

## Mixed-Ligand Complexes of Co(II), Ni(II) And Cu(II) with Mercaptosuccinic Acid And 1, 10-Phenanthroline in Dimethylformamide Media

G. Pushpa Raju<sup>1</sup> V. Tejeswara Rao<sup>2</sup> P.Lakshmi Kishore<sup>2</sup> and G. Nageswara Rao<sup>3</sup>

<sup>1</sup>C.R College, Chilakaluripet, India

<sup>2</sup>MVR PG college, Visakhapatnam-530026, India

<sup>3</sup>School of Chemistry, Andhra University, Visakhapatnam-530003, India

<sup>1,2</sup>tejavonna@gmail.com <sup>2</sup>lakshmikishorep@gmail.com <sup>3</sup>gollapallinr@yahoo.com

### Abstract

The ternary systems of Co(II), Ni(II), and Cu(II) complexes with Mercaptosuccinic acid as Primary Ligand and 1, 10-Phenanthroline as Secondary Ligand are investigated. The stability constants of the complexes were determined pH metrically in Dimethylformamide medium at 303K and  $I = 0.16$  mol/L NaCl. The predominant species detected are MLX, ML<sub>2</sub>X, MLXH and MLX<sub>2</sub>H. Models containing different numbers of species were refined by using the computer program MINIQUAD75. The best-fit chemical models were arrived at based on statistical parameters. The relative stabilities of the ternary complexes and species distributions of all complexes in solution were evaluated.

**Keywords:** Mixed-Ligand; MSA, Phen; Ph Metric Studies; Stability Constants.

### Introduction

The dicarboxylic reductant, 2-mercaptosuccinic acid (MSA), has three species existing in solution with different charges over the pH range. It may exist as doubly or singly protonated form, or as the dianion having the two carboxylates deprotonated [1]. MSA is an important chiral multi-functional intermediate in organic chemistry and has been widely employed in the synthesis of various biologically active sulfur containing compounds such as antileukemic, spiro[indoline-3,2\_-thiazolidine]-2,4-diones [2], and the anti-microbial [3] and antitubercular [4] 4-thiazolidinones. More recently, it has been used in the synthesis of the novel polyanionic inhibitor of HIV and other viruses [5]. The -SH functional group of the latter species remains unionized. 1,10-Phenanthroline (Phen) is a bidentate ligand, and it forms strong complexes with many metal ions. Due to hydrophobicity of aromatic rings in Phen, the solubility of the neutral species is low in water which remarkably increases in organic solvents and also in aqua-organic mixtures. Phen has been reported to be biologically active either alone or in the presence of metal ion.

Small quantities of mineral elements occurring in both plant and animal tissues are called as trace elements. A trace element is considered as essential for both man and animal life if it meets the listed conditions: i) it is present in all healthy tissues, ii) its concentration from one species to the next is fairly constant, iii) depending on the species studied, the amount of each element has to be maintained within its required limit if the functional and structural integrity of the tissues is to be safeguarded and the growth, health and fertility to remain unimpaired, iv) its withdrawal induces reproducibly the same physiological and or structural abnormalities and v) its addition to the diet either prevents or reverses, the abnormalities [6]. Several trace elements are known to fulfill these criteria, of which the most well known are iron, zinc, manganese, selenium, chromium, copper, cobalt, nickel, molybdenum and iodine. Many of them act as catalysts in many enzymatic functions called as metalloenzymes [7].

Cobalt is essential for the production of red blood cells. No metal ion antagonism involving cobalt has been reported, and no ion other than cobalt has been found in nature complexed with the Corrin ring. The effects of cobalt and manganese on some enzymes in the rat liver were studied [8]. Nickel was first suggested to be an essential element in 1936. Nickel is widely distributed in nature, forming about 0.008% of the earth's crust. Water-insoluble nickel compounds may dissolve in biological fluids [9]. Copper is found in certain foods in a greater quantity such as meat, eggs, poultry, nuts, seeds and grains. The human adult requirement is 2 mg/d [10]. The adult human body contains 100-150 mg of copper.



N, N<sup>1</sup>-Dimethylformamide (DMF) is a colorless liquid, miscible with water. DMF solutions were used to process polymer fibers, films, and surface coatings; to permit easy spinning of acrylic fibers; to produce wire enamels, and as a crystallization medium in the pharmaceutical industry [11].

### Materials and Methods

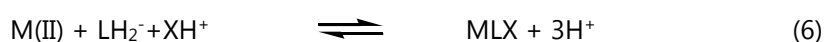
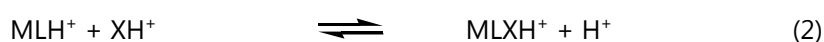
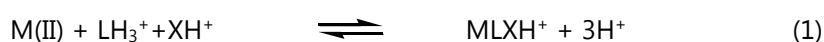
Solutions (0.05 mol L<sup>-1</sup>) of MSA and phen (Himedia, India) were prepared in triple-distilled deionised water by maintaining 0.05 mol L<sup>-1</sup> hydrochloric acid concentration to increase the solubility. Dimethylformamide (Merck, India) was used as received. 2 mol L<sup>-1</sup> Sodium Chloride (Merck, India) was prepared to maintain the ionic strength in the titrand. Sodium hydroxide (Merck, India) of 0.4 mol L<sup>-1</sup> and Hydrochloric acid (Merck, India) of 0.2 mol L<sup>-1</sup> was prepared. Solutions of Co(II), Cu(II) and Ni(II) chlorides (0.05 mol L<sup>-1</sup>) were prepared by dissolving G.R. Grade (Merck, India) salts in triple-distilled water maintaining 0.05 mol L<sup>-1</sup> acid (HCl) to suppress the hydrolysis of metal salts. All the solutions were standardized by standard methods. To assess the errors that might have crept into the determination of the concentrations, the data were subjected to analysis of variance of one way classification [12]. The strengths of alkali and mineral acid were determined using the Gran plot method [13-14].

### Procedure:

The pH measurements of metal-ligand system were carried out in aqueous media containing varying compositions of organic solvent (DMF) in the range of 0–60% v/v maintaining an ionic strength of 0.16 mol L<sup>-1</sup> with sodium chloride at 303.0 ± 0.1 K using a Digital pH meter Elico - MKVI type (readability 0.01) with mechanical stirring carried by a Teflon stirrer. The glass electrode was equilibrated in a well-stirred DMF-water mixtures (0–60% v/v) containing inert electrolyte for several days. The effect of variations in asymmetry, liquid junction potential, activity coefficient, sodium ion error and dissolved carbon dioxide on the response of the glass electrode was accounted for in the form of correction factor [15-17].

### Mixed-Ligand complexes

Titration were carried out in the presence of different relative concentrations of metal ions (M) to primary (MSA, L) to secondary (Phen, X) ligands (M:L:X = 1:2.5:2.5, 1:3.75:5.0, 1:5.0:3.75) with sodium hydroxide. The other conditions are similar to those mentioned earlier [18]. The actual concentrations of each of the ingredients are given in Table 1. A preliminary investigation of alkalimetric titrations of mixtures of MSA and Phen, in different mole ratios, in the presence of mineral acid and inert electrolyte confirmed that these two ligands do not form any condensed species.



**Table 1:** Total initial concentrations of ingredients (in mmol) for mixed ligand titrations in organic solvent-water mixtures.

[NaOH] = 0.4 mol L<sup>-1</sup>; V<sub>0</sub> = 50 mL; Temperature = 303 ± 0.1K; Mineral acid = 1.0 mmol; μ = 0.16 mol L<sup>-1</sup>.

% v/v DMF	Co(II)	Ni(II)	Cu(II)	MSA	Phen	M:L:X
0.0	0.100	0.096	0.098	0.25	0.25	1:2.5:2.5
				0.25	0.375	1:2.5:3.75
				0.375	0.25	1:3.75:2.5

10.0	0.100	0.096	0.098	0.25 0.25 0.375	0.25 0.375 0.25	1:2.5:2.5 1:2.5:3.75 1:3.75:2.5
20.0	0.100	0.096	0.098	0.25 0.25 0.375	0.25 0.375 0.25	1:2.5:2.5 1:2.5:3.75 1:3.75:2.5
30.0	0.100	0.096	0.098	0.25 0.25 0.375	0.25 0.375 0.25	1:2.5:2.5 1:2.5:3.75 1:3.75:2.5
40.0	0.100	0.096	0.098	0.25 0.25 0.375	0.25 0.375 0.25	1:2.5:2.5 1:2.5:3.75 1:3.75:2.5
50.0	0.100	0.096	0.098	0.25 0.25 0.375	0.25 0.375 0.25	1:2.5:2.5 1:2.5:3.75 1:3.75:2.5
60.0	0.100	0.096	0.098	0.25 0.25 0.375	0.25 0.375 0.25	1:2.5:2.5 1:2.5:3.75 1:3.75:2.5

### Results and Discussion:

A preliminary investigation of alkalimetric titrations of mixtures containing different mole ratios of DMF in the presence of hydrochloric acid and inert electrolyte inferred that no condensed species were formed.

The possible primary and secondary ligand forms and resulting ternary complex species are given in Table 2.

**Table 2:** Some of the possible ternary complex species of M(II)-MSA-Phen system

- Constraints:**
1. Maximum number of primary/secondary ligand molecules = 2
  2. Maximum number of Primary + Secondary ligand molecules = 3

S. No.	Ligand form		Ligand number		
	Primary	Secondary	2	3	
1	LH <sub>3</sub>	XH	MLXH <sub>2</sub>	ML <sub>2</sub> XH <sub>4</sub>	MLX <sub>2</sub> H <sub>2</sub>
2	LH <sub>2</sub>	XH	MLXH	ML <sub>2</sub> XH <sub>2</sub>	MLX <sub>2</sub> H
3	LH	XH	MLX	ML <sub>2</sub> X	MLX <sub>2</sub>

### Selection of best fit models

The qualitative evidence for the formation of mixed ligand complexes was obtained from the shift of the precipitation point of mixed ligand systems compared to those of the corresponding binary systems. In all these systems, the pH for precipitation of the mixed ligand systems was found to be more than that for any of the binary systems.

The formation constants for acido-basic equilibria of both the primary and the secondary ligands[19-20] and those for the binary metal complexes[21-22] were fixed in testing various chemical models using MINIQUAD75 program [23]. All the species cited in Table 2 were used to generate different models. The models were evaluated assuming the simultaneous existence of different combinations of species. Models containing various numbers and combinations of species were generated using an expert system CEES [24], and they were refined using MINIQUAD75. The existence of these species was determined by performing an exhaustive modeling study. The models were evaluated assuming the simultaneous existence of different combinations of species. As the number of species increased, the models gave better statistical data denoting the best fit. This indicates that the

final model appropriately fits the experimental data. Such exhaustive modeling was performed for all the systems and the final models are given in Table 3 for ternary complexes of MSA and Phen with Co(II), Ni(II), and Cu(II) in DMF- water mixtures.

**Table 3:** Parameters of best-fit chemical models of MSA- Phen complexes of Co(II), Ni(II) and Cu(II) in DMF - water mixtures. Temperature =303K, Ionic strength =0.16 mol dm<sup>-3</sup>

%V/V	Log $\beta_{MLXH}(SD)$				NP	U <sub>Corr</sub> x10 <sup>-</sup>	Skewness	Kurtosis	$\chi^2$	R-Factor	pH Rang
	1110	1120	1111	1121							
<b>Co(II)</b>											
0.0	-	26.01(8)	26.01(32)	30.71(41)	116	5.46	0.92	5.63	19.12	0.0183	1.8-9.8
10	24.81(38)	--	27.69(55)	31.39(62)	119	7.51	-	6.21	17.68	0.0131	1.8-9.8
20	-	27.98(34)	29.11(96)	32.26(54)	123	4.38	-	4.74	13.39	0.090	1.8-9.8
30	25.26(11)	-	29.34(27)	31.89(35)	122	8.64	-	3.55	16.73	0.0363	1.8-9.8
40	25.01(45)	-	29.55(29)	-	128	9.88	0.90	5.60	66.29	0.0863	1.8-9.8
50	26.22(24)	29.15(21)	-	32.94(16)	135	8.82	-	6.74	75.09	0.0082	1.8-9.8
60	-	29.07(18)	30.26(47)	33.24(15)	150	5.15	-	6.07	42.72	0.0195	1.8-9.8
<b>Ni(II)</b>											
0.0	23.71(14)	-	23.01(48)	-	116	4.08	1.95	5.48	21.6	0.0181	1.8-9.8
10	-	27.46(81)	-	27.61(17)	119	4.23	2.26	6.67	72.42	0.5321	2.1-9.3
20	24.35(11)	-	24.24(36)	27.87(25)	112	4.37	-	11.12	24.33	0.0306	2.1-9.0
30	24.84(30)	-	24.92(11)	-	124	3.21	-	6.08	40.67	0.0217	2.0-9.5
40	-	28.62(52)	25.00(76)	28.88(41)	147	1.57	-	3.72	8.96	0.0387	1.8-8.9
50	25.77(46)	29.01(73)	25.41(8)	-	122	4.08	-	8.24	36.36	0.0077	2.3-8.8
60	-	30.02(11)	26.65(22)	29.77(11)	143	2.00	-	5.41	26.88	0.0117	1.8-8.4
<b>Cu(II)</b>											
0.0	19.51(11)	26.61(9)	19.03(15)	-	108	2.06	1.08	5.21	2.22	0.0196	1.8-9.8
10	19.20(21)	-	20.65(03)	26.02(11)	110	2.25	-	5.40	7.20	0.0020	2.5-8.8
20	-	27.89(44)	-	27.60(71)	116	5.29	1.46	5.75	36.75	0.1632	1.8-8.0
30	20.12(21)	-	20.23(06)	28.76(03)	127	2.11	-	4.54	23.85	0.0177	2.0-8.5
40	21.42(42)	28.27(71)	21.62(61)	-	139	7.35	1.22	5.38	170.7	0.0699	1.8-8.9
50	-	28.26(84)	-	29.86(22)	120	7.93	-	8.35	43.00	0.0359	2.2-8.8
60	22.28(28)	29.38(14)	22.38(85)	-	133	1.17	0.12	3.45	5.45	0.0125	2.2-8.2

### Effect of systematic errors

The computer programs refine the stability constants by minimizing the random errors in the data. But in the presence of considerable systematic errors, not only the  $\beta$ 's are in error, even some species may be rejected. MINIQUAD75 has no provision to vary the dangerous parameters. To rely upon the best-fit chemical model for critical evaluation and compilation, pessimistic errors are introduced in the influential or dangerous parameters like the concentrations of alkali, mineral acid, ligands (primary and secondary) and metal ion. This investigation is useful because the data acquisition is done under varied experimental conditions with different accuracies. The effect of errors in the Concentrations of ingredients (Table 4) is as follows.

Alkali > acid > metal > Phen > MSA

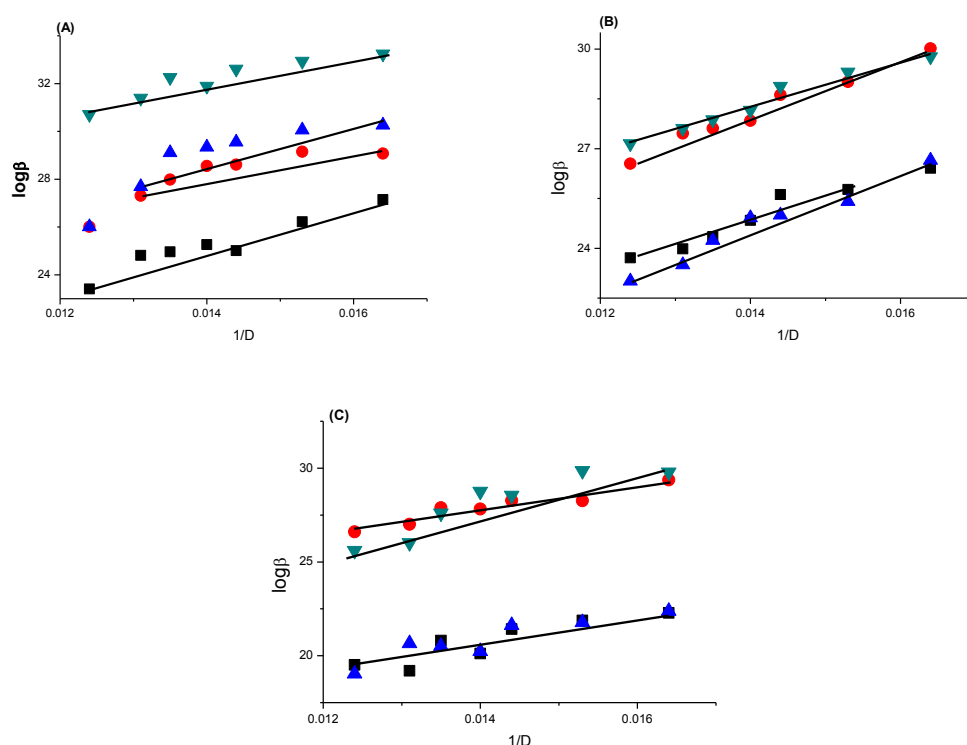


**Table 4:** Effect of errors in influential parameters on the stability constants of ternary complex in 30% v/v DMF-water mixtures Cu-MSA-Phen

Ingredient	% of error	1111	1211
Alkali	0	22.23(14)	30.96(20)
	-2	21.97(06)	30.33(24)
	-5	21.14(14)	Rejected
	+2	Rejected	Rejected
	+5	Rejected	Rejected
Acid	-2	Rejected	Rejected
	-5	Rejected	Rejected
	+2	21.85(08)	30.29(24)
	+5	21.13(10)	Rejected
MSA	-2	22.42(04)	31.28(13)
	-5	22.51(06)	31.57(18)
	+2	22.64(33)	31.56(76)
	+5	22.62(57)	31.42(99)
Phen	-2	22.67(92)	31.67(62)
	-5	22.58(04)	31.02(13)
	+2	22.42(05)	31.21(16)
	+5	22.48(06)	31.33(19)
Metal	-2	22.68(72)	31.67(66)
	-5	22.91(43)	31.74(29)
	+2	22.71(04)	31.67(69)
	+5	22.51(70)	31.68(72)

### Effect of Dielectric Constant of Medium

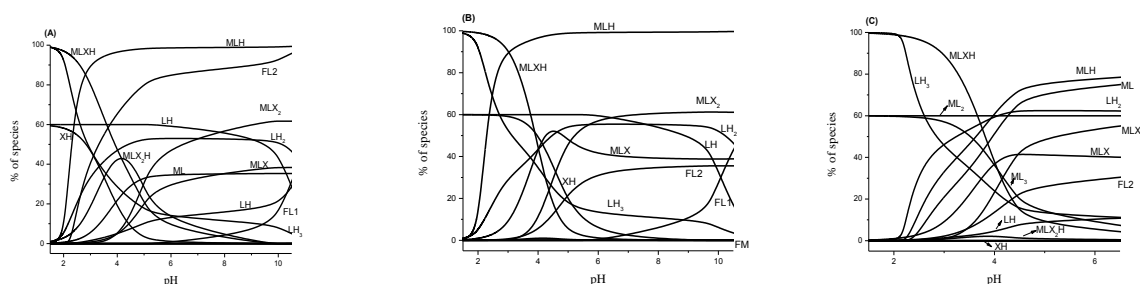
DMF is a versatile polar aprotic and non-coordinating solvent capable of acting as a hydrogen bond acceptor with a random structure. The DMF-water mixture combination of aprotic and protic solvents with a wide range of dielectric constants and with good solubility for polar as well as non-polar solutes. The trends of the stability constant ( $\log \beta$ ) values of the mixed ligand complexes with  $1/D$  ( $D$  is the dielectric constant of the medium) of DMF-water media is given in Fig. 1. The linear trend indicates that either the dielectric constant or the long-range interactions are responsible for the trend in stability. This linear increase in  $\log \beta$  values indicates the dominance of the structure-forming nature of DMF over the complexing ability. The cation stabilizing nature of co-solvents, specific solvent-water interactions, charge dispersion, and specific interactions of co-solvent with solute (indicated by the changes in the solubility of different species in the aqua-organic mixtures) account for the little deviation of the linear relationship.



**Fig. 1: Variation of stability constant ( $\log \beta$ ) values of ternary complexes of (A) Co(II), (B) Ni(II) and (C) Cu(II) with MSA-Phen with reciprocal of dielectric constant ( $1/D$ ) of DMF-water media: (■)  $\log \beta_{\text{mlxh}}$ , (●)  $\log \beta_{\text{mlx}}$ .**

The distribution diagrams were drawn using the formation constants of the best fit model and are shown in Fig. 2. They reveal that the concentrations of binary complexes are less than those of the ternary species, due to the extra stability of the ternary complexes. The protonated ternary species like MLXH are distributed at a lower pH than those of the unprotonated ternary species, MLX. The formation of these complex species can be represented by the following equilibria.

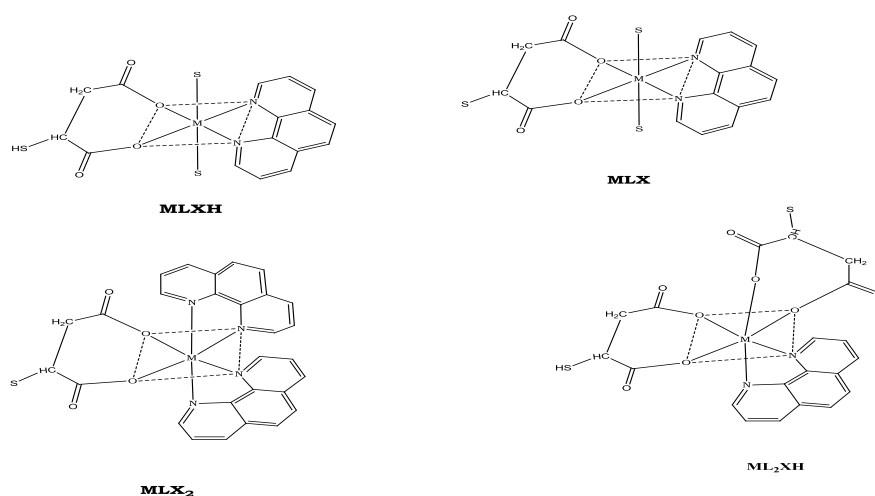
Species distribution of MLXH is high at lower pH, as pH increases MLX species is most predominant and stable. MLX species may be formed by the interaction of  $M(\text{II})$  with  $\text{LH}_3$  and  $\text{XH}$  as the concentration of  $\text{LH}_3$ , and  $\text{XH}$  decreases simultaneously with the increase in pH (equilibrium 5) or may also be formed with the deprotonation of MLXH species (equilibrium 4) or maybe due to the interaction of  $M(\text{II})$  with  $\text{LH}_2$  with  $\text{XH}$  (equilibrium 6), but equilibria 4 is more probable.



**Fig. 2: Distribution diagrams of Co(II)-MSA-Phen complexes in (A) 10% (B) 30% (C) 50% v/v of DMF- water and in mixtures**

### Structures of ternary complexes

The possible structures (Fig. 3) of the complexes proposed are based on the nature of the metal ions and the active sites of ligands (MSA and Phen).



**Fig. 3: Suggested structures of M(II)-Phen-MSA complexes, where S is either solvent or water molecule and M= Co(II), Ni(II) or Cu(II)**

### Conclusions

The following conclusions have been drawn from the modeling studies of the ternary complexes of Co(II), Ni(II) and Cu(II) with MAS and Phen in DMF–water mixtures.

1. The mixed-ligand complex species detected are  $MLX_2$ ,  $MLXH$  and  $MLX_2H$  for Co(II),  $MLXH$  and  $MLX$  for Ni(II) and  $MLX$ ,  $MLX_2$  and  $MLXH$  for Cu(II)

Where L = MSA and X = Phen.

2. The linear increase in the stabilities of the ternary complexes with a decrease in the dielectric constants is due to the dominance of the electrostatic forces.
3. The linear variation of stability constants as a function of  $1/D$  of the medium indicates the dominance of electrostatic forces over non-electrostatic forces. The linear increasing trend with DMF content supports the predominance of the structure forming nature of DMF over its complexing ability.

### References

1. Dutta, A., Saha, B., Ali, M., Banerjee, P. (1997). J. Chem. Res. (M) 1216.
2. Rajopadhye, M., Popp, F.D. (1987). J. Heterocyclic Chem. 24, 1637.
3. Vashi, B.B., Mehta, D.S., Shah, V.H. (1995). Indian J. Chem. 34B, 802.

4. Desai, K., Baxi, A.J. (1992). *J. Indian Chem. Soc.* 69, 212.
5. Dave, M.P., Patel, J.M., Langalia, N.A., Jhaken, K.A. (1984). *J. Indian Chem. Soc.* 61, 891.
6. Leydet, A., Jeantet-Segond, C., Bouchitte, C., Moullet, C., Boyer, B., Roque, J.P., Witvrouw, M., Este, J., Sneock, R., Andrei, G., Clercq, E.D. (1997). *J. Med. Chem.* 40, 350.
7. Cotzias, G. C., Trace substances., (1967). *Environ. Health. Proc. Univ. Mo. Ann. Conf.*, 5.
8. Underwood, E. J., NY (1977). *Trace elements in Human and Animal Nutrition*, Academic Press, 4<sup>th</sup> Ed., 230.
9. Rama, S. V. S., Prakash, R. and Agarwal, V. P., (1985). *Ash. Hig. Rada. Toksikol.* 36, 365.
10. Yamada, M., (1993). *Biol. Trace Elem. Res.*, 36, 89.
11. National research council, Copper in: recommended dietary Allowances, (1980). National Research Council, Washington D. C. Food Nutrition Board, 151.
12. U.S. Environmental Protection Agency. Health and Environmental Effects Profile for N, NDimethylformamide. EPA/600/x-86/141. (1986). Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, Cincinnati, OH.
13. Gran, G. (1952), *Analyst*, 77, 661 – 671.
14. Gran, G. (1988), *Anal. Chim. Acta*, 206, 111 – 123.
15. Latha, M.P., Rao, V.M., Rao, T.S. and Rao, G.N. (2007), *Bull. Chem. Soc. Ethiop.*, 21, 363 –372.
16. Raju BR, Devi KVS, Rao GN. Chemical speciation of Ternary Complexes of L-dopa and 1, 10-Phenanthroline with Co(II), Ni(II) and Cu(II) in low dielectric media. (2012). *Chem Speciation Bioavail.*, 24, 89-96.
17. Raju BR, Devi KVS, Rao GN. Chemical Speciation of Ternary Complexes of Co(II), Ni(II) and Cu(II) with L-dopa, and 1,10-phenanthroline in low dielectric media. (2012). *Chin. J. Inorg Chem.*, 28, 785-794.
18. Srikanth B, Rao PS, Rao VSS, Sastry CK, Rao GN. Effect of micelles on the chemical speciation of binary complexes of Co(II), Ni(II), Cu(II) and Zn(II) with succinic acid. (2009). *J. Serb. Chem. Soc.*, 74, 745-754.
19. Lavanya KV, Rao GN, Rajesh M, Babu MS. Micellar effect on protonation equilibria of L-arginine and L-histidine. (2004). *J. Indian Chem. Soc.*, 81, 384-387.
20. Tejeswararao, V., Laxmi kishore, p., Nageswararao, G. (2018). *J. Emg. Tech. Inno. Res.*, 12, 452-458.
21. Tejeswararao, V., Laxmi kishore, p., Nageswararao, G. (2019). *I. J. Rese.And.Review.*, 1, 1204-1210.
22. Tejeswararao, V., Laxmi kishore, p., Nageswararao, G. (2019). *J. Emg. Tech. Inno. Res.*, 1, 607-616.
23. Laxmi kishore, p., Tejeswararao, V., Nageswararao, G. (2019). *I. J. Rese.And.Review.*, 1, 858-868.
24. Gans P, Sabatini A and Vacca A. An improved computer program for the computation of formation constants from potentiometric data. (1976). *Inorg. Chim. Acta.* 18; 237-241.
25. Briabanti A. Rao RS. Babu AR and Rao GN. CEES.Expert system for complex equilibria. MODGEN. Model generator for metal ligand equilibria in solution phase.(1995). *Ann. Chim. (Italy)*. 85; 1995: 17-29.