

# Thermodynamics and Potentiometric Studies of Mixed Ligand Complexes of Salicylic Acid and Tryptophan with CO(II), Ni (II), CU(II) and Zn(II) ions.

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## Abstract

The interaction of Co(II), Ni(II), Cu(II) and Zn(II) metal ions with Salicylic acid (SAL), Tryptophan (TRP) and mixed ligand (SAL-TRP) have been studied potentiometrically. Potentiometric titrations were carried out at different temperatures. The protonation/stability constants and stoichiometries of the ligands, formed binary and ternary complexes have been calculated at I = 0.1 M KCl in 60-40 % (by v/v) Dimethylsulphuroxide (DMSO)-Water mixture. The stability of ternary complexes was quantitatively compared with the stability of the binary complexes with reference to  $\Delta\log_{10}k$ ,  $\Delta\log_{10}\beta$  and  $\log_{10}x$  parameters. The effect of temperature on protonation of ligands and formation of mixed-ligand complexes was studied at (308, 318 and 328 K) and the corresponding thermodynamics parameters were obtained from the plot of  $\ln\left(\frac{k_{obs}}{T}\right)$  vs  $\frac{1}{T}$ . The protonation was spontaneous, exothermic and entropically unfavourable. The formation of metal complexes has been found to be non-spontaneous, endothermic and entropically favourable. The stability order of complexes with reference to metal ions has been in the order of Cu(II) > Co(II) > Ni(II) > Zn(II) in concord with the Irving-William stability order. The ternary complexes were more stable than binary complexes.

**Keywords:** Potentiometry; Protonation, Salicylic acid, tryptophan, complex formation.

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## I. Introduction

The chemistry of metal-drug coordination compounds is more widespread now than before especially in the design of more biologically active drugs (Singh and Rai, 2014). Mixed ligand complexes differ from traditional complexes in the sense that they are having at least two different kinds of ligands associated with the same metal ion in a complex (Wankhede et al., 2014). Transition metal ions ability to bind a variety of organic ligands in an attempt to get optimal stability and enhanced biological activity. In most cases metal complexes show higher bio-activity than the free ligands. Metal ions are known to affect the action of many drugs (Singh and Rai, 2014). The stability of metal complexes with medicinal drugs perform greater role in the biological and chemical activity.

The ternary complexes derived from the bio-relevant ligands containing N, O donor bonding sites with M (II) ions are utilized in several fields such as biological, analytical industrial and therapeutic applications (Kuhad et al., 2007).

There is evidence that the co-ordination compounds of some metal, especially the 3-d transition, with salicylate ions have increased biological activity. Salicylic acid derivatives (Salicylates) entered into medical practice in the late XIX century and are used till date. Derivatives such as acetylsalicylic acid (Aspirin), sodium salicylate, salicylamide, methyl salicylate, used as pain killers (analgesics), fever (antipyretics) and antithrombotics (antiplatelet agents). (Lising, 2007). Also, metal ions are essential elements for healthy life to human and higher animals (Lanier, et al. 2007). Particularly, the late first row transition metals such as cobalt, nickel, copper and zinc are biologically relevant metals as they are associated with various biomolecules related to essential physiological activities.

In the other hand, amino acids like tryptophan possess specific significance among the other molecules since they are the structural units of proteins found in tissues of the human body. Also, the reaction between metal ions and amino acids is of worthy concern as a model for metal-protein interactions and different biological systems (Jackson, et al., 1990). Amino acids and their ternary complexes are used in various fields

like biology, pharmacy and industry (Pisarewicze, 2005). They are involved in several activities in the human body like neurotransmitter function, PH-setting, cholesterol metabolism, pain treatment, toxins removal and inflammation control. Metallic complexes including salicylic acid and amino acid bearing the importance of both amino acids and salicylates has become of immense biological importance. Also, calculations of stability constants of the complex formation of biologically active ligands with metal ions in addition to calculations of the concentration of each species at any PH are very important for the whole understanding of the physiochemical manner of such compounds (Sigel, 1982).

Additionally, protonation constants are of paramount importance in pharmaceutical studies particularly for the discovery and evaluation of novel compounds that could be effective drugs. We report here the solution equilibrium studies of the mixed ligand complexes of some transition metal ions ( $\text{Cu}^{2+}$ ,  $\text{Co}^{2+}$ ,  $\text{Ni}^{2+}$  and  $\text{Zn}^{2+}$ ), salicylic acid (SAL) as the primary ligand and Tryptophan (TRP) as the secondary ligand are carried out potentiometrically in 6% (V/V) DMSO-water mixture at  $I=0.1\text{mol (dm}^3 \text{ NaCl)}$ . The thermodynamic parameters were calculated and discussed.

## II. Materials And Methods

### Materials

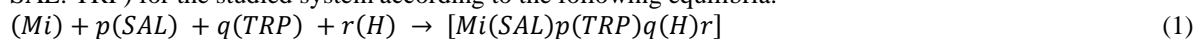
All chemicals utilized in this investigation were of the analytical reagent grade (AR) quality and of highest purity. The reagents were supplied by Bristol Scientific and made by Sigma Aldrich. They include salicylic acid and tryptophan. Metal salts include  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ ,  $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ ,  $\text{NiCl}_2$  and  $\text{ZnCl}_2$ . The metal content of solution was established using complexometric EDTA titrations.

### Methods

#### Potentiometric Titration

The protonation/deprotonation constants of the ligands (salicylic acid and tryptophan) and stability of complex formation were measured potentiometrically. pH-metric titration was carried out by using a calibrated HANA instrument pH meter, a pp13788 Radleys heating magnetic stirrer. The conductance of the cell solution was measured with an El Hama instrument conductometer TH27.

Components of the cell solution was mixed in a beaker and covered with a lid which has three openings for the pH meter, conductometer and tube from the burette. The temperature of the cell solution was measured by a thermometer after heating or placing it in iced water. The cell solution which is made up of ligands (salicylic acid and tryptophan) and metal ions of either ( $\text{Zn}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Ni}^{2+}$  and  $\text{Co}^{2+}$ ) was mixed in specific ratios. The metal ions and ligands were mixed in the ratio of 1:1, 1:2 for the binary complexes and 1:1:1 and 1:2:1 for the ternary system. The mixture was stirred continuously at a constant speed of 1200 rpm during the titration using a pp13788 Radley's heating magnetic stirrer. The mixture was titrated with 0.1M NaOH or 0.1M HCl depending on the initial pH of the complex solution. The titration went on until there was no change in pH even on addition of excess titrant. The pH and volume of the titrant was recorded, the pH-meter reading was converted into  $[\text{H}^+]$  as given in literature (Gundunz *et al.*,1993).The stability constants of the binary complexes were investigated potentiometrically by titration using metal salt (0.001M)+ SAL or TRP ( $1\text{mol/dm}^3$ ).The stability constants of the ternary complexes were investigated using potentiometric data obtained from mixtures of  $\text{M}^{2+}$ , SAL and TRP. The stoichiometries and stability constants of the complex species were determined by examination of various probable composition models as 1:1:1, 1:1:2 and 1:2:1 ( $\text{M}^{2+}$ : SAL: TRP) for the studied system according to the following equilibria.



$$Bipqr = \frac{[Mi(\text{SAL})_p(\text{TRP})_q(\text{H})_r]}{[M]^i[\text{SAL}]^p[\text{TRP}]^q[\text{H}]^r} \quad (2)$$

I,p,q and r are stoichiometric quantities of the metal ions (i),ligands-p(SAL),q(TRP) and protons(r).

## III. Results

Table 1: Stability constant for binary and ternary complexes of salicylic acid (SAL) and tryptophan (TRP) in 60 % DMSO-40 % water at different temperatures.

System	T°C	i	p	q	R	$\text{Log}_{10}\beta$	$\text{Log}_{10}k_1^a$	$\text{Log}_{10}k_2^b$	$\text{Log}_{10}k_1^a - \text{Log}_{10}k_2^b$
SAL	15	0	1	0	1	$3.92 \pm 0.02$			
		0	1	0	2	$9.52 \pm 0.02$			
TRP		0	0	1	1	$9.81 \pm 0.01$			
Cu-SAL		1	1	0	0	$4.03 \pm 0.03$	4.03	3.71	0.36
		1	2	0	0	$7.74 \pm 0.04$			

*Thermodynamics and Potentiometric Studies of Mixed Ligand Complexes of Salicylic Acid ..*

Cu-TRP	1	0	1	0	1.11±0.01	1.11	0.47	0.64
	1	0	2	0	1.58±0.08			
Co-SAL	1	1	0	0	8.29±0.09	8.29	7.53	0.75
	1	2	0	0	17.82±0.02			
Co-TRP	1	0	1	0	4.08±0.08	4.08	3.50	0.58
	1	0	2	0	7.66±0.06			
Ni-SAL	s1	1	0	0	4.07±0.08	4.07	3.54	0.52
	1	2	0	0	7.62±0.02			
Ni-TRP	1	0	1	0	4.29±0.09	4.29	3.64	0.65
	1	0	2	0	7.93±0.03			
Zn-SAL	1	1	0	0	5.28±0.00	5.28	4.55	0.72
	1	2	0	0	9.83±0.03			
Zn-TRP	1	0	1	0	5.38±0.08	5.38	5.14	0.24
	1	0	2	0	11.54±0.04			
Cu-SAL-TRP	1	1	1	0	20.20±0.00			
Zn-SAL-TRP	1	1	1	0	14.40±0.00			
Co-SAL-TRP	1	1	1	0	13.20±0.00			
Ni-SAL-TRP	1	1	1	0	17.40±0.00			
SAL	25	0	1	0	9.97±0.07			
TRP		0	0	1	5.97±0.07			
		0	0	1	9.10±0.00			
Cu-SAL	1	1	0	0	1.56±0.06	1.56	1.23	0.33
	1	2	0	0	1.03±0.03			
Cu-TRP	1	0	1	0	2.88±0.08	2.88	0.71	2.17
	1	0	2	0	3.59±0.09			
Zn-SAL	1	1	0	0	2.50±0.00	2.50	2.22	0.75
	1	2	0	0	4.72±0.02			
Zn-TRP	1	0	1	0	4.10±0.00	4.10	3.12	0.98
	1	0	2	0	7.52±0.02			
Co-SAL	1	1	0	0	4.40±0.00	4.40	2.70	0.78
Co-TRP	1	2	0	0	7.10±0.00			
	1	0	1	0	2.92±0.02	2.92	1.05	1.87
	1	0	2	0	5.97±0.07			
Ni-SAL	1	1	0	0	4.08±0.08	4.08	2.49	0.54
	1	2	0	0	6.57±0.07			
Ni-TRP	1	0	1	0	5.10±0.00	5.10	3.91	1.19
	1	0	2	0	9.01±0.01			
Cu-SAL-TRP	1	1	1	0	22.20±0.00			
Ni-SAL-TRP	1	1	1	0	18.20±0.00			
Co-SAL-TRP	1	1	1	0	14.00±0.00			
Zn-SAL-TRP	1	1	1	0	13.20±0.00			
SAL	35		1	0	4.90±0.00			
		0	1	0	7.40±0.00			
		0		2				
TRP		0	0	1	5.60±0.00			

Cu-SAL	1	1	0	0	5.30±0.00	5.30	4.90	0.37
	1	2	0	0	10.20±0.00			
Cu-TRP	1	0	1	0	4.10±0.00	4.10	3.40	0.70
	1	0	2	0	7.50±0.00			
Zn-SAL	1	1	0	0	6.20±0.00	6.20	4.30	0.83
	1	2	0	0	10.50±0.00			
Zn-TRP	1	0	1	0	4.00±0.00	4.00	3.90	0.03
	1	0	2	0	7.70±0.00			
Co-SAL	1	1	0	0	3.40±0.00	3.40	2.80	0.87
	1	2	0	0	6.20±0.00			
Co-TRP	1	0	1	0	6.10±0.00	6.10	4.10	2.00
	1	0	2	0	10.20±0.00			
Ni-SAL	1	1	0	0	3.50±0.00	3.50	3.00	0.60
	1	2	0	0	6.50±0.00			
Ni-TRP	1	0	1	0	4.50±0.00	4.50	3.00	1.50
	1	0	2	0	7.50±0.00			
Cu-SAL-TRP	1	1	1	0	21.76±0.06			
Ni-SAL-TRP	1	1	1	0	12.40±0.00			
Co-SAL-TRP	1	1	1	0	10.80±0.00			
Zn-SAL-TRP	1	1	1	0	10.50±0.00			

logK<sub>1</sub><sup>a</sup>: Corresponds to the first association constant of the ligand or formation of 1:1 ML complex  
 logK<sub>2</sub><sup>b</sup>: Corresponds to the second association constant of the ligand or formation of 1:2 ML<sub>2</sub> complex.  
 I,p,q,r are stoichiometric quantities of the metal ions (i),ligands p(SAL),q(TRP) and protons (r).

Table 2: Evaluated values of log<sub>10</sub>β; Δlog<sub>10</sub>K; Δlog<sub>10</sub>β and log<sub>10</sub>X for the formation of [M(SAL)(TRP)] complexes in 60 %-40 % DMSO-water mixture at I = 0.1 M KCl and T = 35 °C.

Complex	log <sub>10</sub> β <sub>1110</sub> (exp)	Δlog <sub>10</sub> K <sup>a</sup>	log <sub>10</sub> X <sup>b</sup>	log <sub>10</sub> β <sub>stat</sub> <sup>c</sup>	Δlog <sub>10</sub> β <sup>d</sup>
Cu-SAL-TRP	21.76	12.36	25.74	1.23	20.53
Ni-SAL-TRP	12.40	4.40	10.80	1.15	11.25
Co-SAL-TRP	10.80	1.30	5.20	1.20	9.60
Zn-SAL-TRP	10.50	0.30	2.80	1.25	9.25

$$\Delta \log_{10} K^a = \log_{10} \beta_{1110} - \log_{10} \beta_{1100} - \log_{10} \beta_{1010}$$

$$\log_{10} X^b = (2 \log_{10} \beta_{1110} - \log_{10} \beta_{1020} - \log_{10} \beta_{1200})$$

$$\log_{10} \beta_{stat}^c = \log_{10} 2 + 1/2 \log_{10} \beta_{1020} + 1/2 \log_{10} \beta_{1200}$$

$$\Delta \log_{10} \beta^d = \log_{10} \beta_{1110} - \log_{10} \beta_{stat}$$

Table 3: Thermodynamics parameters for the association of M-SAL and M-SAL-TRP complexes.

System	T(k)	k <sub>obs</sub>	k <sub>obs</sub> /T	Log <sub>10</sub> k <sub>obs</sub> /T	1/T (K <sup>-1</sup> )
Cu-SAL	288	0.32	0.0011	-2.9586	0.0035
	298	0.33	0.0011	-2.9576	0.0034
	333	0.37	0.0011	-2.9566	0.0030
Zn-SAL	288	0.72	0.0025	-2.6021	0.0035
	298	0.75	0.0025	-2.6020	0.0034
	333	0.83	0.0025	-2.6018	0.0030
Co-SAL	288	0.75	0.0026	-2.5850	0.0035
	298	0.78	0.0026	-2.5848	0.0034
	333	0.87	0.0026	-2.5847	0.0030
Ni-SAL	288	0.52	0.0017	-2.7447	0.0035
	298	0.54	0.0018	-2.7446	0.0034
	333	0.60	0.0018	-2.7445	0.0030
Cu-SAL-TRP	288	20.20	0.0701	-1.1540	0.0035
	298	20.95	0.0703	-1.1530	0.0034
	333	23.47	0.0705	-1.1520	0.0030

Zn-SAL-TRP	288	14.40	0.050	-1.3010	0.0035
	298	14.90	0.050	-1.3010	0.0034
	333	16.65	0.050	-1.3010	0.0030
Co-SAL-TRP	288	13.19	0.0458	-1.3391	0.0035
	298	13.68	0.0459	-1.3381	0.0034
	333	15.33	0.0460	-1.3371	0.0030
Ni-SAL-TRP	288	18.21	0.0632	-1.1990	0.0035
	298	18.93	0.0635	-1.1970	0.0034
	333	21.11	0.0634	-1.1980	0.0030

Table 4: Thermodynamic parameters for the association of M-SAL and M-SAL-TRP:

System	$\Delta H$ (KJ/mol)	$\Delta S$ (JK <sup>-1</sup> mol <sup>-1</sup> )	$\Delta G$ (KJ/mol)
Co-SAL	3.56	-20.15	6006.26
Zn-SAL	4.75	-21.62	6446.32
Ni-SAL	-2.97	-22.80	6791.43
Cu-SAL	29.69	-24.48	7324.73
Cu-SAL-TRP	29.69	-9.49	2857.71
Ni-SAL-TRP	5.94	-9.94	2968.06
Zn-SAL-TRP	1.66E-10	-10.82	3.224E-3
Co-SAL-TRP	29.69	-11.02	338.71

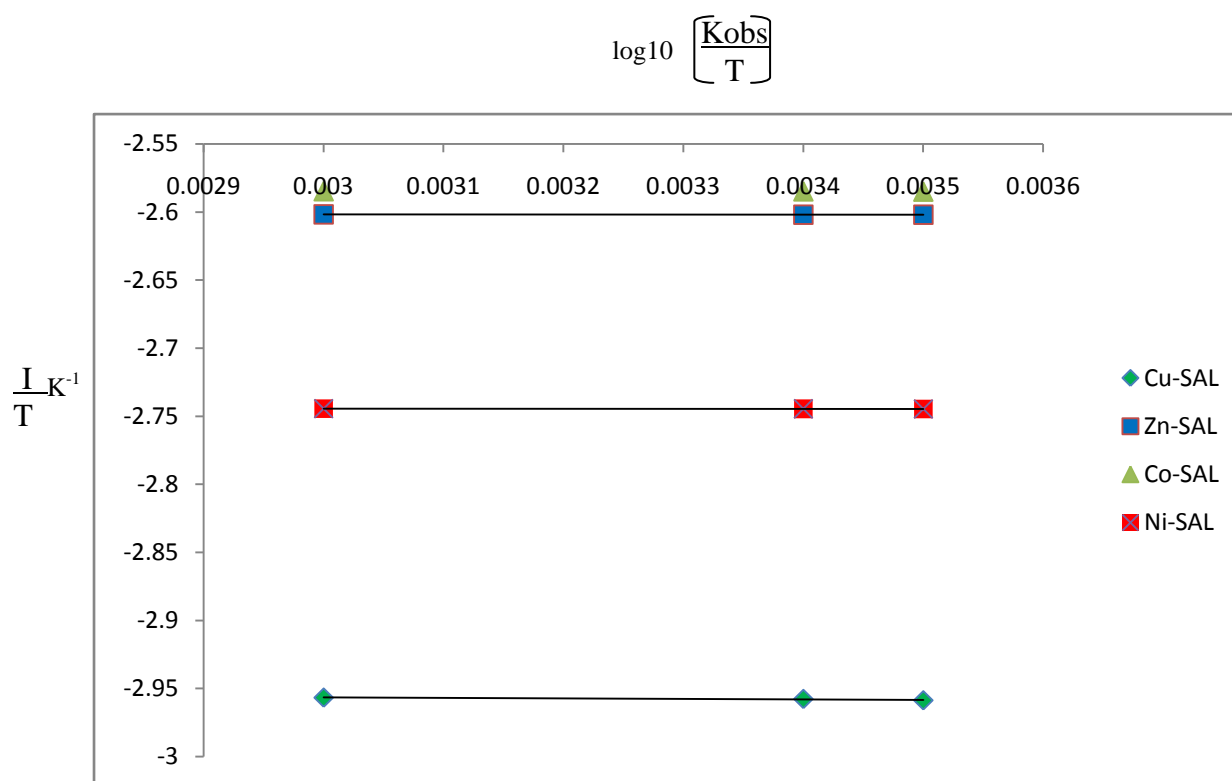
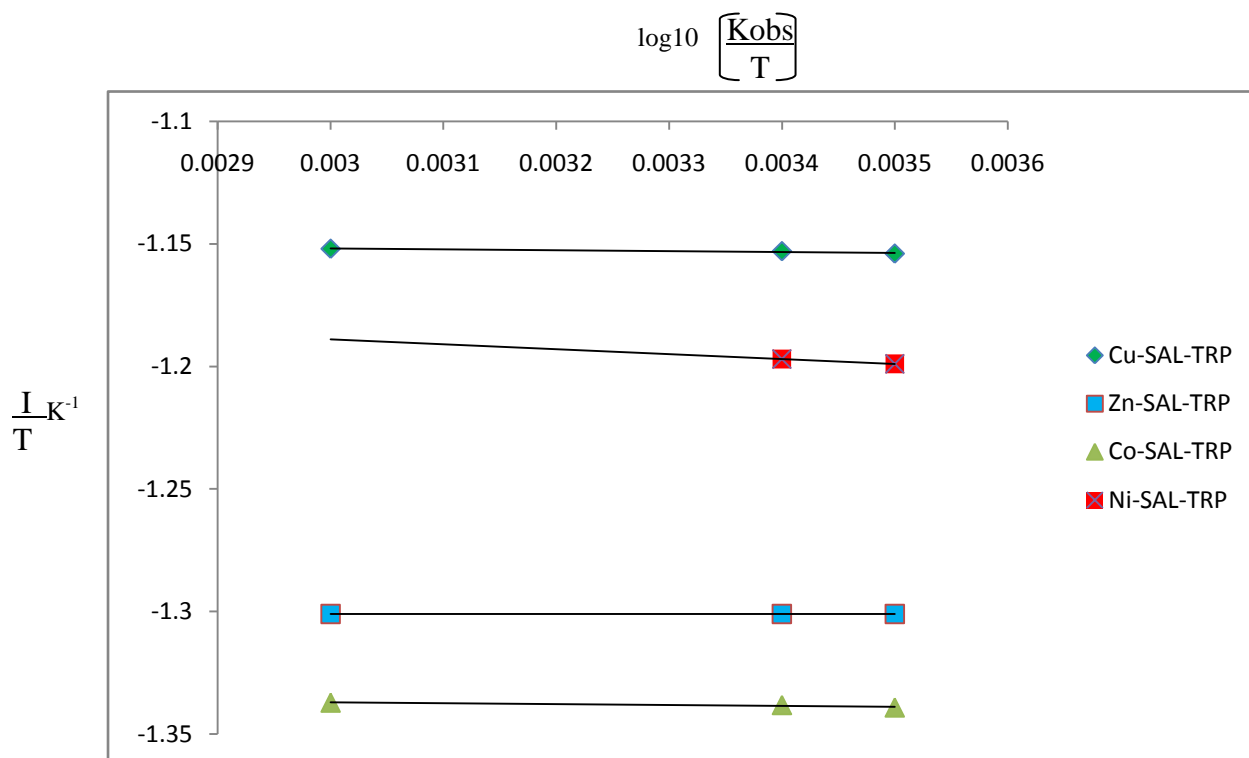


Figure 1: Van't Hoff plot of  $\log_{10}k_{obs}/T$  of M(II)-SAH binary complexes versus  $1/T$

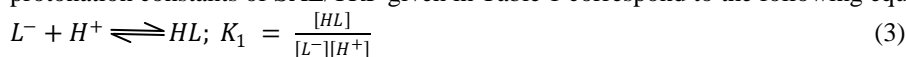

 Figure 2: Van't Hoff plot of  $\log_{10}k_{\text{obs}}/T$  of M(II)-SAL-TRP Ternary complexes versus  $1/T$ 

## IV. Discussion

### 4.1. Equilibrium Studies

#### 4.1.1. Protonation constants of salicylic acid (SAL) and tryptophan (TRP)

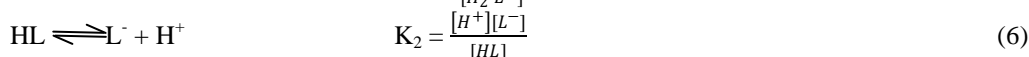
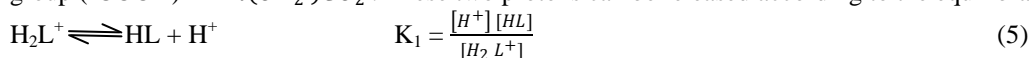
The results of pH titration are summarized in Table 1. The salicylic acid and tryptophan can accept two protons in protonic solution to give the acid  $H_2(\text{TRP})$  and  $H_2(\text{SAL})$ . The protonation constants ( $K$ ) in stability study expressed in terms of proton-ligand formation constant or protonation constants is given by Eqs (3) and (4). The protonation constants of SAL/TRP given in Table 1 correspond to the following equilibria (3 and 4):



The  $\log_{10}K_1$  value is linked to the attachment of proton to the phenolic oxygen in SAL and  $\log_{10}K_2$  value is related to the attachment of proton to the carboxyl oxygen atom in SAL ligand. Also, two protonation constants for the investigated tryptophan amino acid were calculated according to Eqs (3) and (4). The  $\log_{10}K_1$  value was associated to the attachment of proton to the  $NH_2$ -group in tryptophan and  $\log_{10}K_2$  value corresponds to the protonation of carboxylic group (Zamzam *et al.*, 2018). As can be noticed in Table 1, the value of protonation constant for salicylic acid (9.97) is higher than that of tryptophan (5.97). This suggested the presence of only oxygen atoms on salicylic acid, which is a very strong acceptor of hydrogen bond and nitrogen atom on tryptophan which can be a donor during the forming of hydrogen bond (Seliger *et al.*, 2016).

#### 4.1.2 Deprotonation constants of salicylic acid (SAL) and tryptophan (TRP)

Table 2 represents the pH titration results of protonated salicylic acid and tryptophan. Upon the addition of sodium hydroxide diprotonation occurs. The two protons in  $H_2L^+$  are certainly bounded at the terminal acetate group ( $-RCOO_2^-$ ) and amino group ( $-NH_2$ ) in  $RCH(NH_3^+)CO_2^-$  and phenolic group ( $-OH$ ) and carboxylic group ( $-COOH$ ) in  $Ph(OH_2^+)CO_2^-$ . These two protons can be released according to the equilibria (5) and (6).

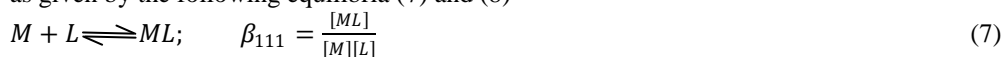


The decrease in the pH values of protonated salicylic acid and tryptophan was linked to the deprotonation constant  $\log K_1$  and  $\log K_2$  of salicylic acid and tryptophan. This indicated the consecutive release of protons from the terminal acetate group ( $-RCOO_2^-$ ) and amino group ( $-NH_2$ ) in  $RCH(NH_3^+)CO_2^-$  and phenolic group ( $-OH$ ) and carboxylic group ( $-COOH$ ) in  $Ph(OH_2^+)CO_2^-$ , suggesting the oxygen donor atoms on acetate group of the tryptophan as the preferred coordination site for the first metal center, and the nitrogen atom on amino group

from the pendant arms for the second coordination site and oxygen donor atoms on carboxylic group as the first preferred coordination site on salicylic acid and oxygen donor atom on phenolic group as the second preferred coordination site on salicylic acid (Yumnam and Rajkumary, 2009).

#### 4.1.3. Metal-ligand stability of binary complexes

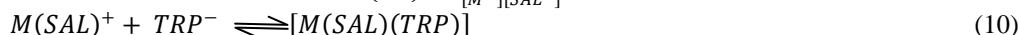
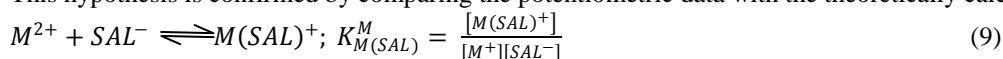
Binary complex formed shifted the pH values from lower to higher as compared to the free ligand solution (SAL or TRP). This indicated that formation of complexes was through release of hydrogen ion upon complex formation (Mahrouka *et al.*, 2014). Calculation of the stability constants of all binary complexes with SAL and TRP taking into account all the possible species ( $H_2L$ ,  $HL$ ,  $L$ ,  $M(II)$ ,  $ML$  and  $ML_2$ ). Table 1 shows the logarithm of the formation constants for all types of complexes, which have been identified using Potentiometric titration as given by the following equilibria (7) and (8)



Stability constants that have been obtained in this study were consistent with the values reported in literature, but the little difference in values between them is due to the difference in the practical conditions of the experiments ( $I = 0.1$  M KCl and 60-40 % DMSO- water mixture). The difference between the stability constants for the complexes formed in the molar ratios 1:1 and 1: 2 is usually positive, ranging between 0.24-2.17. The positive value of difference between the stability constants  $\log_{10}K_1$  and  $\log_{10}K_2$  were attributed to the more freely available sites on the metal for coordination of the first ligand than the second one. The study showed increase of stability constants of metal chelates for the same ligand at constant temperature in this arrangement  $Cu^{2+} > Ni^{2+} > Co^{2+} > Zn^{2+}$  (Mahrouka *et al.*, 2014). This order of stability indicated that the changes in the heat of complex formation across this series results from a combination of the influence of both the polarizing ability of the metal ion and the stabilization energy of crystal field (Mahrouka *et al.*, 2014).

#### 4.1.4. Metal-ligand stability of ternary complexes

According to the difference between the complexation ability of SAL and TRP, the ternary complex formation may proceed through either a simultaneous or stepwise mechanism. The formation constants of the binary metal(II) complexes with salicylic acid and the tryptophan were found approximately to be of the same order. Accordingly, the coordination of salicylic acid and tryptophan will occur simultaneously according to Eq. (9). This hypothesis is confirmed by comparing the potentiometric data with the theoretically calculated values.

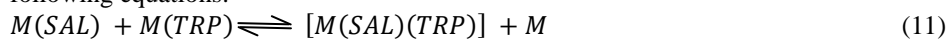


The stability constants for ternary complexes are given in Table 1. The stability constants of the ternary systems in terms of metal ions obeyed this order  $\log_{10}K[Cu(SAL)(TRP)] = 22.20 > \log_{10}K[Ni(SAL)(TRP)] = 18.20 > \log_{10}K[Co(SAL)(TRP)] = 14.00 > \log_{10}K[Zn(SAL)(TRP)] = 13.20$ . This order reflects that the stability of  $Zn^{2+}$  with the ligand compound is the lowest in the selected ions. This is due to the lower charge and specific behaviour of metal ion,  $Cu^{2+}$  has a greater lattice and solution energies hence higher formation constant for complexes of  $Cu^{2+}$  ions hence  $Cu^{2+}$  shows higher stability as expected.  $Co^{2+}$  complexes with ligand is more stable than corresponding  $Ni^{2+}$  complexes. This is attributed to the size of the metal ions. The order of stability constant of the metal chelates under investigation are  $Zn^{2+} < Co^{2+} < Ni^{2+} < Cu^{2+}$  which is in conformity with the Irving Williams natural order of stability (Al-Ahdal *et al.*, 2013).

### 4.2 Comparison of the Stability Constants of the Ternary Complexes with those of the Binary Complexes

#### 4.2.1 $\Delta \log K$ parameter

$\Delta \log_{10}K$  parameter represents the difference between the stabilities of the binary and ternary complexes. This parameter also reflects the effect of the coordinated primary ligand towards the coming secondary ligand. The characteristics of using  $\Delta \log_{10}K$  parameter in comparing stabilities of ternary and binary complexes were reviewed and accepted (Cotton *et al.*, 2000). As a result of more available coordination sites for binding of ligand in the binary than in the ternary complexes, it was expected that, negative values for  $\Delta \log_{10}K$  should be obtained. Depending on the scientific fact that the values of  $\Delta \log_{10}K$  depend on the coordination number of metal ion, the values of  $\Delta \log_{10}K$  coefficient for a regular and distorted octahedral geometries are -0.4 and -0.9 respectively (Segel 1980). According to Segel 1980, the relative stability of the ternary  $M(SAL)(TRP)$  (11) complexes in comparison to its binary complexes  $M(SAL)$  (11) and  $M(TRP)$  (12) can be expressed by the following equations:

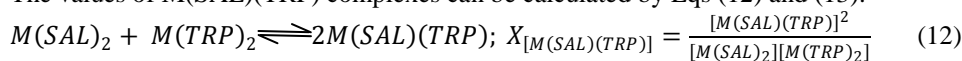


$$\Delta \log K_{[M(SAL)(TRP)]} = \log \beta_{[M(SAL)(TRP)]} - (\log \beta_{M(SAL)} - \log \beta_{M(TRP)})$$

In this study, the amino acid is coordinated with great ease with the free metal ion than with the complex metal ion  $M(SAL)^+$  in which the Lewis-acidity of metal(II) ion is depressed. Therefore, the value of  $\Delta\log_{10}K$  must be negative. According to the  $\Delta\log_{10}K$  values that have been obtained in this study and given in Table 2, the positive values of  $\Delta\log_{10}K$  can be considered as strong evidence for the occurrence of promoted stability of the formed complexes involving  $\pi$ -back donation from the negatively charged amino acid to the  $\pi$ -system of the SAL. The enhanced stability of ternary complexes in comparison to the binary complexes can also be explained by suggestion of inter-ligand interaction that exists between TRP amino acid ligand and SAL acid ligand

#### 4.2.2. Disproportionation constant

The quantitative stability of mixed-ligand complexes can be expressed in terms of disproportionate constant. The values of  $M(SAL)(TRP)$  complexes can be calculated by Eqs (12) and (13).



$$\log X_{[M(SAL)(TRP)]} = 2\log\beta_{[M(SAL)(TRP)]} = (\log\beta_{M(SAL)_2} + \log\beta_{M(TRP)_2}) \quad (13)$$

The value of  $\log_{10}X$  on statistical basis equals +0.6 for all geometries (Aljahdali *et al.*, 2013). The more positive  $\log_{10}X$  values than the statistical illustrates remarkable degree of stability of the ternary complexes. Large positive values of  $\log_{10}X$  as given in Table 2 assume the obvious stability of the ternary complexes than those in the corresponding binary compounds. Similar results have been published in the scientific literature with 2-picolyamine, bipyridyl and imidazole-4-acetic acid (Aljahdali and E-Sheriff, 2013).

#### 4.2.3. Stabilization constant

The stability of the ternary complexes can be calculated on the basis of statistics using Eq (14). The stabilization constant resulting from the difference between the measured stability constant values for the ternary complexes and those calculated on statistical basis can be calculated using Eq (15).

$$\log_{10}\beta_{satc} = \log 2 + \frac{1}{2}\log_{10}\beta_{1020} + \frac{1}{2}\log_{10}\beta_{1200} \quad (14)$$

$$\Delta\log_{10}\beta = \log_{10}\beta_{mean} - \log_{10}\beta_{calc} \quad (15)$$

The large difference between the measured values of the ternary complexes and the calculated statistical values indicated that mixed-ligand complexes are more stable than the corresponding binary  $M(SAL)_2$  and  $M(TRP)_2$  complexes. This stability enhancement is referred to as a "ligand effect" which is related to the electrostatic factors arising from charge neutralization, since in the formation of  $M(SAL)TRP$ , one positive charge of  $M(SAL)^+$  is neutralized by the deprotonated tryptophan amino acid, this leads to increased  $\sigma$  covalence (Mahrouka *et al.*, 2014).

### 4.3 Results of Thermodynamics

The values of thermodynamic parameters that are related to the protonation of both salicylic acid (SAL), tryptophan (TRP) and their metal(II) complexes have been calculated from the temperature dependent data given in Table 1. Values of  $\Delta H^\circ$  and  $\Delta S^\circ$  were obtained by drawing the relationship between the values of equilibrium constants ( $\ln K$ ) versus reciprocal of temperature ( $1/T$ ) ( $\ln K = -\Delta H^\circ/RT + \Delta S^\circ/R$ ) leading to an intercept  $\Delta S^\circ/R$  and a slope  $-\Delta H^\circ/R$  (Fig. 3 and 4).

The positive values of the heat content  $\Delta H^\circ$  showed the process of formation of the binary and ternary complexes were endothermic demonstrating that the process of chelation was preferable at high temperature. Moreover, the formation of the coordinate bond between the metal ion and the ligand often increases the charge density on the metal So, its affinity for the next ligand molecule causing an increase in  $\Delta H^\circ$  of the complexes. But  $\Delta H^\circ$  was negative for Ni-SAL which showed that the process of formation of this complex was exothermic demonstrating that the process of chelation was preferable at low temperature. Large positive values of the Gibb's free energy associated with the process of formation of binary and ternary complexes illustrate the non-spontaneity of the process (Mahrouka *et al.*, 2014).

All negative values of entropy  $\Delta S^\circ$  for both complexes indicate that the process of formation is not spontaneous and is not entropically favourable. In addition, negative value of entropy is due to increased order as a result of solvation process. (Iorungwa *et al.*, 2019).

## V. Conclusion

The present study allowed us to obtain the stability constant of Cu(II), Co(II), Ni(II) and Zn(II) with mixed ligand (SAL-TRP). The stability order of the complexes with reference to the metal ions was in the order of  $Cu(II) > Ni(II) > Co(II) > Zn(II)$  in concordance with the Irving-William stability order. The result of the comparison of the stability of ternary and binary complexes, it can be concluded that the ternary complexes were more stable than the binary complexes. The study proved that, ternary and binary formation was non-



spontaneous, entropically unfavorable and endothermic except binary complex of Ni(II) which was exothermically formed.

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