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Studies 0n Ion Association of Some A-Amino Acids with L-Ascorbic Acid In Aqueous Solution at Different Temperature

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Abstract
Molar conductivity of ascorbic acid (*AA*) with some α–amino acids (glycine (*Gly*), methionine (*Met*), cysteine (*Cys*) and tryptophan (*Trp*)) in aqueous solution was measured at range temperatures from 298 *K* to 313 *K*. Λ_o. The limiting molar conductivity, K_A, the association constant was calculated using the Shedlovsky method, and *R*, the association distance calculated by Stokes–Einstein equation. The thermodynamic parameters (The heat of association ΔH^o, the change in Gibbs free energy ΔG^o, the change of entropy ΔS^o), and (ΔE_S), the activation energy were also calculated. All of the results obtained were discussed. The data showed the increasing in Λ_o, with the increasing of temperature. The positive values for (ΔS^o) and (ΔE_S) showed a decrease in solvation of ion–pair and signifying the higher mobility of the ions. The negative value of ΔH^o, refers that the association processes are exothermic. The negative values of ΔG^o, are for ion association in aqueous solution and increase with the increase in temperature.

Keywords: Amino acids, ascorbic acid, ion association, conductance measurements, association distance, association constant and thermodynamic properties.

دراسة الارتباط الايوني لحامض الاسكوربيك مع بعض الاحماض الامينية في المحلول المائي عند درجات حرارة مختلفة

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الخلاصة
قيست التوصيلية المولارية لحامض الاسكوربيك مع بعض الاحماض الامينية في محاليلها المائية عند مدى درجات الحرارة من(298 K) الى (313 K) . و حسبت التوصيلية المولارية المحددة وثابت الارتباط باستخدام طريقة (Shedlovsky method). مسافة الارتباط تم حسابها باستخدام معادلة (Stokes–Einstein Eq.). وكذلك حسبت الثوابت الثرموديناميكية ($\Delta H^o, \Delta G^o, \Delta S^o$) وطاقة التنشيط ($\Delta E_S$). النتائج اظهرت ازدياد التوصيلية المولارية المحددة مع زيادة درجة الحرارة، ودلت القيم الموجبة للثوابت ($\Delta S^o, \Delta E_S$) الى انخفاض في عملية التمذوب، والى الزيادة في حركة الايونات. واظهرت النتائج ازدياد القيم السالبة للثابت الثرموديناميكي (ΔG^o) لعملية الارتباط الايوني في المحلول المائي بزيادة درجة الحرارة. وكذلك ظهرت القيم سالبة للثابت الثرموديناميكي (ΔH^o) دلالة على ان عملية التجمع الايوني باعثة للحرارة.

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1 Introduction

Amino acids are important and essential to all life [1]. They commonly exist as polymers famous as polypeptides and proteins. "Proteins serve as nutrients, regulate metabolism, assist in the absorption of oxygen, and play important roles in the functioning of the nervous system, provide the mechanical basis for muscle contraction, represent a major support material for the body, and assist in the transfer of genetic information [2]. Ascorbic acid (famous as vitamin C) in other side plays significant functions in the human body [3]. So, human tissues contain high concentrations of vitamin C (between 7–70 mg %) [4]. It is necessary for collagen synthesis, the protein that serves numerous connective roles in the body [4–5].

Neuronal ascorbate "content as maintained by this protein also has relevance for human disease, since ascorbate supplements decrease infarct size in ischemia–reperfusion injury- models of stroke, and since ascorbate may protect neurons from the oxidant damage associated with neurodegenerative diseases such as Alzheimer's, Parkinson's, and Huntington's [6].

Production of "certain hormones and neurotransmitters and the metabolism of some amino acids and vitamins require vitamin C. This vitamin also assists the liver in the detoxification of toxic substances in the system, and the blood in fighting infections. Ascorbic acid is important to the proper function of the immune system. As an antioxidant, it reacts with compounds like histamines and peroxides to reduce inflammatory symptoms. Its antioxidant property is associated with the reduction of cancer incidence [5].

So the interaction of proteins and amino acids with ascorbic acid (Figure-1) plays an important functions in biochemical processes [4–7].

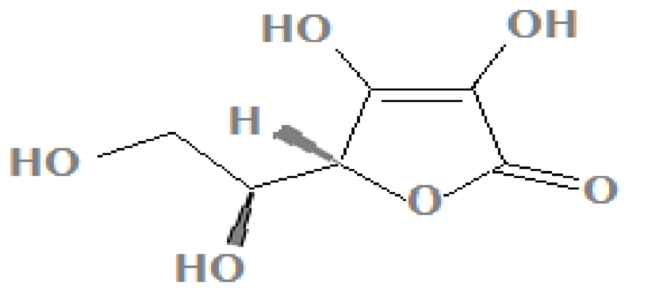


Figure 1-L-Ascorbic acid [6].

One of the most interactions is the "ion association", which is commonly used in solution chemistry [8]. As it is well known, there are two distinctive mechanisms for ionic association. The first one of ionic association is chemical association in which there is a true chemical bond. The second mechanism, result from electrostatic association, in which the association process is attributable to strong Columbic interactions, and this is one of the most fundamental atomic interactions in chemistry and biology [9].

Ion pairs (also known as salt bridge) of electrostatically interacting cationic and anionic moieties are important for proteins and nucleic acids to perform their function. Crucial intermolecular ion pairs are often found in the structures of protein–drug complexes, suggesting that deeper knowledge of ion pairs can improve drug design. Despite the fundamental importance of bio molecular ion pairs, it seems that their physicochemical properties are not well known in the molecular biology, structural biology, biophysics, and biochemistry research communities [10]. The concept of ion association, with the formation of solvent separated or contact ion pair, is involved [11].

The transport properties of "mixtures of ionic liquids (conductance, viscosity, and transference numbers) are important because the values provide useful and sensitive information about ion–solvent interaction, ionic association, and solvent structure [12, 13].

The present work reports the comparative studies of conductance measurements, association distance, association constant and, thermodynamic properties for ion association of ascorbic acid with some α–amino acids in aqueous solution at temperatures ranges from 298–313 *K*.

2 Experimental

Ascorbic acid (*AA*), glycine (*Gly*), methionine (*Met*), cysteine (*Cys*), and tryptophan (*Trp*) amino acids were purchased from "Merch" with purity at 99.9 %.

Deionized water used in preparation of solutions have specific conductance in the range of (2–3×10^{-6} *S/cm*). Solvent densities, ρ_o, viscosities, η, and relative permittivity, ε_r, are represented in Table-1. The specific conductivities were measured by digital conductivity bridges with a dip type immersion conductivity cell were used.

All the solutions of ascorbic acid and amino acids were prepared at different concentrations (2–5×10^{-3} *mol/L*) with carefully upon preparation by dissolving required quantity of the sample in conductivity water. Conductivity measurements were done at the temperature range (298–313 *K*), under control by using water bath and thermometer.

The measurements of mass using in preparation of solutions were done by using (Sartorius RC 210D) an analytical balance.

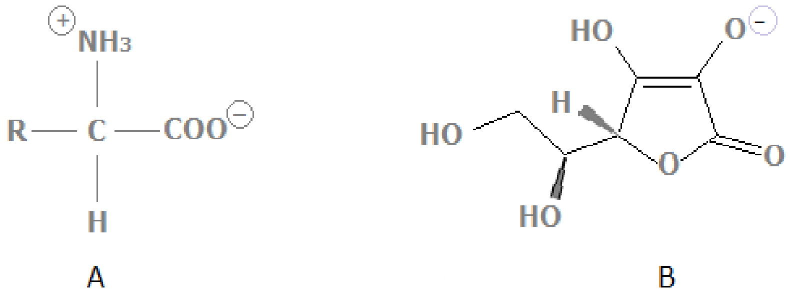
3 Results and discussion

3.1 Conductance of aqueous solution for ascorbic acid: amino acids at different temperatures. Many chemical reactions require a suitable solvent. Water is the solvent of choice in inorganic chemistry [14], has an imperative role in biological environments, and it's basic to all life.

A few basic "interactions are responsible for holding proteins together. The properties of water are intimately involved in these interactions. Polar amino acid chains can participate in hydrogen bonding to water, or hydrophobic side chains can interfere with it. Neutral polar side chains are uncharged, but they have groups (*–OH, –SH, NH, CO*) that can hydrogen-bond to water. In an unfolded protein, these residues are hydrogen-bonded to water. They prefer to be exposed to water, but if they are found in the protein interior they are hydrogen-bonded to other polar groups. On the surface of the protein, a charged residue can be solvated by water, and it is easy to separate oppositely charged ions because of the high dielectric constant of water [15]. The interaction of proteins and amino acids with ascorbic acid plays an important role in biochemical processes, and because the "structural complexity of proteins, direct thermodynamic study is quite difficult. So the low molecular weight model compounds such as amino acids are studied [8].

The numerous papers [4–7] study the relation between proteins and amino acids with ascorbic acid doesn't reports a study of conductance measurements, association constant and, thermodynamic properties for ion association of ascorbic acid with α–amino acids in aqueous solution.

The predominate state of amino acids and ascorbic acid in neutral solution can be represented in Scheme-1.



Scheme-1: A: L-α-amino acid at pKa= 2 to pKa= 9 [16], B: L-Ascorbic acid at pKa= 4 to pKa= 14 [17].

The physical properties of distilled water are given in Table-1 as reported in literature [18,19].

Table 1-Densities, ρ^o, viscosities, η, and relative permittivity, ε_r, of conductivity water at different temperatures

T/K	ρ^o / g m^{-3}	η /g m^{-1}s^{-1}	ε_r
298	0.9971	0.8903	78.30
303	0.9957	0.7974	76.55
308	0.9941	0.7194	74.83
313	0.9923	0.6531	73.15

The conductivity measured as specific conductivity κ, and converts to molar conductivity Λ, by using the following relation:

$$\Lambda = \frac{1000\ \mathrm{K}}{C} \qquad (1)$$

The affinity between different charge ions is measured by association constant. So the conductivity data were analyzed for 1:1 ascorbic acid to amino acids in aqueous solution uses set of equations.

Associations constant were calculated from the conductance data by using Shedlovsky method (*Eq. 2*) [11,20].

$$\frac{1}{\Lambda S(Z)} = \frac{1}{\Lambda_o} + \frac{K_A C \Lambda f_{\pm}^{2} S(Z)}{\Lambda_o^{2}} \qquad (2)$$

Where Λ, is the molar conductance, Λ_o, is the limiting molar conductance, C, is the concentration of solution, $f_{\pm}$, is the activity coefficient of the free ions, γ, is the degree of dissociation, K_A, is the observed association constant and $f_{\pm}$, is the mean activity coefficient of the free ions which calculated using equation 3:

$$-\log f_{\pm} = \frac{A\sqrt{I}}{1+BR\sqrt{I}} \qquad (3)$$

$$A = \frac{1.8247\times10^{6}}{(DT)^{3/2}}; \quad B = \frac{0.5209\times10^{10}}{\sqrt{DT}}$$

Where: R, is the maximum center to center distance between ions in the ion pair association, D, is the dielectric constant, η, is the viscosity (*g m-1s-1*), and T, is the temperature in K.

$$S(Z) = \left(\frac{Z}{2} + \sqrt{1+\left(\frac{Z}{2}\right)^{2}}\right)^{2} \qquad (4)$$

$$Z = \left[\frac{S}{\Lambda_o^{3/2}}\right]\sqrt{C\Lambda}; \quad S = \alpha\Lambda_o + \beta\ ; \quad \beta = \frac{82.501}{\eta\sqrt{DT}}\ ; \quad \alpha = \frac{0.8204\times10^{6}}{(DT)^{3/2}}$$

The degree of dissociation γ, in case of S (Z) can be given by:

$$\gamma = \frac{\Lambda S(Z)}{\Lambda_o} \qquad (5)$$

The result from (*Eq. 2*) compared with Fuoss–Kraus equation (*Eq. 6*) [21], and, the result is very iterative.

$$K_A = \frac{1-\gamma}{c\gamma^{2} f^{2}} \qquad (6)$$

The electrostatic radius for positive and negative diffusing species ions ($R_{\pm}$) can be calculated by using Stokes–Einstein equation **(***Eq. 7***)** [22]**.**

$$R_{\pm} = \frac{kT}{6\pi\eta D} \qquad (7)$$

Where D, is the diffusion coefficient, k, is the Boltzmann constant, T, is the temperature in Kelvin, η, is the dynamic viscosity, and $R_{\pm}$, is the hydrodynamic radius of the diffusing species.

The diffusion coefficient values of diffusing species ascorbic acid and tryptophan [23], glycine [24], methionine [25], and cysteine [26] represent in Table–2 as reported in literature, and the radius of the diffusing species $R_{\pm}$, results from Stokes–Einstein equation are shown in Table–3.

Table 2-Values of diffusion coefficients, $D /10^{-9}\ m^2/s$, of ascorbic acid and amino acids in aqueous solution

			D/ 10⁻⁹ m²s⁻¹		
T/K	***AA***	***Gly***	***Met***	***Cys***	***Trp***
298	0.68	1.00	0.57	0.78	0.66
303	0.83	1.30	0.72	0.93	0.81
308	0.98	1.45	0.86	1.10	0.97
313	1.14	1.59	1.00	1.30	1.10

Table 3-Radius of the diffusing species, $R_{\pm}$ */angstrom* (A^o), of ascorbic acid and amino acids in aqueous solution

			R/ A°		
T/K	***AA***	***Gly***	***Met***	***Cys***	***Trp***
298	3.66	2.50	4.30	3.20	3.70
303	3.40	2.30	3.90	3.00	3.40
308	3.24	2.20	3.70	2.90	3.28
313	3.12	2.20	3.60	2.70	3.24

As shown in Scheme-1, the amino acid (at pH between 2 and 9) contains both a positive α-ammonium and a negative carboxylate group [16], so the conductivity is very little. For this reason, the conductivity of the ascorbic acid solution (Table-4) was taken for a comparative with the conductivity of ion association between amino acids and ascorbic acid.

Table 4-The molar conductivity, Λ/Scm^2mol^{-1}, of ascorbic acid in aqueous solution at different temperature

		T/ K		
AA	298	303	308	313
C×10⁻³ M	***Λ***	***Λ***	***Λ***	***Λ***
2	256	259	261	262
3	224	225	227	229
4	204	206	207	208
5	185	186	187	188

The molar conductivity, Λ, of 1:1 ascorbic acid: amino acids in aqueous solution at different temperature are listed in Tables–(5–8).

The limiting molar conductivity, Λ_o, can be calculated by linear extrapolation from the plot of molar conductivity, Λ, versus the square root of the molar concentration, $C^{1/2}$ [11, 27] as showed in the Figure below.

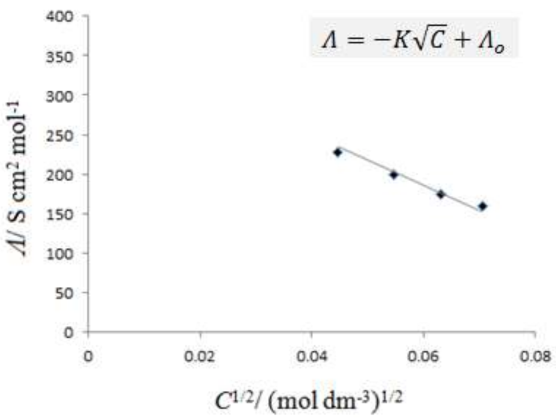


Figure 2-The plot of molar conductivity, Λ, versus $C^{1/2}$ for ascorbic acid: glycine in aqueous solution at *298 K*.

Table 5-The molar conductivity, Λ/Scm^2mol^{-1}, of 1:1 ascorbic acid: glycine in aqueous solution at different temperature

		T/ K		
Gly.	298	303	308	313
C×10⁻³ M	***Λ***	***Λ***	***Λ***	***Λ***
2	228	230	233	235
3	199	201	203	205
4	175	176	178	179
5	159	160	161	162

Table 6-The molar conductivity, Λ/Scm^2mol^{-1}, of 1:1 ascorbic acid: cysteine in aqueous solution at different temperature

		T/ K		
Cys.	298	303	308	313
$C\times10^{-3}$ *M*	***Λ***	***Λ***	***Λ***	***Λ***
2	175	178	181	183
3	147	149	151	153
4	131	132	133	134
5	119	120	121	122

Table 7-The molar conductivity, Λ/Scm^2mol^{-1}, of 1:1 ascorbic acid: methionine in aqueous solution at different temperature

		T/ K		
Met.	298	303	308	313
$C\times10^{-3}$ *M*	***Λ***	***Λ***	***Λ***	***Λ***
2	232	234	235	238
3	208	210	211	212
4	180	182	183	184
5	162	163	164	165

Table 8-The molar conductivity, Λ/Scm^2mol^{-1}, of 1:1 ascorbic acid: tryptophan in aqueous solution at different temperature

		T/ K		
Trp.	298	303	308	313
$C\times10^{-3}$ *M*	***Λ***	***Λ***	***Λ***	***Λ***
2	157	159	161	170
3	134	135	137	138
4	117	118	119	120
5	106	107	108	110

Association distance (distance parameter) *R*, is the distance between center–to–center for the ions in the formed of ion-pair, and calculated as the summation of cation and anion radii in angstrom (A^o) in addition to diameter of water molecule (equal to 2.80 A^o) [28].

The observed association constant, K_A, the limiting molar conductivity, Λ_o, and the distance of the association, *R*, are shown in Tables-(9-12).

Table 9-The limiting molar conductivity, Λ_o/ $S\ cm^2\ mol^{-1}$, observed association constant, K_A/dm^3mol^{-1}, and hydrodynamic radius of ion pair association, R/A^o, of 1:1 ascorbic acid: glycine in aqueous solution at different temperature.

		Gly		
T/ K	***298***	***303***	***308***	***313***
Λ_o	377	378	380	382
K_A	169	165	162	160
R	8.96	8.50	8.24	8.12

Table 10-The limiting molar conductivity, Λ_o/ $S\ cm^2\ mol^{-1}$, observed association constant, K_A/ $dm^3\ mol^{-1}$, and hydrodynamic radius of ion pair association, R/ A^o, of 1:1 ascorbic acid: cysteine in aqueous solution at different temperature

		Cys		
T/ K	**298**	**303**	**308**	**313**
Λ_o	320	323	326	328
K_A	237	231	227	224
R	9.66	9.20	8.94	8.62

Table 11-The limiting molar conductivity, Λ_o/ $S\ cm^2\ mol^{-1}$, observed association constant, K_A/ $dm^3\ mol^{-1}$, and hydrodynamic radius of ion pair association, R/ A^o, of 1:1 ascorbic acid: methionine in aqueous solution at different temperature.

		Met		
T/K	**298**	**303**	**308**	**313**
Λ_o	385	387	390	392
K_A	172	170	168	167
R	10.76	10.10	9.74	9.52

Table-12: The limiting molar conductivity, Λ_o/ S cm^2 mol^{-1}, observed association constant, K_A/ dm^3 mol^{-1}, and hydrodynamic radius of ion pair association, R/ A^o, of 1:1 ascorbic acid: tryptophan in aqueous solution at different temperature.

		Trp		
T/K	**298**	**303**	**308**	**313**
Λ_o	275	277	278	281
K_A	206	202	197	171
R	10.16	9.60	9.32	9.16

The ascorbic acid solution appear rising in molar conductivity relative to the conductivity of amino acids with ascorbic acids solution (as shown in Tables 4-8). This indicates that the ion association is taken place. The values of Λ, for these solutions retain the relation: AA > Met > Gly > Cys > Trp.

From Tables-(9-12), it is shown that Λ_o, values increase for ion association as the temperature increase, and the same trend is seen for K_A, values. The increase of Λ_o, with increasing of temperature, is due to the decrease of solvent viscosity [28], and higher mobility or a reduced amount of solvation of the ions in aqueous solution. This is owing to the fact that the growth thermal energy effects in greater bond breaking and also leads to higher mobility and higher frequency of ions because of variant in translational, rotational, and vibrational energy of molecules [29]. Both conductance and diffusion include movement of ions, and therefore, a connection between them will be exist [30]. So the radius of ion association is decrease as temperature increase (and as the diffusion coefficient increase), and the association distance (R/A^o) takes a sequence Met>Trp> Cys> Gly.

The values of K_A, for studied solutions retain the relation Cys > Trp > Met > Gly at all temperatures.

3.2 Thermodynamic functions measurements of ascorbic acid: amino acids in aqueous solution:

The activation energy (ΔE_S), (which is defined in a chemical system as the amount of energy available for a reaction to take place) can be calculated from equation of S. A. Arrhenius (*Eq. 8*) [12].

$$log\Lambda_o = -\left(\frac{\Delta E_S}{2.303R}\right)\left(\frac{1}{T}\right) + logA \qquad (8)$$

Where: R, ideal gas constant, A, Arrhenius factor, ΔE_S, Arrhenius activation energy, and T, is the temperature.

By plotting a graph between ($log\Lambda_o$) and $(1/T)$, straight line is obtained as displayed in Figure-3, with slope equal to $(-\Delta E_S/ 2.303R)$ from which ΔE_S value can be calculated. As shown, ΔE_S, has a positive value which points to the high mobility of ions in the solution and thus high Λ_o values.

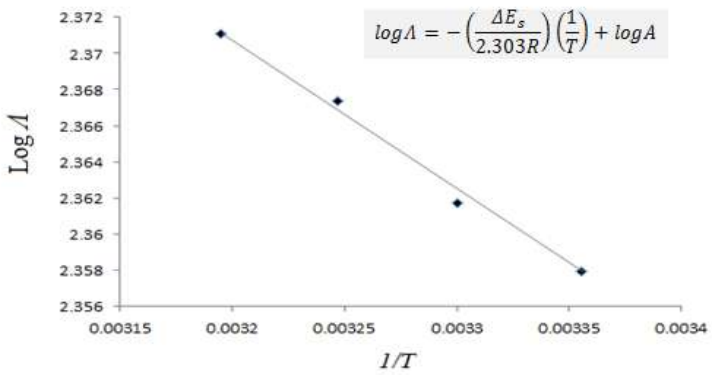


Figure 3-The plot of log Λ as a function of $1/T$ for ascorbic acid: Glycine in aqueous solution.

The heat of association ΔH^o, (or the standard enthalpy of formation refers to the enthalpy change when one mole of a compound is formed from its elements) calculated by applying Van't Hoff's expression (*Eq. 9*) [12].

$$\log K_A = -\left(\frac{\Delta H^o}{2.303R}\right)\left(\frac{1}{T}\right) + \left(\frac{\Delta S^o}{2.303R}\right) \quad (9)$$

The ΔH^o, value results from $(-\Delta H^o/2.303R)$, the slope that obtained by a plot of a graph between log K_A, and $1/T$, as shown in Figure bellow.

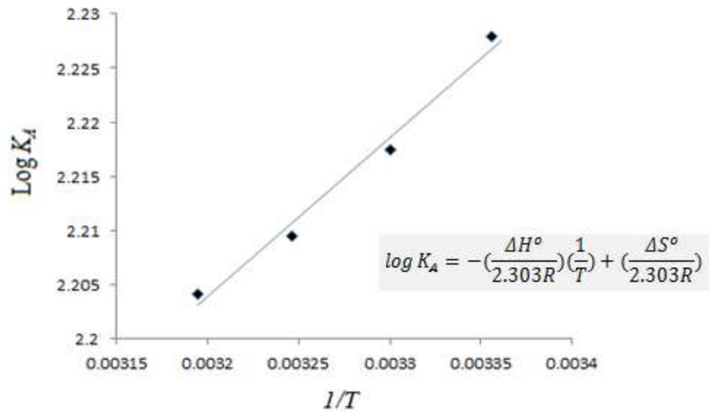


Figure 4-The plot of log K_A as a function of $1/T$ for Ascorbic acid: Glycine in aqueous solution at different temperature.

The change in Gibbs free energy ΔG^o, (a measure of usable energy in the system) throws the association process is obtained from (*Eq. 10*) [8].

$$\Delta G^o = -RT\ln K_A \quad (10)$$

Gibbs-Helmholtz equation (*Eq. 11*) [8] was used to estimate the change of entropy, ΔS^o, (the state function that gives a measure of disorder or randomness).

$$\Delta G^o = \Delta H^o - T\Delta S^o \quad (11)$$

The data result from equation (8-11) can be shown in Tables-(13-16).

Table 13-Thermodynamic parameters: ΔG^o ($KJ\ mol^{-1}$), ΔS^o ($J\ K^{-1}mol^{-1}$), ΔH^o ($KJ\ mol^{-1}$), and ΔE_s ($KJ\ mol^{-1}$), of 1:1 ascorbic acid: glycine in aqueous solution at different temperature.

		Gly		
T/K	**298**	**303**	**308**	**313**
ΔG^o	-13.50	-13.70	-13.96	-14.21
ΔS^o	38.70	38.70	42.30	39.10
ΔH^o		-1.98		
ΔE_s		+1.92		

Table 14-Thermodynamic parameters: ΔG^o ($KJ\ mol^{-1}$), ΔS^o ($J\ K^{-1}mol^{-1}$), ΔH^o ($KJ\ mol^{-1}$), and ΔE_s ($KJ\ mol^{-1}$), of 1:1 ascorbic acid: cysteine in aqueous solution at different temperature.

		Cys		
T/K	***298***	***303***	***308***	***313***
ΔG^o	-12.50	-13.05	-13.31	-13.56
ΔS^o	32.85	34.13	34.42	34.67
ΔH^o		-2.71		
ΔE_s		+2.59		

Table 15-Thermodynamic parameters: ΔG^o ($KJ\ mol^{-1}$), ΔS^o ($J\ K^{-1}mol^{-1}$), ΔH^o ($KJ\ mol^{-1}$), and ΔE_s ($KJ\ mol^{-1}$), of 1:1 ascorbic acid**:** methionine in aqueous solution at different temperature.

		Met		
T/K	**298**	**303**	**308**	**313**
ΔG^o	-13.49	-13.74	-13.98	-14.24
ΔS^o	39.10	39.27	39.42	39.62
ΔH^o		-1.84		
ΔE_s		+0.66		

Table 16-Thermodynamic parameters: ΔG^o ($KJ\ mol^{-1}$), ΔS^o ($J\ K^{-1}mol^{-1}$), ΔH^o ($KJ\ mol^{-1}$), and ΔE_s ($KJ\ mol^{-1}$), of 1:1 ascorbic acid: tryptophan in aqueous solution at different temperature.

		Trp		
T/ K	***298***	***303***	***308***	***313***
ΔG^o	-12.53	-12.77	-13.01	-13.36
ΔS^o	28.96	29.27	29.58	30.22
ΔH^o		-3.90		
ΔE_s		+1.94		

From Tables-(13-16) the result data show that:

The activation energy ΔE_S, is a positive result for the ion association in aqueous solution and this signifying that higher mobility of the ions in aqueous solution and therefore a higher Λ_o, values. The values of ΔG^o, decrease with increase in temperature. The decrease in ΔG^o, values for the ion association in aqueous solution to fewer values at rising temperature favoritisms the transfer of the free solvent molecules to the bulk solvent and this indication to a reduced ΔG^o values. The values of ΔG^o, are negative for the ion association in aqueous solution. This indicates that the association is favorite rather than the dissociation process in aqueous solution. The parameter ΔH^o, shown negative values in aqueous solution, and this refers that the interaction between ions with a negative values to exothermic association processes in nature but the value is very small. A positive ΔS^o, values indicate an increase in disorder of ions in aqueous solution, because of reduction in the solvation of ion-pair related to that of the free ion. This can be due to increase in the freedom degree throw association processes, and this is because the freedom of solvent molecules [12, 28, 29].

4 Conclusions

Molar conductivity of ascorbic acid with some α–amino acids in aqueous solution has been reported at T = 298 to 313 K. The limiting molar conductivity Λ_o, and the association constant K_A, are calculated using the Shedlovsky method. The association distance R, calculated by Stokes–Einstein equation. The data indicate that Λ_o, values increase for ion association as the temperature increase, and the same trend is seen for K_A, values. The increase of Λ_o, with an increase of temperature is due to the decrease of solvent viscosity [28], and higher mobility or a reduced amount of solvation of the ions in aqueous solution. This is owing to the fact that the growth thermal energy effects in greater bond breaking and also lead to higher mobility and higher frequency of ions because of variant in translational, rotational, and vibrational energy of molecules [29]. Both conductance and diffusion include movement of ions, and therefore, a connection between them will be exist [30]. So the radius of ion association is decrease as temperature increase (and as the diffusion coefficient increase). ΔH^o, ΔG^o, ΔS^o, the thermodynamic parameters and ΔE_S, the activation energy also calculated. ΔE_S, is a positive result for the ion association in aqueous solution and this signifying that higher mobility of the ions in aqueous solution.

The values of ΔG^o, decrease with increase in temperature for the ion association in aqueous solution because of transfer of the free solvent molecules to the bulk solvent. The values of ΔG^o, are negative to indicate that the association is favorite rather than the dissociation process in aqueous solution. The parameter ΔH^o, shown small negative values in aqueous solution refer to exothermic association processes in nature, and this can be caused by the interaction between ions. A positive ΔS^o, values indicate an increase in randomness of ions in aqueous solution, because of reduction in the solvation of ion-pair related to that of the free ion, and this is because the free solvent molecules [12, 28, 29].

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