



Determination of Formation Constant and Thermodynamic Parameters for Interaction between Vanadyl Sulfate and Gliclazide in Aqueous – Organic Solvent at Various Temperatures

Esam A. Gomaa¹, Amr Negm¹ and Marwa M. Rashed^{1*}

¹Department of Chemistry, Faculty of Science, Mansoura University, 35516 Mansoura, Egypt.

Authors' contributions

This work was carried out in collaboration between all authors. Author EAG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AN and MMR managed the analyses of the study. Author MMR managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Our work aims to measure the conductivity of vanadyl complexes in an aqueous-organic medium at various temperatures ranging from (298.15, 303.15, 308.15 and 313.15 K). The experimental data of Λ_m and Λ_o were dissected in place of the calculation of formation constants for every form of the stoichiometric complexes. The formation constants (K_f) for the metal complexes were studied for every form of complexes obtained 1:1 and 1:2 metal to ligand molar ratio (M:L) via using formation equation. It is observed that the limiting equivalent conductance increased with the increment in temperature. Thermodynamic parameters (i.e., ΔG_f^0 , ΔH_f^0 , ΔS_f^0) are estimated from the temperature dependence of the ion formation constant. Vanadyl complexes show formation within experimentally various temperatures which are supported by the negative value of ΔG_f^0 . The positive values of ΔS_f^0 in most cases and positive values of ΔH_f^0 indicate that the formation process occurred spontaneously as well as endothermic and vice versa at all respective temperatures.

*Corresponding author: E-mail: marwa.rashed84@yahoo.com;

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1. INTRODUCTION

Conductance measurement is one of the most accurate and widely used physical methods for investigation of the electrolyte of solutions [1,2]. Conductivity measurements are widely used in industry. Some studies have used the electrolytic conductance measurements for studying the interaction of some ligands with some metal cations and determination of the formation constants of the formed complexes. Some physicochemical techniques such as spectrophotometer and polarography have been used [3–5] to study the complex formation between GL and vanadyl sulfate in the solutions. The conductometric technique is a sensitive and inexpensive method with a simple experimental arrangement for such investigations. Conductometric analysis can be used for many titration procedures where ionic species are involved. As the conductance of a solution relates to the total ionic content, it can be used to follow reactions that result in a change in this quantity. Conductometry is an electrochemical technique, which provides us with most precise data for ions in the solution [6]. There is an increasing interest in the study of complexation reactions in different solvent systems and their interpretation in terms of solute's preferential solvation by one of the mixed solvent components [7–9].

Dimethylformamide (DMF) acts as a strong solvent which characteristic by the most benefited in fiber and film production and also in a coating and adhesive formulations. DMF used as a solvent due to it is the most economic solvent when comparing with the cheap solvents due to its solving more solid substances in practical operating viscosities. DMF is especially an efficient solvent with vinyl polymers, polyacrylonitrile, epoxy resins, polyamides, and urethanes. Due to its high purity and selective solvent characteristic, DMF is used for instance in removing or gaining acetylene, and removing butadiene from hydrocarbons processes.

Vanadyl sulfate is an inorganic compound of vanadium(V). This highly hygroscopic substance blue solid is one of the maximum common sources of V in the lab, reflecting its high stability. It features the vanadyl ion, VO^{2+} , which has been called the "most stable diatomic ion" [10] It is a major commercial source of V and also an

intermediate in the extraction of V from petroleum residues. It is a component of some experimental drugs and food supplements. $VOSO_4$ exhibits insulin-like effects [11].

Gliclazide (GL) is an oral antihyperglycemic agent, it used for medicament of non-insulin dependent diabetes mellitus which belongs to the sulfonylurea class of insulin secretagogues. It works by stimulating β cells of the pancreas to release insulin [12].

In this work, the formation constants and stoichiometry of the complexation were elucidated by conductometric titration of VO^{2+} solutions with GL solution. The conductometric method for the study of $(VO-GL)^{2+}$ complexes in various H_2O/DMF mixtures and temperatures were used to investigate the effect of solvent properties on the stabilities of the resulting.

2. EXPERIMENTAL

2.1 Materials

Vanadyl sulfate ($VOSO_4 \cdot 3H_2O$, 99.5%), Gliclazide and DMF (99.5%) were supplied from Sigma-Aldrich company, which used without further refining. Deionized water which has a specific conductivity = $0.07 \mu S cm^{-1}$ at $25^\circ C$ was furthermore used for binary solvents preparation [13-16].

Specific conductance measurements of the salt solutions that previously prepared were measured by using LF 191 (Germany) conductivity meter with accuracy $\pm 0.01\%$ of a cell constant value $1 \pm 10\% cm^{-1}$. The cell constant was determined with KCl solutions [17-21]. MLW 3230 ultra-thermostat was connected to the Conductivity Bridge to give constant temperature ($\pm 0.006^\circ C$).

A solution of $VOSO_4$ ($1 \times 10^{-3} mol \cdot dm^{-3}$) was put into a titration cell. Thermostated at used the temperature and also measured the conductance of the solution [22-25]. The ligand gliclazide ($1 \times 10^{-4} mol \cdot dm^{-3}$) was transported step by step to the titration cell using a recalibrated micropipette. After each transfer measured the conductance of the solution. The addition of the gliclazide solution was continued until the total concentration of the gliclazide was higher four times approximately than the Vanadyl ions. The

conductance of the solution was measured by titration of gliclazide as a ligand with Vanadyl sulfate as a metal salt. The molar conductance of the complexes ML and the formation constant of the complexes (K_f) were estimated by computer fitting to the molar conductance mole ratio data. The temperatures used are 298.15, 303.15, 308.15 and 313.15 K.

3. RESULTS AND DISCUSSION

3.1 Determination of Molar Conductance

The specific conductance of solutions under study of the salt with a concentration range of (1×10^{-3} - 7.1×10^{-4} mol.L⁻¹) in binary mixed solvents with the alcohol mass fractions of 0, 30 and 60% of DMF-water at various temperatures (298.15, 303.15, 308.15 and 313.15 K) was obtained. The molar conductance (Λ_m) for VOSO₄ solutions in the presence of gliclazide in used solvents at various temperatures was determined by using equation (1) and summarized in Table 1.

$$\Lambda_m = \frac{(K_s - K_{solv}) \cdot K_{cell} \cdot 1000}{c} \quad (1)$$

Where (K_s , $\mu\text{S cm}^{-1}$) is the obtained specific conductance of the solution under study and K_{solv} is the specific conductance of used solvent, K_{cell} is the cell constant and C is the molar concentration of the metal salt (VOSO₄) solution.

From Table 1, when comparing the obtained data for VOSO₄ in the presence of gliclazide, we observed that the value of molar conductance (Λ_m) was inversely proportional with increasing the fraction of the organic-aqueous solvent as shown in Fig.2 so has the following direction 60% < 30% < 0% [26]. This is related to solvent-solvent interaction (the formation of

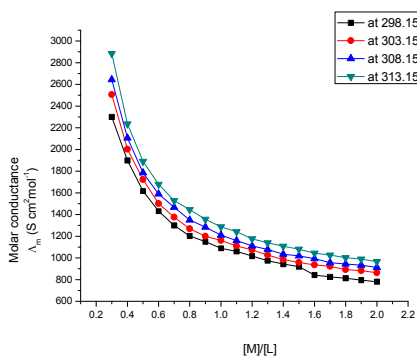


Fig. 1. Conductometric titration curves for VOSO₄ in the presence of GL in pure H₂O at various temperatures

intramolecular and intermolecular hydrogen bonding) between DMF and water which create impediment to the mobility of ions, reduce the dissociation and solvation of VOSO₄ molecules, and also the electrostatic force between vanadyl sulfate and gliclazide play an important role in this decreasing the value of molar conductance. Also, we observed that the increase in values of limiting molar conductance for VOSO₄ in used solvents with rising temperature as shown in Fig. 1 this is because of increasing of kinetic energies of ions in solution.

3.2 Determination of Formation Constant

By drawing the relation between molar conductance (Λ_m) for VOSO₄ in presence of gliclazide and its molar ratio of [M]/[L] concentrations at various temperatures, the different lines were obtained with two breaks which indicates formation of two complexes which have different stoichiometry as the following 1:2 and 1:1 (M:L) complexes, as done in previous works [27-28]. See Figs. 3-5.

By using equation (2) [29-32] to calculate formation constants (K_f) for VOSO₄ complexes for every form of complexes 1:1 and 1:2 (M:L) with gliclazide.

$$K_f = \frac{\Lambda_m - \Lambda_{obs}}{(\Lambda_{obs} - \Lambda_{ML})[L]} \quad (2)$$

Where Λ_{obs} is the molar conductance of solution during titration, Λ_m is the limiting molar conductance of the VOSO₄ alone, Λ_{ML} is the molar conductance of the complex and [L] is the ligand concentration. The obtained values of the formation constant (K_f) for all studied systems were summarized in Tables 2 and 3.

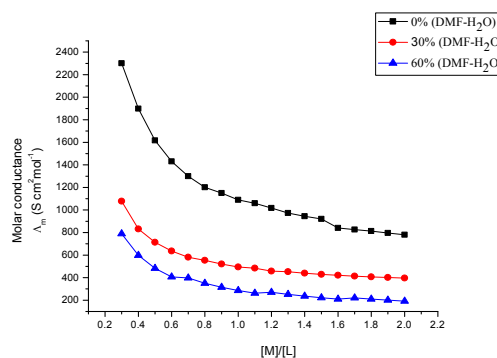


Fig. 2. Conductometric titration curves for VOSO₄ in the presence of GL in used solvents at 298.15 K

Table 1. The molar conductance ($\Lambda_m \pm 0.07$, $\text{S cm}^2 \text{mol}^{-1}$) for VOSO_4 in the presence of gliclazide at various temperatures in the used solvents

Solvent	C[M]/[L] (mol. d m ⁻³)	Λ (S cm ⁻² mol ⁻¹)			
		298.15	303.15	308.15	313.15
0%(DMF-H₂O)	0.3	2300.33	2506.33	2643.66	2884
	0.4	1898	2002	2106	2236
	0.5	1617	1722	1785	1890
	0.6	1431	1501.66	1590	1678.33
	0.7	1299.28	1375.71	1467.42	1528.57
	0.8	1201.5	1269	1350	1444.5
	0.9	1150.55	1199	1283.77	1356.44
	1	1089	1161.6	1210	1287
	1.1	1059.54	1110	1160.45	1241.18
	1.2	1017.33	1073.33	1110.66	1176
	1.3	973.54	1025.69	1077.84	1138.69
	1.4	944.57	985.28	1034.14	1107.42
	1.5	920	958.33	1019.66	1081
	1.6	841	935.25	993.25	1044
	1.7	825.88	922.23	956.65	1025.47
	1.8	812.88	891.55	944	1003
30%(DMFH₂O)	0.3	1078.06	1091.8	1133	1201.66
	0.4	832	858	910	988
	0.5	714	735	777	840
	0.6	636	671.33	706.66	742
	0.7	580.857	596.14	642	672.57
	0.8	553.5	580.5	621	648
	0.9	520.777	545	581.33	617.66
	1	495	525.25	547.25	583
	1.1	484.363	504.54	524.72	565.09
	1.2	457.333	485.33	513.33	550.66
	1.3	452	469.38	495.46	530.23
	1.4	439.714	464.14	488.57	513
	1.5	429.333	452.33	475.33	498.33
	1.6	420.5	442.25	471.25	493
	1.7	412.941	426.70	468	474.88
	1.8	406.444	419.55	458.88	465.44
60%(DMFH₂O)	0.3	789.66	930.77	1063.64	1030
	0.4	598	728	858	858
	0.5	483	588	693	693
	0.6	406.33	530	618.33	583
	0.7	397.42	458.57	535	519.71
	0.8	351	405	472.5	459
	0.9	314.88	363.33	423.88	411.77
	1	286	336.05	385	378.18
	1.1	262.36	343.09	383.45	373.36
	1.2	270.66	317.33	354.66	345.33
	1.3	252.07	295.53	330.31	339
	1.4	236.14	276.85	309.42	317.57
	1.5	222.33	260.66	291.33	299
	1.6	210.25	268.25	290	297.25
	1.7	220.23	254.64	275.29	282.17
	1.8	209.77	242.55	262.22	268.77

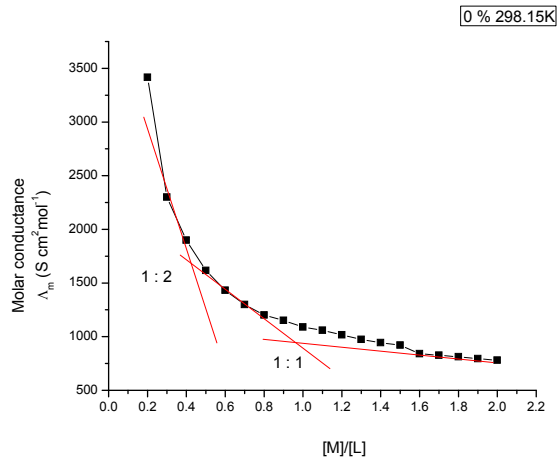


Fig. 3. Conductometric titration curves for $VOSO_4$ to GL in water at 298.15K

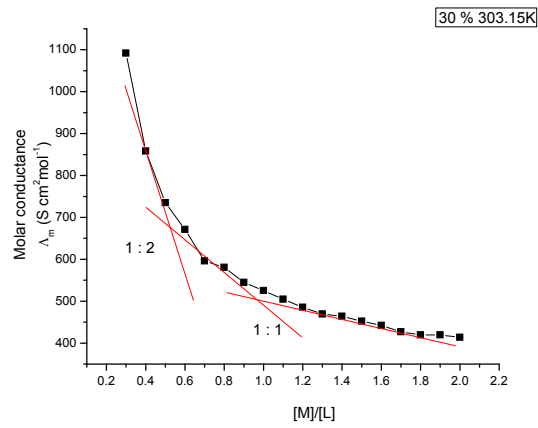


Fig. 4. Conductometric titration curves for $VOSO_4$ to GL in 30% (DMF- H_2O) at 303.15K

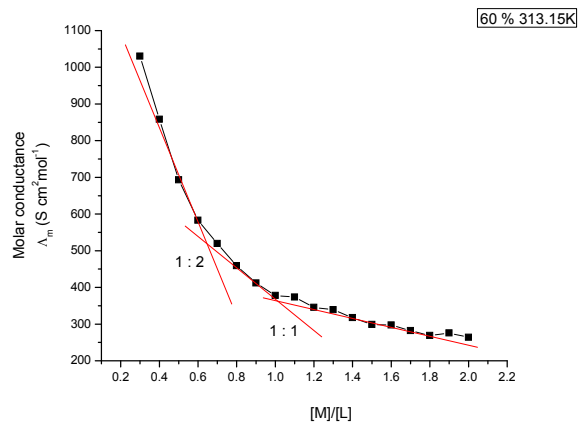


Fig. 5. Conductometric titration curves for $VOSO_4$ to GL in 60% (DMF- H_2O) at 313.15K

Table 2. Limiting molar conductance (Λ_o) ($\pm 0.05 \text{ S cm}^2 \cdot \text{mol}^{-1}$), formation constant (K_f) ($\pm 0.02 \text{ mol/dm}^3$), for VOSO_4 to gliclazide (GL) complex (1:2) formation at various temperatures in used solvents

Solvent	T/K	[L] $\times 10^5$ (mol. d m ⁻³) $\times 10^5$	[M] $\times 10^5$ (mol. d m ⁻³) $\times 10^5$	Λ_o (S cm ² .mol ⁻¹)	$\Lambda_{obs.}$ (S cm ² .mol ⁻¹)	log K_f (mol/dm ³)
0% (DMF-H ₂ O)	298.15	9.524	4.761	2300	1617	3.988
	303.15			2506.33	1722	4.055
	308.15			2660.83	1785	4.127
	313.15			2884	1890	4.199
30% (DMF-H ₂ O)	298.15	9.524	4.761	1078	714	4.10
	303.15			1091.8	735	4.05
	308.15			1133	777	4.00
	313.15			1201.66	840	3.95
60% (DMF-H ₂ O)	298.15	9.524	4.761	789.67	483	4.428
	303.15			930.6	588	4.316
	308.15			1063.65	693	4.217
	313.15			1030	693	4.118

Table 3. Limiting molar conductance (Λ_o) ($\pm 0.05 \text{ S cm}^2 \cdot \text{mol}^{-1}$), formation constant (K_f) ($\pm 0.02 \text{ mol/dm}^3$), for VOSO_4 to gliclazide (GL) complex (1:1) formation at various temperatures in used solvents

Solvent	T/K	[L] $\times 10^5$ (mol. d m ⁻³) $\times 10^5$	[M] $\times 10^5$ (mol. d m ⁻³) $\times 10^5$	Λ_o (S cm ² .mol ⁻¹)	$\Lambda_{obs.}$ (S cm ² .mol ⁻¹)	log K_f (mol/dm ³)
0% (DMF-H ₂ O)	298.15	9.09	9.09	1617	1088	4.30
	303.15			1722	1163	4.29
	308.15			1785	1210	4.27
	313.15			1890	1287	4.25
30% (DMF-H ₂ O)	298.15	9.09	9.09	714	495	4.02
	303.15			735	525.3	4.08
	308.15			777	547.3	4.13
	313.15			840	583	4.19
60% (DMF-H ₂ O)	298.15	9.09	9.09	483	286	4.89
	303.15			588	336	5.12
	308.15			693	385	5.34
	313.15			693	378.2	5.51

From Tables 2 and 3 we observed that the formation constant for $VOSO_4$ complexes with stoichiometry (1:1) in 30%, 60% (DMF- H_2O) and (1:2) stoichiometry in 0% (DMF- H_2O) increases with temperature increase, so it shows that the complexation is thermopile reaction which showed an exothermic formation process. The formation process of complexes mainly dependence on temperature which showed that the relation between complexation and desolvation of ions by increasing temperature, the desolvation of ions take a great place which caused of the ions will be nearer than before by electrostatic force between ions, so the formation of complexes increased [33]. But when comparing the values of the formation constant for $VOSO_4$ complexes with stoichiometry (1:2) in 30%, 60% (DMF- H_2O) and (1:1) stoichiometry in 0% (DMF- H_2O) decreases with temperature increase which showed an endothermic formation process.

3.3 Determination of Thermodynamics Parameter

The Gibbs free energy of formation for every stoichiometry complex (ΔG_f^0)

was determined by applying equation (3) [34-38]:

$$\Delta G_f^0 = - 2.303 RT \log K_f \quad (3)$$

By drawing the relation between $1/T$ and $\log K_f$, for all complexes strait lines were obtained as shown in Figs. 6, 7 and 8) as explains in previous works [35-40].

The change in the standard enthalpy (ΔH_f^0) for the complexation reaction was determined in the usual manner from the slope of the *Van't Hoff* plot which equal $(-\Delta H_f^0 / 2.303R)$. The change in entropy (ΔS_f^0) for $VOSO_4$ stoichiometric complexes were determined [31] for every form of complexes (1:2) and (1:1) (M: L) by applying Gibbs-Helmholtz equation (4) [41-45]:

$$\Delta G_f^0 = \Delta H_f^0 - T \Delta S_f^0 \quad (4)$$

The thermodynamic parameters (ΔH_f^0 , ΔS_f^0 , and ΔG_f^0) for the complexation between vanadyl sulfate and gliclazide are summarized in Tables 4, 5.

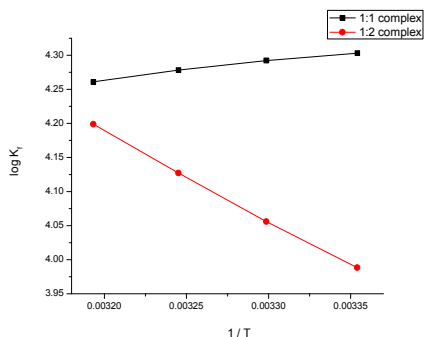


Fig. 6. $\log K_f$ against $1/T$ for $VOSO_4$ to GL in water.

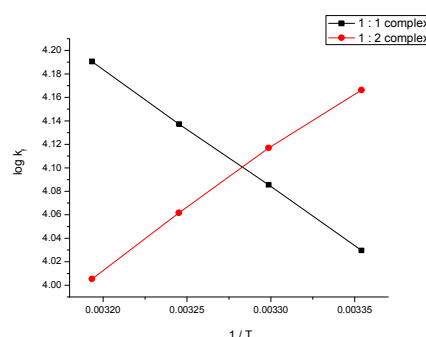


Fig. 7. $\log K_f$ against $1/T$ for $VOSO_4$ to GL in 30% (DMF- H_2O)

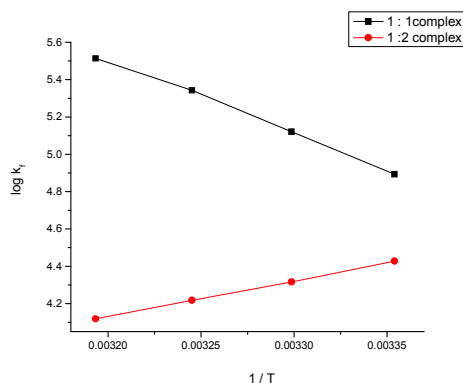


Fig. 8. $\log K_f$ against $1/T$ for $VOSO_4$ to GL in 60% (DMF- H_2O)

Table 4. Gibbs free energies (ΔG_f^0) Enthalpy change (ΔH_f^0) and entropy change (ΔS_f^0) for VOSO₄ formed complexes (1:2 M/L) with GL at various temperatures in used solvents

Solvent	T/K	ΔG_f^0 (kJ mol ⁻¹)	ΔH_f^0 (kJ.mol ⁻¹)	ΔS_f^0 (J mol ⁻¹ K ⁻¹)
0% (DMF-H ₂ O)	298.15	-22.77	25.11	160.61
	303.15	-23.54	25.11	154.52
	308.15	-24.35	25.11	160.54
	313.15	-25.18	25.11	160.60
30% (DMF-H ₂ O)	298.15	-23.78	-19.23	15.27
	303.15	-23.89	-19.23	15.38
	308.15	-23.96	-19.23	15.36
	313.15	-24.01	-19.23	15.27
60% (DMF-H ₂ O)	298.15	-25.27	-36.69	-38.27
	303.15	-25.05	-36.69	-38.38
	308.15	-24.88	-36.69	-38.31
	313.15	-24.69	-36.69	-38.30

Table 5. Gibbs free energies (ΔG_f^0) Enthalpy change (ΔH_f^0) and entropy change (ΔS_f^0) for VOSO₄ formed complexes (1:1 M/L) with GL at various temperatures in used solvents

Solvent	T/K	ΔG_f^0 (kJ mol ⁻¹)	ΔH_f^0 (kJ.mol ⁻¹)	ΔS_f^0 (J mol ⁻¹ K ⁻¹)
0% (DMF-H ₂ O)	298.15	-24.58	-5.37	64.43
	303.15	-24.91	-5.37	64.45
	308.15	-25.24	-5.37	64.47
	313.15	-25.55	-5.37	64.42
30% (DMF-H ₂ O)	298.15	-23.95	19.12	144.44
	303.15	-23.71	19.12	141.29
	308.15	-24.41	19.12	141.26
	313.15	-25.13	19.12	141.29
60% (DMF-H ₂ O)	298.15	-27.94	74.49	343.55
	303.15	-29.72	74.49	343.78
	308.15	-31.52	74.49	344.04
	313.15	-33.06	74.49	343.45

Generally; it was noticed that the thermodynamic parameters were affected by the temperature as the temperature increase the negativity of free energies (ΔG_f^0) increase as well, this shows that the systems under study are spontaneous; this clearly shows that the complex formation process prefers a lower value of the dielectric constant medium.

Enthalpy (ΔH_f^0) has positive values in pure water with stoichiometric (1:2), 30% and 60% DMF-H₂O with stoichiometric (1:1) this clearly shows that the formation reactions in these cases are endothermic, in the meantime other cases with negative values are exothermic reactions.

In all cases, the entropy (ΔS_f^0) has positive values so the spontaneity of the reaction is more favored for these complexation processes. As the positivity increase the degree of disorderliness increase as well. Except in case of 60% (DMF-H₂O) 1:2 stoichiometric we observed

that the entropy has negative value. In natural systems entropy known as an increase of randomness or disorder, and negative entropy means an increase of organization or orderliness. Negative entropy is also known as negentropy. Individual systems can experience negative entropy, but overall, natural processes in the universe trend toward entropy.

Thermodynamic parameters changes for the complexation process in (DMF-H₂O) were determined by the solvent composition. By applying Raoult's law for vapor pressure depression of binary systems, it was noticed a great deviation from ideal behavior of the binary systems, this was due to interaction between solvent's molecules, because DMF is a dipolar solvent which enables the formation of strong hydrogen bond with water; by acquiring its hydrogen atoms especially when totally miscible with water, Doubly bound oxygen is usually a good hydrogen acceptor. When water is mixed with strong hydrogen-acceptors.

4. CONCLUSIONS

The results obtained in this work showed that the composition of the binary solution and solvent properties are very important since the stability depends on the solvent-solvent interaction nature, which takes a great place in the solution. As the temperature increases the formation constant increase as well, and also with the proportion of DMF increases. Even the exceptional manner of 60% (DMF-H₂O) mixed solvent was studied. The more negative values of ΔG_f° showed that the formation reaction is spontaneous in nature. The positive charge of ΔS_f° is indicating that the entropy is the driving force for the formation reaction except in case of 60% (DMF-H₂O) in 1:2 stoichiometric has a negative charge. The positive charge of ΔH_f° is showed that the formation process is endothermic. The negative charge of the enthalpy change (ΔH_f°) is showed that the formation process is exothermic. Conductometric measurements revealed the 1:1 [LM] stoichiometry complexes more expected than 2:1 complex [L₂M].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Fernandez-Prini R. Physical chemistry of organic solvent systems. Covington Ed. A. K., Dickinson T., Plenum Press, New York. 1973;Chapter 5.
2. Gray, James R. Conductivity analyzers and their application. In Down, R.D; Lehr, J.H. Environmental Instrumentation and Analysis Handbook, Wiley. 2004;491–510.
3. Nezhadali A, Hosseini HA, Langara P. Study of complex formation between iodoquinol (IQ) and Co²⁺, Mn²⁺, Cd²⁺, Pb²⁺ and Zn²⁺ cations in DMF/EtOH binary solvent mixtures using spectrophotometry. Polish J. Chem. 2009;83:573–580.
4. Nezhadali A, Hosseini HA, Langra P. Study of complex formation between iodoquinol (IQ) and Co²⁺, Mn²⁺, Cd²⁺, Pb²⁺ and Zn²⁺ cations in binary aqueous/non-aqueous solvent using spectrophotometry. E-J. Chem. 2007;4: 581–586.
5. Nezhadali A, Langara P, Hosseini HA. Study of complex formation between 5, 7-diiodo-8-hydroxyquinoline and Zn²⁺, Cd²⁺, Pb²⁺ and Tl⁺ cations in binary non-aqueous solvents using square wave polarography technique (SWP). J. Chin. Chem. Soc. 2008;55:271–275.
6. Hakimi M, Nezhadali A, Naemi A. Conductometric study of complex formation between Cu(II) ion and 4-amino-3-ethyl-1,2,4-triazol-5-thione in binary ethanol/water mixtures, E-J. Chem. 2008;5:551–556.
7. Christopher RK, Glasson A, Lindoy LF, George V, Meehana M. Developments in the d-block metallo-supramolecular chemistry of polypyridyls. Coord. Chem. Rev. 2004;252:940–948.
8. Fainerman-Melnikova M, Nezhadali A, Rounaghi Gh, Mcmurtrie C, Kim J, Gloe J, Langer K, Lee SS, Lindoy LF, Nishimur T, Park MK, Seo LL. Metal ion recognition via selective detuning. The interaction of selected transition and posttransition metal ions with a mono-N-benzylated O₂N₃-donor macrocycle and its xylyl- bridged ring analogue. J. Chem. Soc. Dalton Trans. 2004;122–128.
9. Nezhadali A, Rabani N. Competitive bulk liquid membranetransport of Co(II), Ni(II), Zn(II), Cd(II), Ag(I), Cu(II) and Mn(II), cations using 2,20-dithio (bis) benzothiazole as carrier. Chin. Chem. Lett. 2011;22:88–92.
10. Bauer G, Günter V, Hess H, Otto A, Roidl O, Roller H, Sattelberger S. Vanadium and vanadium compounds. Ulmann, s Encyclopedia of Industrial Chemistry, Willey-VCH, Weinheim; 2005.
11. Crans DC, Trujillo AM, Pharazyn PS, Cohen MD. How environment affects drug activity: Localization, compartmentalization and reactions of a vanadium insulin-enhancing compound, dipicolinatooxovanadium(V). Coord. Chem. Rev. 2011;255(19-20):2178–2192.
12. Sarkar A, Tiwari A, Bhasin PS, Mitra M. Pharmacological and pharmaceutical profile of Gliclazide: A review. Journal of Applied Pharmaceutical Science. 2011;01(09):11-19.
13. Sokol V, Tominić I, Tomaš R, Višić M. Croat. Chem. Acta. 2005;78(1):43.
14. Roy MN, Gurung BB, Dakua VK. Int. J. Thermophys. 2006;27(5):1539.

15. Dash UN, Mahapatra JR, Lal B. J. Mol. Liq. 2006;124:13.
16. Be šter-Rogač M, Hauptman N, Barthel J. J. Mol. Liq. 2007;29:131–132.
17. Wypych-Stasiewicz A, Szejgis A, Chmielewska A, Bald A. Conductance studies of NaBPh₄, NBu₄I, NaI, NaCl, NaBr, NaClO₄ and the limiting ionic conductance in water? Propan-1-ol mixtures at 298.15 K. J. Mol. Liq. 2007;130:34–37.
18. Gileadi E, Kirowa-Eisner E. Electrolytic conductivity—the hopping mechanism of the proton and beyond. Electro. Chimica Acta. 2006;51:6003.
19. Rahimi-Nasrabadi M, Ahmadi F, Pourmortazavi SM, Ganjali MR, Alizadeh K. Conductometric study of complex formations between some substituted pyrimidines and some metal ions in acetonitrile and the determination of thermodynamic parameters. J. Mol. Liq. 2009;144:97–101.
20. El-Dossoki FI. Conductometric and spectroscopic studies of the ion pair association of sodium and potassium Picrate in 2- butanone. J. Mol. Liq. 2011;160:119–123.
21. Tsierkezos NG, Molinou IE. Transport properties of 2: 2 symmetrical electrolytes in (water+ ethylene glycol) binary mixtures at T= 293.15 K. J. Chem. Thermodyn. 2006;38:1422–1431.
22. Dagani MJ, Barda HJ, Benya TJ, Sanders DC. "Bromine Compounds" in Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH, Weinheim; 2000. DOI: 10.1002/14356007
23. Opgrande JL, Dobratz CJ, Brown EE, Liang JC, Conn GS, Wirth J, Shelton J. In: Kroschwitz J.I., M. Howe-Grant (Eds.), Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Wiley, New York. 1992;4:103–115.
24. Gomaa EA. Molal solubility, dissociation, association and solvation parameters for saturated benzoic acid solutions in various solvents at 298.15 K. Physics and Chemistry of Liquids. 2012;50:279–283.
25. Gomaa EA. Thermodynamic and polarization parameters of dibenzo-18-crown- 6 in mixed methanol water solvents. American Journal of Polymer Science. 2012;2(3):35-38.
26. Singh NM. Ion association and solvation behaviour of metal (II) chlorides in binary mixtures of methanol+ water: A conductance method. Asian Journal of Chemistry. 2016;28(4):910.
27. Marcus Y. The properties of solvents. Wiley, London; 1998.
28. Gomaa EA. Journal of King Saud University. 1991;3(1):1411.
29. Debye P, Huckel E. Z. Phys. 1923;24:185, 305.
30. Stokes R, Robinson R. Journal of the American Chemical Society. 1948;70: 1870-1878.
31. Takeda Y. Bull. Chem. Soc. Jpn. 1983;56: 3600.
32. Gomaa EA. A nalele Uni.din Bucuresti-Chimie. 2010;19(1):45-48.
33. El-Dossoki FI. Conductometric and thermodynamic studies on the ionic association of HCOONH₄, phCOONH₄, HCOONa and phCOONa in aqueous–organic solvents. J. Mol. Liq. 2008;142:72–77.
34. Read DE, Purves CB. J. Am. Chem. Soc. 1952;74:116–119.
35. Kim JI, Cecal A, Born HJ, Gomaa EA. Physik Chemic Z., Neue Folge. 1978;110:209.
36. Gomaa EA, El-Khouly AA, Mousa MA. Association of salicylic acid in acetonitrile – water media. Indian Journal of Chemistry. 1984;23:1033.
37. Gomaa EA. Single ion thermodynamics for Cl⁻, Br⁻, I⁻, Ph₄B⁻, K⁺, Rb⁺, Cs⁺ and Ph₄As⁺ in mixed hexamethylphosphort. Thermochemica Acta. 1985;91:235.
38. Abu El-Nader HM, Gomaa EA. Mansoura Science Bulletin. (A Chem.). 1996;23(1).
39. Gomaa EA, El-Askalany AH, Moussa MNH. Rev. Roum. Chim. 1987;32:243.
40. Shehatta IS, El-Askalany AH, Gomaa EA. Thermodynamic parameters of transfer and solution of oxalic acid in dimethylsulphoxide-water media. Thermochemica Acta. 1993;219:65.
41. Schrier EE, Pottle M, Scheraga HA. J. Am. Chem. Soc. 1964;86:3444–3449.
42. Suzuki E, Taniguchi Y, Watanabe T. J. Phys. Chem. 1973;77:1918–1922.
43. Gomaa EA, Abdel Razek MG. Thermodynamics of the solvation of CaSO₄ in mixed DMF-H₂O at 301.15 K.

- International Research Journal of Pure and Applied Chemistry. 2013;3:320-329.
44. Gomaa EA, Abou Elleef EM. Thermodynamics of the solvation of potassium thiocyanate in mixed DMF-H₂O solvents at 301.15K. Science and Technology. 2013;3:118-122.
45. Kazemia MS, Mahdaviab Z. Journal of General Chemistry. 2013;83:2472-2478. DOI: 10.1134/S1070363213120451

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