⁻¹	S. mol ⁻¹ cm ² Pa.s	A		dm ³ mol ⁻¹			
$w_1 = 0.00$	298.15	302	171	269	0.0030	129	998	1.01	0.665	0.944
	303.15	332	177	266	0.0031	144	1316	0.76	0.618	0.944
	308.15	337	178	243	0.0034	154	1368	0.74	0.615	0.943
	313.15	348	184	216	0.0038	171	1430	0.70	0.604	0.942
$w_1 = 0.30$	298.15	123	85	112	0.0073	90	786	1.280	0.711	0.941
	303.15	132	88	107	0.0076	100	879	1.114	0.689	0.940
	308.15	138	91	102	0.0080	113	955	1.050	0.680	0.937
	313.15	142	93	93	0.0088	125	1008	0.991	0.667	0.936
$w_1 = 0.50$	298.15	76	38	71	0.0115	80	2334	0.429	0.522	0.944
	303.15	84	40	69	0.0118	91	2574	0.389	0.505	0.944
	308.15	93	43	70	0.0116	106	2844	0.350	0.497	0.938
	313.15	97	44	63	0.0129	119	2917	0.352	0.494	0.939

Table 3. The activation energy (E_a) and the thermodynamic parameters of association ($\Delta G \circ_A, \Delta H \circ_A, \Delta S \circ_A$) are calculated for nano-sized SiCl₄ at different temperatures.

Mass fraction of	Т	Ea	Ea	-∆G° _A	$-\Delta G^{\circ}_{A}$	ΔH°_{A}	ΔH°_{A}	ΔS°_{A}	ΔS°_{A}
$(EtOH-H_2O)(w_1)$		(F-SH)	(FHFP)	(F-SH)	(FHFP)	(F-SH)	(FHFP)	(F-SH)	(FHFP)
	K	KJ.mol ⁻¹	KJ.mol ⁻¹	kJ.mol ⁻¹	kJ.mol ⁻¹	kJ.mol ⁻¹	kJ.mol ⁻¹	J.mol ⁻¹	J.mol ⁻¹
$w_1 = 0.00$	298.15	3.28	3.32	17.21	17.32	6.02	6.9	77.92	80.89
	303.15			17.52	18.11			77.66	82.12
	308.15			17.93	18.46			77.74	82.18
	313.15			18.38	18.92			77.93	82.44
$w_1 = 0.30$	298.15	3.36	3.39	16.61	16.51	12.08	11.8	96.23	95.19
	303.15			17.26	17.14			96.78	95.46
	308.15			17.72	17.85			96.72	95.52
	313.15			18.09	18.01			96.35	95.64
$w_1 = 0.00$	298.15	4.06	4.10	19.48	19.23	12.1	11.9	105.93	104.52
	303.15			20.07	19.79			106.14	105.71
	308.15]		20.73	20.38]		106.56	104.90
	313.15			21.07	20.77			105.93	105.26

We found that by comparing the data obtained from two conductivity equations used the Fuoss-Shedlovsky (F-SH) and Fuoss-Hsia-Fernández-Prini (FHFP), the difference in outcomes data resulted from two mathematical theories is very small which proved that the validity of mathematical theory and the behaviour of salt does not change with the change of applied equation. So, we decided to complete the calculations of the remained metal salts by using (FHFP) conductivity equation.



Figure 4. The plot of Log K_Avs. (1/T) at various temperatures for nano-sized tetrachlorosilane by applying (F-SH) theory in $w_1 = 0.00$ (- \blacksquare -), $w_1 = 0.30$ (- \blacksquare -), $w_1 = 0.50$ (- \blacksquare -) and by applying (FHFP) theory in $w_1 = 0.00$ (- \blacksquare -), $w_1 = 0.30$ (- \blacksquare -), $w_1 = 0.50$ (- \blacksquare -) of (EtOH-H₂O) mixed solvents

4. CONCLUSIONS

The conductivity measurements for nano-sized tetrachlorosilane in pure water and mixed solvent of $(EtOH-H_2O)$ at various temperatures are studied to get some information about the ion-solvent interactions and ion-ion association. The association constant (K_A) are determined by applying FHFP and

5. REFERENCES

1. Biao, L.; Tan, S.; Meng, Q.; Jing, G.; Xuewei, Z.; Liu, Z.; Υ. Green Synthesis, Characterization and Fu. of Application Proanthocyanidins-Functionalized Gold 2018, 53, Nanoparticles. Nanomaterials 8. https://doi.org/10.3390/nano8010053...

2. Dierking, I.; Shakhawan, A. Correction:Lyotropic Liquid Crystal Phases from Anisotropic Nanomaterials. *Nanomaterials* **2017**, *7*, 305, <u>https://doi.org/10.3390/nano8010045</u>.

3. Nadaroğlu, H.; Alaylı, G.A.; Ince, S. Synthesis of Nanoparticles by Green Synthesis Method. *International Journal of Innovative Research and Reviews* **2017**, *1*, 6–9.

4. Zaky, R.; Fekri, A. Solid state ball milling as a green approach to prepare Cu(II) complexes: structural, spectral, DFT, and DNA studies. *New J. Chem.* **2017**, *41*, 4555–4563. https://doi.org/10.1039/C7NJ00840F.

5. Al-Hazmi, G.A.A.; Abou-Melha, K.S.; El-Metwaly, N.M.; Althagaf, I.; Zaki, R.; Shaaban, F. Green Synthesis for 3-(2-Benzoylhydrazono)-N-(pyridin-2-yl) butanamide Complexes: Spectral, Analytical, Modelling, MOE Docking and Biological Studies. *Inorg Organomet Polym Mater.* **2019**, https://doi.org/10.1007/s10904-019-01326-6.

6. Abu El-Reash, G.M.; Zaky, R.R.; El-Gamil, M.M.; El-Emam, S.M. Synthesis, characterization, computational, conductometric titration and DNA binding studies of N' 1, N' 2 -bis (3-hydroxy-5,5-dimethylcyclohex-2-en-1-ylidene) oxalohydrazide complexes. *J. Mol. Liq.* **2019**, *288*, https://doi.org/10.1016/j.molliq.2019.111030.

7. Simmler, W. Silicon Compounds, Inorganic. In: *Ullmann's Encyclopedia of Industrial Chemistry*. Weinheim: Wiley-VCH, 2000; <u>https://doi.org/10.1002/14356007.a24_001</u>.

8. Fan, H.Y. Solar Grade Silicon Refining By chemical Vapour Deposition. MASc. *Thesis, University of Toronto* **2007**.

9. Woditsch, P.; Koch, W. Solar grade silicon feedstock supply for PV industry. *Solar Energy Materials & Solar Cell* **2002**, *72*, 11-26, <u>https://doi.org/10.1016/S0927-0248(01)00146-5</u>.

F-SH equations. The outcomes data indicated to as the temperature increase, the association constant increase, which leads to a decrease in the endothermic nature of ion pair formation and ions mobility.

10. Schei, A.; Tuset, J.K.; Tveit, H. Production of High Silicon Alloys. *Tapir Forlag* **1998**, 3-20.

11. Jiang, Y.; Zhang, Z.; Zhou, Z.; Yang, H.; Zhang, Q. Enhanced Dielectric Performance of P(VDF-HFP) Composites with Satellite–Core-Structured Fe2O3@BaTiO3 Nanofillers. *Polymers* **2019**, *11*, 1541, https://doi.org/10.3390/polym11101541.

12. Gomaa, E.A.; Zaky, R.R.; Shokr, A. Effect of calcon carboxylic acid on association process of vanadyl sulfate in water-N,N-dimethyl formamide mixed solvents. *Chemical Data Collections* **2017**, *11*, 67–76, https://doi.org/10.1016/j.cdc.2017.08.002.

13. Gomaa, E.A.; Zaky, R.R.; Shokr, A. Estimated the physical parameters of lanthanum chloride in water-N,N-dimethyl formamidee mixtures using different techniques. *J. Mol. Liq.* **2017**, *242*, 913–918, https://doi.org/10.1016/j.molliq.2017.07.108.

14. Alarifi, I.M. Investigation the conductivity of carbon fiber composites focusing on measurement techniques under dynamic and static loads. *J. Mater. Res. Technol.* **2019**, *8*, 4863–4893, https://doi.org/10.1016/j.jmrt.2019.08.019.

15. Lionetto, F.; Mele, C.; Leo, P.; D'Ostuni, S.; Balle, F.; Maffezzoli A. Ultrasonic spot welding of carbon fiber reinforced epoxy composites to aluminum: mechanical and electrochemical characterization. *Compos. Part B Eng.* **2018**, *144*, 134–142, https://doi.org/10.1016/j.compositesb.2018.02.026

16. Stylianakis, I.; Kolocouris, A.; Kolocouris, N.; Fytas, G.; Foscolos, G.B.; Padalko, E.; Neyts, J.; De Clercq, E. Spiro[pyrrolidine-2,2'-adamantanes]: Synthesis, anti-influenza virus activity and conformational properties. *Bioorganic Med. Chem. Lett.***2003**, *13*, 1699–1703, <u>https://doi.org/10.1016/S0960-894X(03)00231-2</u>.

17. Refat, H.M.; Fadda, A.A. Synthesis and antimicrobial activity of some novel hydrazide, benzochromenone, dihydropyridine, pyrrole, thiazole and thiophene derivatives.

Eur. J. Med. Chem. **2013**, 70, 419–426, <u>https://doi.org/10.1016/j.ejmech.2013.09.003</u>.

18. Zaky, R.R.; Yousef, T.A.; Ibrahim, K.M. Co(II), Cd(II), Hg(II) and U(VI)O₂complexes of o-hydroxyacetophenone[N-(3-hydroxy-2-naphthoyl)] hydrazone: Physicochemical study, thermal studies and antimicrobial activity. *Spectrochim. Acta-Part A Mol. Biomol. Spectrosc.* **2012**, *97*, 683–694, https://doi.org/10.1016/j.saa.2012.05.086.

19. Onsager, L. The theory of electrolytes. Z. Phys. 1927, 28, 277–298.

20. Walden, P. Über den Zusammenhang zwischen dem Grenzleitvermögen $\lambda \infty$ derbinären Elektrolyte in nichtwässerigen Lösungsmitteln und der Viskosität $\eta \infty$ derletzteren $\lambda \infty \cdot \eta \infty =$ konst, Z. Anorg. Allg. Chem. **1920**, 113, 85.

21. Shekaari, H.; Zafarani-Moattar, M.T.; Mirheydari, S.N. Conductometric analysis of 1-butyl-3-methylimidazolium ibuprofenate as an active pharmaceutical ingredient ionic liquid (API-IL) in the aqueous amino acids solutions. Thermodyn. 2016, 103, 165 - 175,J. Chem. https://doi.org/10.1016/j.jct.2016.07.047.

22. Walden, P. Über Die Ionendurchmesser in Nichtwässerigen Lösungen. Z. Anorg. Allg. Chem. **1929**, 113, 125.

23. Justice, J.C. Conductance of electrolyte solutions. *Comprehensive Treatise of Electrochemistry* **1983**, *5*, 223–338.

24. Singh, N.M. Ion association and solvation behaviour of metal (II) chlorides in binary mixtures of methanol + water: a conductance method. *Asian J. Chem* .2016, 28, 910, https://doi.org/10.14233/ajchem.2016.19653.

25. Szejgis, A.; Bald, A.; Gregorowicz, J.; Kinart, C.M. Conductivity studies on LiBr, NaBr, KBr and CsBr solutions in binary mixtures of N, N+ dimethylformamide with water at 298.15 K. *Phys. Chem. Liq.* **1997**, *34*, 89, https://doi.org/10.1080/00319109708030563.

26. Rao, K.C.; Subha, M.C.S.; Rao, S.B. Ion-pair association constants of alkali and alkalineearth metal formats in formic acid-acetonitrile mixtures at 30 degrees C-A conductance. *Indian J. Chem.* **1989**, *28A*, 102–105.

27. El-Dossoki, F.I. Conductometric and thermodynamic studies on the ionic association of HCOONH 4, phCOONH 4, HCOONa and phCOONa in aqueous–organic solvents. *J. Mol. Liq.* **2008**, *142*, 72–77, https://doi.org/10.1016/j.molliq.2008.05.001.

28. Gomaa, E.A.; Tahoon, M.A. Ion association and solvation behavior of copper sulfate in binary aqueous-methanol mixtures at different temperatures. *J. Mol. Liq.* **2016**, *214*, 19–23, https://doi.org/10.1016/j.molliq.2015.11.046.

29. Gomaa, E.A.; Tahoon, M.A.; Shokr, A. Ionic association and solvation study of $CoSO_4$ in aqueous-organic solvents at different temperatures. *Chem. Data Collect.* **2016**, *3–4*, 58–67, https://doi.org/10.1016/j.cdc.2016.06.005.

© 2020 by the authors. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).