



Estimate the Ionization Constant, Thermodynamic Parameters of Some Valine – Metal ion complexes

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Abstract The metal complexes of valine with Cr(III), Mn(II), Fe(II), Fe(III), Ni(II), Cu(II), and Cd(II), were synthesized, the structure of prepared compounds has been investigated by using different methods including conductivity measurements, melting point, and I.R spectroscopy. The ionization constants (pKa) Moreover, thermodynamic parameters of the ligand and metal complexes were calculated and discussed by applying the potentiometric technique.

Keywords metal complexes, valine, potentiometric technique

Introduction

The amino acid ligands are present as twitter ions, in which the nitrogen is weakly basic and the hydroxyl group is weakly acidic. The p^{ka} values of the proton dissociation from the neutral α -amino acids have been determined potentiometrically in the pH range from 2.7 to 8.5, almost all amino acids are present mainly as the single protonated form HL ($L = R-CH_2-COO^-$). The proton being attached to the α -amino group. A few amino acids occur as the H_2L or H_2L^+ forms at lower pH values [1].

The functional groups in amino acids are responsible for the chelation. Evidently, the chelation takes place by the amino-carboxylate group with a simultaneous abstraction of the proton on the α -amino group. The basicity of the carboxylate group is somewhat diminished in comparison to the uncomplex state [2].

Valine (abbreviated Val) is an essential amino acid (an α -amino acid) that is utilized within the biosynthesis of proteins. It is important for muscle metabolism and the growth of tissue. It contains an α -amino group (which is in the protonated $-NH_3^+$ form under biological conditions), an α -carboxylic acid group (which is in the deprotonated $-COO^-$ form under biological conditions), and a side chain isopropyl group, making it a non-polar aliphatic amino acid. It is fundamental in humans, meaning the body cannot synthesize it. It must be obtained from the diet [3].

The molecular formula is $C_5H_{11}NO_2$, the other name is 2-Amino-3-methylbutanoic acid, the chemical structure is shown in Figure 1:

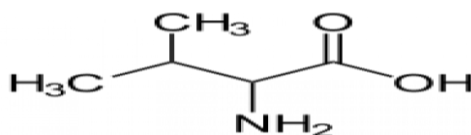


Figure 1: Chemical Structure of L-Valine

Coordination complexes of transition metals have been widely studied for their antibacterial, antifungal and potential cytotoxic chemotherapeutic agents. They have been evaluated against several pathogenic fungi and bacteria with promising results. One of the approaches to increase the efficacy of the drugs consists in their modification of physical and chemical factors. In addition to its ability to combat infection or neoplastic disease, these new agents must exhibit selective toxicity, chemical stability, and optimum rates of bio-transformation and elimination [3].

This study aims to organize new complexes through modified interactions between Valine (Legend) and some metal ions including (Cr (III), Mn (II), Fe (II), Fe (III), Ni (II) and Cu (II), Cd (II) and), as well as calculating thermodynamic parameters (ΔH , ΔS , and ΔG), and estimating pka values for prepared complexes.

2. Materials and Methods

2.1. Materials

All chemicals which used in this study were laboratory grade. They including: $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$, CdCl_2 , FeCl_2 , FeCl_3 , $\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$, $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$, and Valine. In addition to some chemical as: ammonia, ethanol, NaOH, HCl.

2.2. Synthesis of metal –L- Valine - complexes

The complexes were prepared by the following method: 0.09 mole of CrCl_3 was dissolved in 100 ml ammonia, then added with stirring to 0.09 mole of Valine ligand in 100 ml ammonia, whereas, the metal chlorides of (NiCl_2 , CuCl_2 , CdCl_2 , FeCl_3 , FeCl_2 and MnCl_2) were dissolved in 100 ml distilled water then added with stirring to 0.09 mole of Valine ligand in 100 ml distilled water. The reaction mixture was refluxed and then left overnight. The precipitated solid complexes were separated out by filtration, then washed with water and dried over P_2O_5 for many days.

2.3. Infra-red spectra

The infrared spectra of the ligands and their metal complexes were taken in potassium bromide discs using the I.R-spectrophotometer covering the range from 200 to 4000 cm^{-1} .

2.3. Determination of electrical conductivity

The electrical conductivity of the solutions of the complexes was measured using conduct meter (Type HANA).

2.3. Melting point

The melting point of the studied complexes were measured by using Melting point equipment, Type Toldo Melo.

2.4. Potentiometric determination of the ionization constants of the ligands and the stability constants of their metal chelates

The ionization constants of the ionizable groups are determined potentiometrically [using Jenway, pH-meter 3310] applying Sarin and Munshi technique which involve preparation of the three mixtures:

- 5 ml of standard 0.01M HCl + 5 ml of 1M NaCl + 15 ml ethanol.
- 5 ml of 0.01M HCl + 5 ml of 1M NaCl + 15 ml of ethanol + 0.5 ml of 0.1M ligand.
- 5 ml of 0.01M HCl + 5 ml of 1M NaCl + 15 ml of ethanol + 0.5 ml of 0.1 M Ligand + 0.5 ml of 0.1 M metal chloride.

Each one of the above three mixtures were titrated potentiometrically against standard sodium hydroxide solution (0.05M) using pH – meter at a particular temperature and ionic strength. The values of pH were recorded after each addition of NaOH. The relation between pH and volume of NaOH added was drawn for each mixture.

The three titration curves obtained are referred to as:

- acid titration curve.
- ligand titration curve.



(c) complex titration curve.

The three titration curves (a, b and c) were plotted for each chelate. The previous procedure was repeated for all of 7 chelates.

2.5. Determination of thermodynamic parameters

The following thermodynamic parameters: ΔG° , ΔH° and ΔS° were determined for each chelate depending on their stability constants.

The free energy of formation (ΔG°) of a complex is related to its stability constant by the relation

$$\Delta G^\circ = -2.303 RT \log \beta \quad (1)$$

R = universal gas constant.

T = absolute temperature.

$\log \beta$ = stability constant of the complex

Enthalpy of formation (ΔH°) and entropy (ΔS°) were calculated by plotting $\log \beta$ versus $1/T$.

We can specify the quantitative dependence of the stability

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (2)$$

$$\Delta G^\circ = -2.303 RT \log \beta = \Delta H^\circ - T\Delta S^\circ$$

we can rearrange this equation to give

$$\log \beta = -\Delta H^\circ / (2.303 RT) + \Delta S^\circ / (2.303 R) \quad (3)$$

Note that this is a linear equation of the form $y = m x + b$, where $y = \log \beta$, $m = -\Delta H^\circ / (2.303 R) = \text{slope}$, $x = 1/T$, and $b = \Delta S^\circ / (2.303 R) = \text{intercept}$. This means that if the values of K for a given reaction are determined at various temperature, a plot of $\log \beta$ versus $1/T$ will be linear, with slope $-\Delta H^\circ / (2.303 R)$ and intercept $\Delta S^\circ / (2.303 R)$. This result assumes that both ΔH° and ΔS° are independent of temperature over the temperature range considered. This assumption is a good approximation over a relatively small temperature range.

3. Results and Discussion

3.1. Characterization of the prepared complexes

The physical properties of the prepared complexes as (colors, conductivity and melting point were given in Table (1).

Table 1: The colors, conductivity and melting point of valine complexes

Complex	Parameter	Color	E.C (5S)	Melting point (°C)
Val – CrCl ₃		Violet	2.78	277
Val – CuCl ₂		Blue	1.60	256
Val – NiCl ₂		Green whit	1.90	300
Val – CdCl ₂		Whit	2.35	298
Val – FeCl ₂		Yellowish brown	1.94	240
Val – FeCl ₃		Orange	2.50	226
Val – MnCl ₂		Brown	1.97	340
Val – ZnCl ₂		Green	7.67	344

From Table (1) it is clear that the colors of ligand were changed from brown color of free ligand to several colors according to the type metal, this change mainly due to the effect the linkage between the Schiff base, and for to the difference of electrons in 3d orbital's, where during the attracting between the Schiff base and the metal the electrons which are in d orbital and portion them for group the high and less in energy, the magnetic frequency beam is proportion with the difference in energy between the two states energy in atom. Some electrons rise into energy high level. And ability nothingness the atom on absorbing several from the beam frequencies, the color of the complex depended on the number electrons in orbital d for metal and on the nature ligand whenever increase strongly ligand increasing the difference in energy between the two groups 3d the separate [4].



The results of electrical conductivity (EC) were ranged between (1.60 – 7.67 $\mu\text{S}/\text{cm}$), supports the presence of non – electrolyte nature for these complexes, also these values indicated that no anions existed outside the coordination sphere.

The difference in the melting point values between free ligand and complexes, mainly attributed to the bounded between the metals and the ligand.

3.2. Infrared spectra studies

The I.R spectra were used to know the mode of the prepared complexes. This is simply done by comparing the infrared spectra of the complexes to that of the ligand. A comparison of the IR spectra of the ligand and its metal complexes brings out the following:

1- The bands of Valine is located at 3144 cm^{-1} and 2934 cm^{-1} and 1563 cm^{-1} are assigned to OH (H_2O) and N-H and C = O, respectively. The first band of the free ligand is shifted to higher frequency in case of the most complexes (Cd, Cr, Cu and Ni) and completely disappeared in case of the Mn complex. On the other hand, the δ N-H ligand band is subjected to changes in position in the Cd, Cr, and Cu complexes but completely disappeared in case of the Ni complexes. From these results can come to a conclusion that the amino group is of major importance for coordination in most of the studied complexes.

2- The ligand gave two infrared spectral bands in the vicinity of 1658 cm^{-1} and 1409 cm^{-1} attributable to the asymmetric and symmetric vibrations of the carboxyl groups [5]. The band at 1409 cm^{-1} is slightly shifted in case of cadmium , chromium complexes and shifted to lower frequency, but still existing in the same position in case of the zinc complex and becomes of broad nature in case of manganese and nickel complexes [6].

It was reported that the metal- oxide. stretching frequencies lie within the range 700-500 cm^{-1} . In most of the metal complexes possible coupling can occur. This can be attributed to $\gamma_{(\text{M-O})}$ ring deformation. In many instances two bands are observed: one of medium to strong intensity and a weaker band at frequency 10 - 40 cm^{-1} lower than the stronger band. However, the frequency of $\gamma_{(\text{M-O})}$ is not very sensitive to the atomic mass of M [7]. The nitrogen atom tends to lower the solubility of the complexes in non- solvents. So the complexes of oxygen-nitrogen ligands are in general, either sparingly soluble or insoluble in non-polar solvents from the sparse data available, oxygen-nitrogen ligands appear to give rise to a smaller reduction, in -the inter electronic repulsion energy than oxygen - oxygen Ligands. This presumably is due to that the nitrogen atom having a low position compared to some donor atom in the nephelauxetic series [8]. Also, the metal-nitrogen stretching frequencies can occur over a wide range, viz. from 600 to below.

3- The band Located at 988 cm^{-1} in the free ligand could be assigned to diametric structure, Such band is shifted in the most prepared complexes, but absent in case of Ni complexe. Based on the I.R data of the Fundamental groups (N–H, NH_2 and COOH) and the data obtained from the electronic measurements gathered with the elemental analysis. The bands of the studied complexes were shown in Table 2.

Table 2: Fundamental infrared band (cm^{-1}) for the prepared Valine complexes

Complex	OH(H_2O)	NH_2	C= O	M-O	M - N
Val-Ni(II)	-	2932	1582	752	493
Val-Cu(II)	3279	3157	1610	645	489
Val-Cd(II)	-	2934	1583	663	476
Val-Fe(III)	3347.49	-	1590	685	415
Val-Fe(II)	3347.41	-	1586	635	414
Val-Cr(II)	3230	2966	1610	687	476
Val-Mn(II)	-	2966	1589	720	471

3.3. Thermodynamic parameters of ionization of the valine- metal complexes

The experimental procedure used in this work has been discussed in the experimental section. In this case the following three solutions have been prepared:

a- A solution containing the mineral acid alone.



b- A solution containing the mineral acid and the ligand only.

c- A solution containing the mineral acid, ligand and metal ion.

Each one of the above three solutions was titrated with standard sodium hydroxide solution and are referred to as curves a, b and c, respectively. The experimental results so obtained at various temperatures (25°C and 35°C), the titration curves of the all ligands and metal ions studied are given in Figures (2-14).

The ionization constants (pK_a) of the ionizable groups in the investigated ligands of amino acid were determined by applying the potentiometric technique described by some studies [9], they using titration curves (a) and (b). Inspection of the titration curves for the ligands (curves b) shows that these are characterized by the presence of one sharp jump indicative of one neutralization equilibrium for each ligand.

The stability constants of the studied metals complexes with amino acids using the method described by Sarin and Munshi [10]. The stability constant for each complex was determined at two different temperatures (25° and 35°C), in order to determine the thermodynamic parameters for each complex.

Referring to the titration curves it can be found that the complex titration curve is separated from ligand titration curve, the end points of the titration of the three mixtures increase in the order $a < b < c$. The potentiometric curves are almost S-shaped (Figure 15).

All calculations in this research were carried out by "Microsoft Excel" program, and the curves were obtained using "Origin" program,

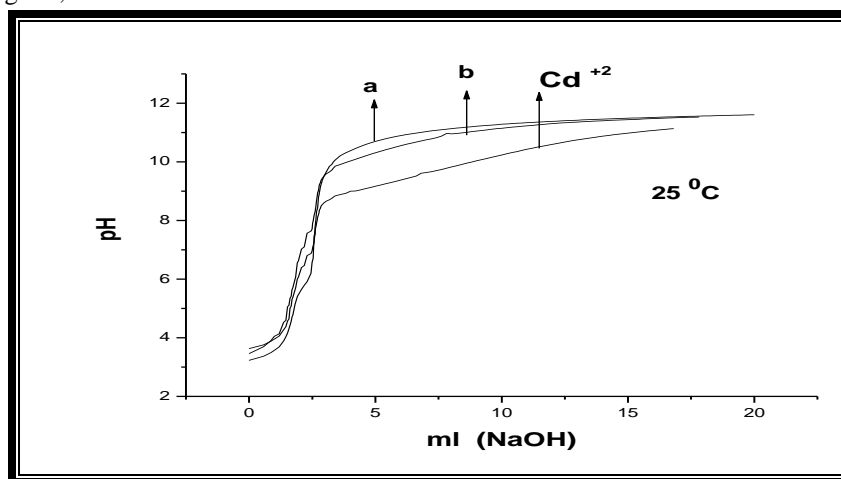


Figure 2: The titration curves of Cd^{+2} complex at 25 °C

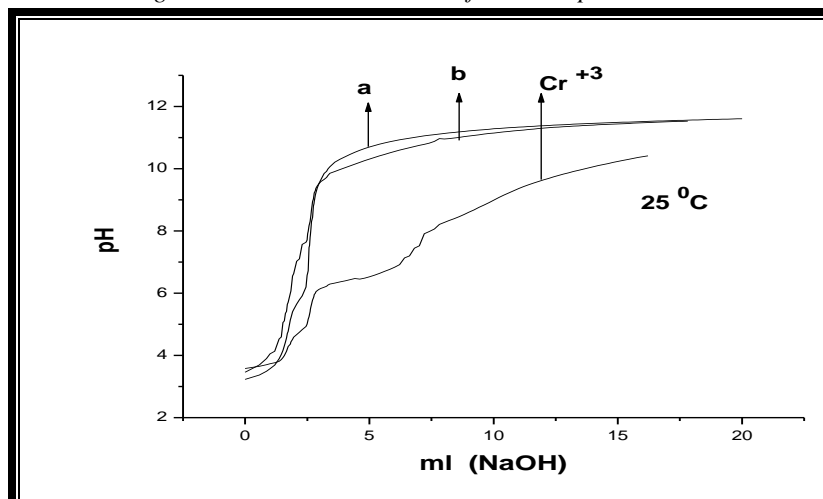


Figure 3: The titration curves of Cr^{+3} complex at 25 °C

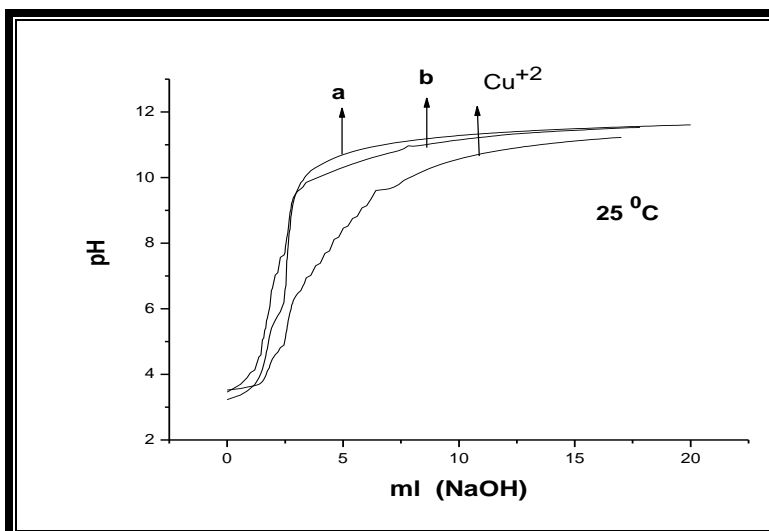


Figure 4: The titration curves of Cu^{+2} complex at 25 °C

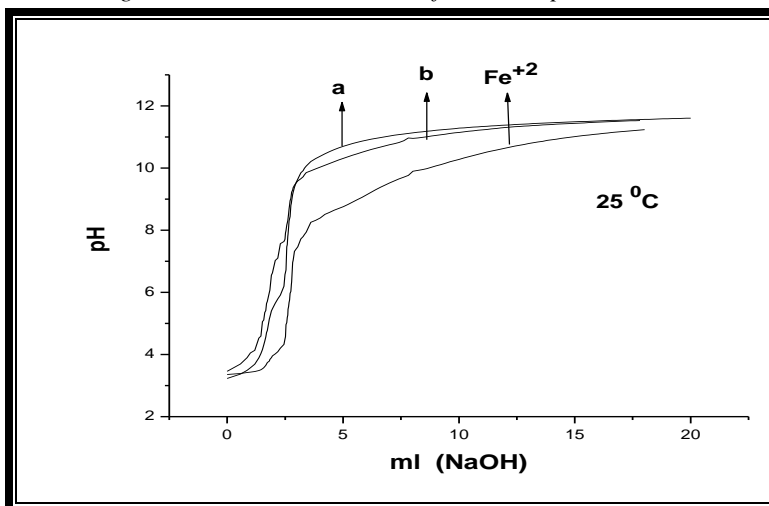


Figure 5: The titration curves of Fe^{+2} complex at 25 °C

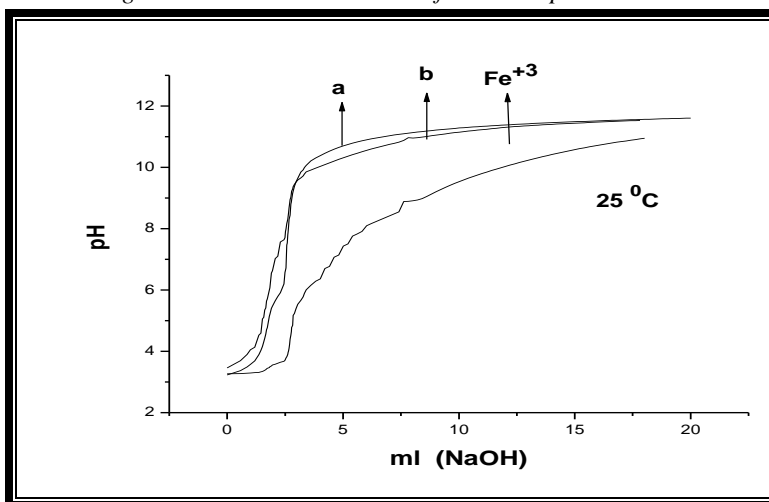


Figure 6: The titration curves of Fe^{+3} complex at 25 °C

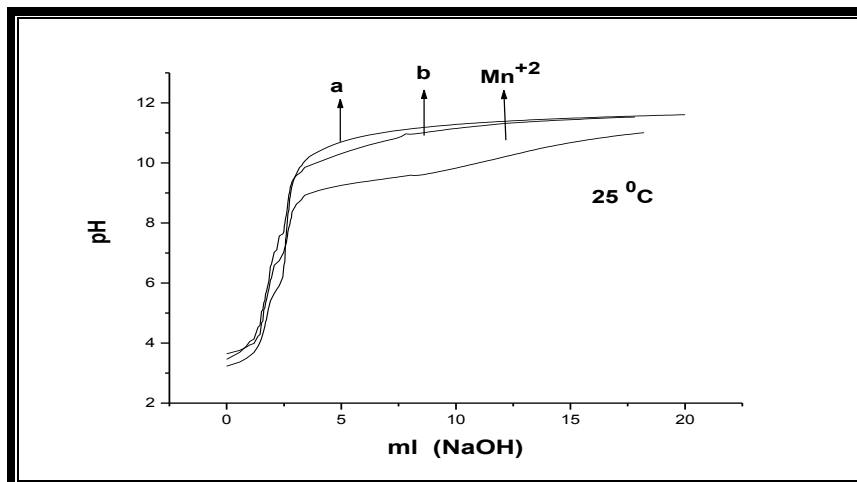


Figure 7: The titration curves of Mn^{+2} complex at $25\text{ }^{\circ}C$

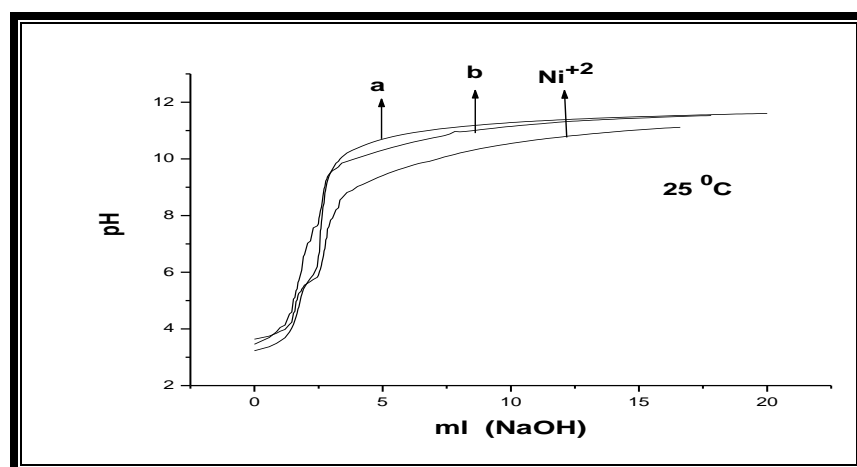


Figure 8: The titration curves of Ni^{+2} complex at $25\text{ }^{\circ}C$

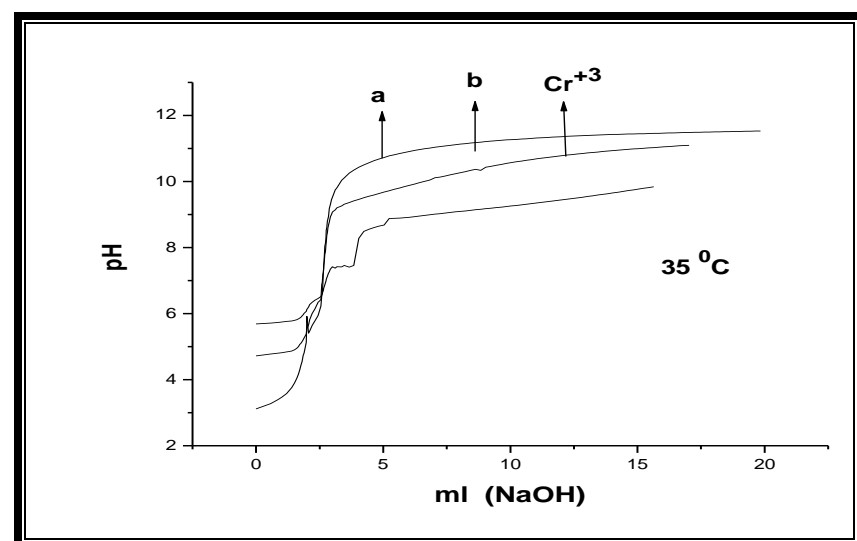


Figure 9: The titration curves of Cr^{+3} complex at 35 °C

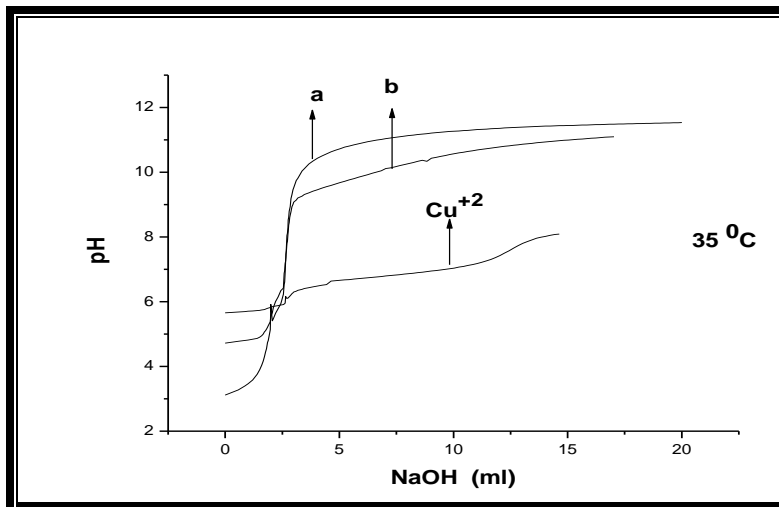


Figure 10: The titration curves of Cu^{+2} complex at 35 °C

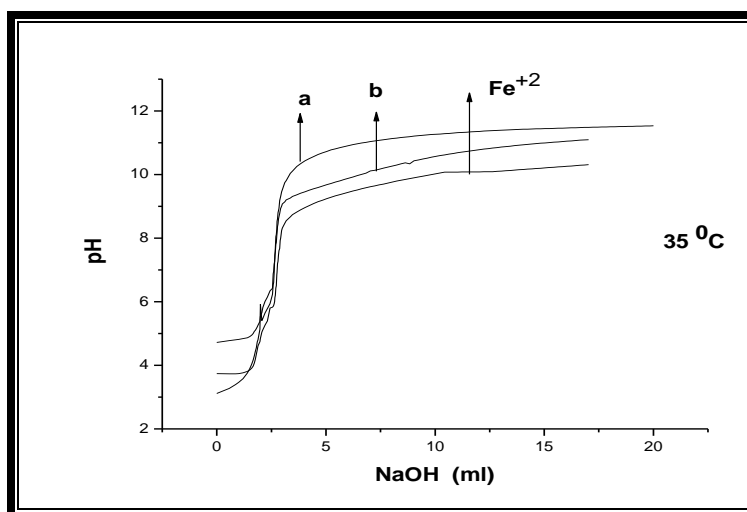


Figure 11: The titration curves of Fe^{+2} complex at 35 °C

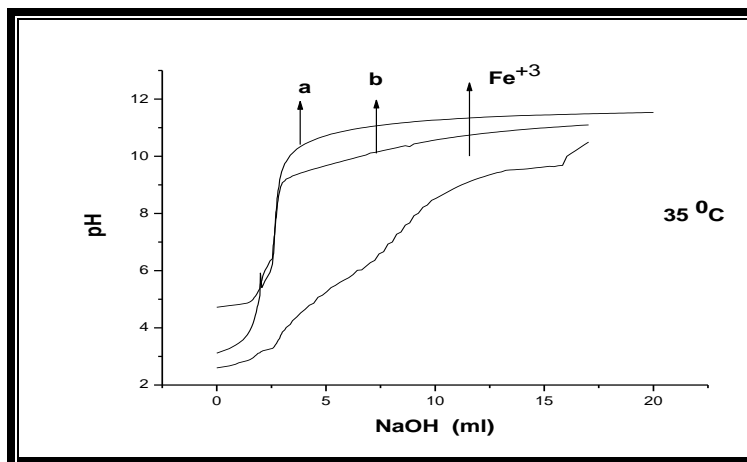


Figure 12: The titration curves of Fe^{+3} complex at 35 °C

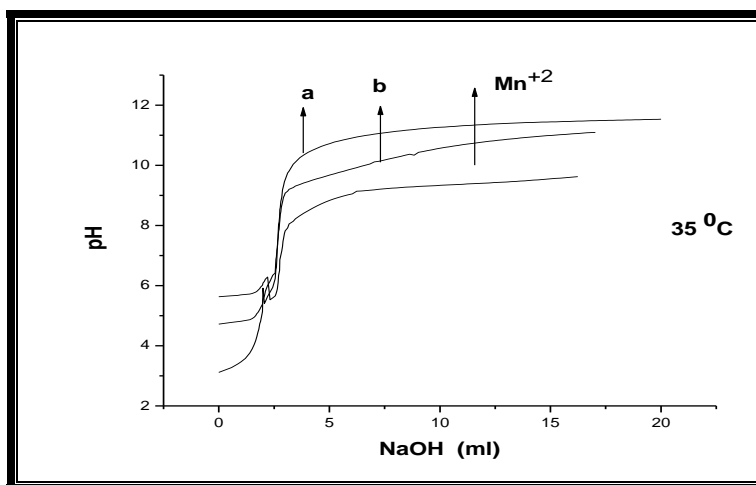


Figure 13: The titration curves of Mn^{+2} complex at 35 °C

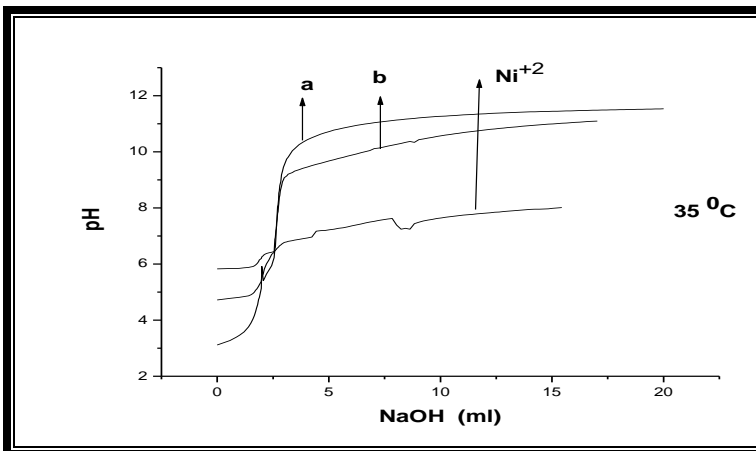


Figure 14: The titration curves of Ni^{+2} complex at 35 °C

The behavior of such compounds at different temperatures was investigated in the temperature values of 25 – 35 °C . The data are represented in (Figure 15) and (Table 3). From equation (1):

$$pka = (\Delta H / 2.303RT) + \text{Const.}$$

On plotting the pka (log β) values versus $1/T$, straight lines are obtained with a slope amounting to $\Delta H / 2.303$, from which the ΔH values, (K.Cal /mole) can be computed (5).

1- The free energy values , ΔG (K.cal/mole) are calculated based on the equation (1)

$$\Delta G = 2.303 RT \text{ pk}$$

2- The ΔS values are achieved based the equation (2)

$$\Delta G = \Delta H - T\Delta S$$

One can come to the following observations and conclusions: The p^{Ka} values of Valine ligands increase with the increasing temperature. Table III, interesting observation can be made. In case of the ligands under investigation, the ΔS values are of negative sign .such finding goes parallel to those reported for ligands containing amino acids [10-12] through intermolecular hydrogen bonding [13-15].



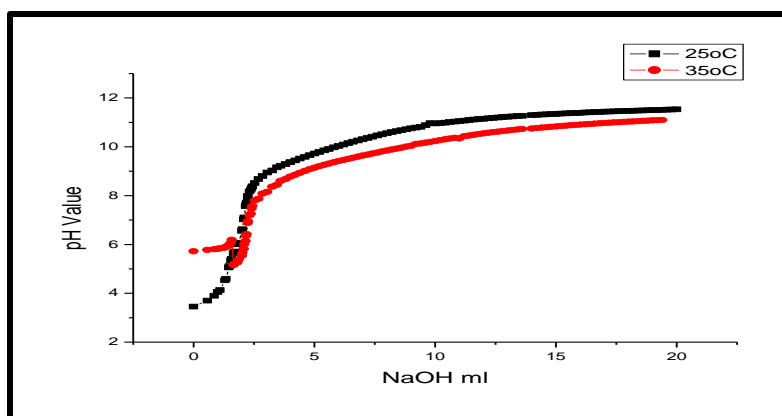


Figure 15: pH-titration curves of Valine at different temperatures

Table 3: Thermodynamic parameters of ionization of the valine- metal complexes

Parameter	Pk (log β)		ΔG at25°C KJ/mol	ΔG at 35°C KJ/mol	ΔH KJ/mol	ΔS J / Kmol
	25°C	35°C				
Compound						
Val-Cd	6.19	6.17	35.33	36.40	3.25	-107.64
Val-Cr	3.69	7.5	21.05	44.23	- 669.57	- 2317.52
Val-Cu	3.55	5.43	20.27	32.02	- 330.10	-1175.71
Val-Fe⁺²	2.94	9.0	16.77	53.08	- 1064.99	- 3630.07
Val-Fe⁺³	9.2	8.9	52.49	52.48	52.72	- 0.77
Val-Mn	5.89	8.2	33.61	48.36	- 405.96	- 1524.56
Val-Ni	5.18	6.34	29.57	37.39	-203.44	-781.92

4. Conclusion

The p^{K_a} values of Valine ligands decrease with the increasing temperature. The values of the overall stability constants of the complexes obtained are relatively high indicating good stability for the complexes. In case of the ligands under investigation, the ΔS values are of negative sign .such finding goes parallel to those reported for ligands containing amino acids.

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