Heliyon 7 (2021) e06729

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Speciation study involving mononuclear binary transition metal (Co^{II}, Ni^{II} and Cu^{II}) complexes of L-methionine in non-ionic micellar medium

Robbi Neeraja [a,b], Gandham Hima Bindu [a,*]

[a] Department of Engineering Chemistry, AUCE (A), Andhra University, Visakhapatnam, 530003, Andhra Pradesh, India
[b] Department of Chemistry, Govt. Degree College (Men), Srikakulam, 532001, Andhra Pradesh, India

ARTICLE INFO

Keywords:
Chemical speciation
Metal ions
L-methionine
TX-100
MINIQUAD75

ABSTRACT

The present work aims to evaluate the binding capacities of binary complexes of L-Methionine with transition metal ions Co^{II}, Ni^{II} and Cu^{II} in Triton X 100-water mixtures, a non-ionic micellar media of different compositions (0.0–2.5% (v/v)), investigated under the experimental conditions of 0.16 mol/dm^3 ionic strength using $NaNO_3$ at a temperature of 303.0 ± 0.1 K Potentiometrically. The potentiometric data was assessed by Irving-Rossotti pH metric technique with the least-squares method of MINIQUAD75, a computer program. The selectivity of the best fit model obtained by continuous exhaustive chemical modelling studies and the accuracy of the results is assessed based on statistical parameters. MLH, ML and ML_2 are the identified species for the three M(Co^{II}, Ni^{II} and Cu^{II}) -Met systems. The shift in the equilibrium of binary metal-methionine complexes with variation in composition (0.0–2.5%) of the solvent can be explained by electrostatic together with non-electrostatic forces contributed by the interaction of solute with solvent.

1. Introduction

Metals play an active role in biological reactions, as they exist in ionic form in body fluids. Some of them need to be in trace amounts, familiar as essential metals. Any deviation from this portion causes metabolic disorders [1, 2, 3]. Amino acids play a vital role in producing proteins and peptides and additionally forming some nitrogen compounds like hormones, enzymes are active in the body physiologically, hence they well regarded as foundation stone of living organisms [4]. Hence, the study of metal-amino acid complexes is of immense importance with wide applications in the field of biology, therapeutic use in drug designing and diagnosis of disease in medicinal inorganic chemistry [5], which offers a better chance to understand the binding affinities involved in metal-protein residues. Thus, researchers have made an extensive study on metal complexes with bioactive ligands [6, 7, 8, 9, 10, 11, 12, 13, 14].

Study of Chemical speciation not only offers species distribution and availability in a particular environment but also provides its chemical composition and structural aspects [15, 16]. A lot of research is going on in first row transition metals owing to its availability and cost economy in addition to its biological applications [17, 18, 19, 20, 21]. Co^{II}, Ni^{II} and Cu^{II} are essential trace metals which have wider applications in biological processes due to their ability to form various coordination numbers, geometries, accessible redox states and adaptive ability towards ligand substitution reactions in thermodynamics as well as in kinetic studies, and these trace metal complexes also have a wide scope of structural diversity [22].

L-Methionine (Met), an essential or indispensable amino acid, cannot be produced in the body acquired by diet only. In methionine metabolism, SAM(S-adenosyl methionine) is a key intermediate, which acts as a co-enzyme of its remarkable versatility. SAM can donate methyl group to all most all body moieties like amino acids of proteins, DNA, RNA and even to a metal, hence it is regarded as a universal methyl donor because at present a large number (60) of metyltransferases are found to be in mammals [23, 24]. In addition to its wide applications in biology, Met and derivatives of Met are often utilized in organic reactions as asymmetric catalysts [25, 26]. Generally ligand, met behaves like a bidentate through its active sites of amino together with carboxylic acid groups having high affinity to coordinate with these metal ions (Co^{II}, Ni^{II} and Cu^{II}) [27, 28, 29, 30, 31, 32, 33, 34]. Binary complexes of transition metals (Co^{II}, Ni^{II} and Cu^{II}) of L-methionine in different media are reported earlier by Paper Ionophoretic technique and Potentiometric method [35, 36].

Triton X-100 (TX-100), a neutral surfactant, is often used like a lysis buffer in cell biology to extract protein and cellular organelles. When it is

---

* Corresponding author.
E-mail address: himabinduauce@gmail.com (G. Hima Bindu).

https://doi.org/10.1016/j.heliyon.2021.e06729
Received 5 October 2020; Received in revised form 15 December 2020; Accepted 1 April 2021

dissolved in water at a concentration higher than its critical micelle concentration (CMC) value of 0.22 mM, it undergoes self-assemble process to develop a non-ionic spherical micelle. In this micelle the uncharged hydrophobic tail and the hydrophilic head groups are arranged at the interior and exterior of it respectively, which is very much similar to cellular membranes in living beings, where the phospholipids are likely to form a bilayer of similar kind. These permeable membranes are ion selective and participated in cell signalling, cell adhesion and ion conductivity like cellular process [37, 38].

Normally, water is chosen as a suitable solvent for representing biological conditions, but combination of TX-100 and Water mixture becomes the best solvent, since they form micelle with membrane proteins at lipid bilayers very much simulate to physiological conditions. To the best of the resources available existing on this knowledge database, there are no previous reports on speciation study involving mononuclear binary complexes of transition metal (Co^{II}, Ni^{II} and Cu^{II}) complexes of L-methionine in TX 100-water mixture are studied under the present experimental conditions.

2. Experimental and instrumentation

2.1. Materials

Analytical Reagent Grade chemicals and triply distilled deionized water free of dissolved $CO_{2(g)}$ and $O_{2(g)}$ were used to prepare all solutions necessary for the experiment. Solutions of 0.2 mol/dm^3 mineral acid (HNO_3, Qualigens, India), 0.4 mol/dm^3 Sodium Hydrate (NaOH, Qualigens, India), 2.0 mol/dm^3 sodium salt of nitric acid ($NaNO_3$, Qualigens, India) were prepared. To Know the concentration of NaOH free from $CO_{2(g)}$, standardized with Potassium Hydrogen Phthalate. Solution of freshly prepared 0.1 mol/dm^3 of L-Methionine (E-Merck, Germany) and prepare 0.1 mol/dm^3 of Nitrate salts of metal ions (Co^{II}, Ni^{II} and Cu^{II}) have 0.05 mol/dm^3 of mineral acid (HNO_3) to enhance the dissolvability of solutes and repress the generation of metal hydroxides from their respective salts. Complexometric titrations used to standardize all these solutions [39]. The concentration of acid and alkali can be checked by Gran-plot method [40, 41]· Prepare solutions of TX-100 of varying compositions from 0.0 to 2.5% (v/v) from the received chemical, TX-100 (Merck, India). To check out the errors in the concentration of ingredients, the research data was treated with the analysis of variance (ANOVA) [42].

2.2. Instrumentation

The experimentation was carried out by using a digital pH meter (Model, L1-120) have an accuracy of 0.01 connected to a glass electrode with an internal reference, sensitive to a pH of 0–14. The potentiometric titrations were done at constant temperature and ionic strength of 303.0 ± 0.1 K and 0.16 mol/dm^3 respectively under inert atmosphere. Instrument is calibrated with 0.05 mol/dm^3 mono potassium Phthalate of pH 4.01 and with 0.01 mol/dm^3 of Sodium tetra borate decahydrate of pH 9.18. The electrode was immersed in a properly stirred solvent, till the electrode undergoes complete equilibration, this can be checked thoroughly by titrating strong acid versus alkali. To produce accurate results, triplicate titrations were done and the results obtained were not differing more than 0.02 units.

2.3. Procedure

Initially, free acid titrations were done, until reproducible results were obtained; this data is used to calculate log F (correction factor). If prepared a set of solutions have a total content of 50 mL and concentration of metal and ligand are maintained in the ratio of 1.0:2.5, 1.0:3.5 and 1.0:5.0 in all compositions of TX 100-water mixtures.

a) Free acid titration: Acid (5.0 mL, 0.2 mol/dm^3 HNO_3).
b) Ligand titration: Acid (5.0 mL, 0.2 mol/dm^3 HNO_3) + Ligand (5.0/7.0/10.0 mL, 0.1 mol/dm^3).
c) Metal ligand titration: Acid (5.0 mL, 0.2 mol/dm^3 HNO_3) + Ligand (5.0/7.0/10.0 mL, 0.1 mol/dm^3) + Metal (2.0 mL, 0.1 mol/dm^3).
d) Metal ligand titration in TX-100: Acid (5.0 mL, 0.2 mol/dm^3 HNO_3) + Ligand (5.0/7.0/10.0 mL, 0.1 mol/dm^3) + Metal (2.0 mL, 0.1 mol/dm^3) +TX-100 (5.0 mL, varies from 0.0-2.5% (v/v).

The above analytes were titrated with a titrant, 0.4 mol/dm^3 of NaOH solution.

2.4. Modelling studies

SCPHD [43], a computer program required to evaluate the correction factor in data given by free acid titrations, which accounts the errors occurred at the glass electrode during the experimentation via discrepancy in asymmetric potential, diffusion potential, liquid junction potential, alkaline error, activity coefficient, dissolved inorganic carbon (CO_2) at the membrane of the Ion-selective electrode. Input the data to MINIQUAD75 [44], to determine the stability of binary metal (Co^{II}, Ni^{II} and Cu^{II}) - methionine system, – log K_w, correction factor [45, 46] and acidity constants of met are set to be constant throughout the process of refinement.

3. Results and discussion

Alkali metric titration curves obtained from potentiometric data reveals the existence of acido-basic equilibria of L-met in TX100-water mixture in the region of $2.0 < pH > 10.0$. The active pH region of the met is taken into consideration, exhaustive modelling studies were carried out by considering various model numbers with different combinations of alkali metric titration data were fed to MINIQUAD75. Study on exhaustive modelling of a representative system shown in Table 1.

The potentiometric data obtained was subjected to modelling studies; the outcomes of the best suitable systems for the binary transition complexes of L-met with Co^{II}, Ni^{II} and Cu^{II} in TX 100- water mixture at varying compositions of 0.0–2.5% (v/v) were listed in Table 2.

Standard deviation of formation constants of binary complexes is very low, represents the precision of these parameters. The sum of the least squares of all experimental points, such as variation in concentration of ingredients (metal (Co^{II}, Ni^{II} and Cu^{II}) ions, met and proton) in each stage of the experimental point emended for degrees of freedom, U_{corr} is very low. Small values of mean, standard deviation (S.D) and also mean deviation for the systems indicate that the residuals are approximate to zero mean with low scattering [47, 48]· For any perfect normal distribution system kurtosis value must be “3” and skewness must be a value of “0”. From Table 2 most of the residuals follow leptokurtic (sharp peak, >3), few of them follow platykurtic (flat peak, < 3). In the present data skewness ranges from -1.01 to 0.47. This data is evident to notify that the residuals follow Gaussian dispersion, because of this least squares approximation is applicable to the collected data. The acceptability of the model was noticeable via another statistical factor discrepancy index (R-factor). Thus, these statistical measures indicate the best suitable systems corroborate to binary complex equilibria in TX 100-water mixture. The reported data in literature listed in Table 3 were in good agreement with the experimental results.

4. Effect of systematic errors on best suitable system

To achieve best suitable systems, an investigation has been carried out knowingly enter the pessimistic errors within the ingredients (NaOH, HNO_3, Metal (Co^{II}, Ni^{II} and Cu^{II}), met and correction factor) concentration, obtained results shown in Table 4. Observed, from modelling studies, there is an increase in standard deviation and sometimes rejected the species also. The magnitude of formation constants are effected due to these concentration errors following the order NaOH > HNO_3 > met > metal > correction factor. Thus modelling studies show the correctness of the proposed models, which best fit under the experimental conditions.

Table 1. Exhaustive modeling studies of transition complexes of Cu^{II}-met complexes in 0.5% (v/v) of TX 100-water mixture, pH range: 1.64–5.12, NP = 44.

Modelling Number	log β(SD)			Ucorr	Skewness	Kurtosis	χ^2	R-factor
	ML	MLH	ML_2					
1	7.55 (26)	————	————	80.23	-1.20	3.50	56.24	0.0291
2	————	12.81 (37)	————	72.79	-0.02	14.35	147.76	0.0277
3	————	————	13.87 (22)	84.65	-1.15	3.26	70.67	0.0299
4	8.61 (13)	12.76 (11)	————	8.09	0.44	3.57	11.88	0.0091
5	7.38 (33)	————	13.62 (56)	80.47	-1.25	3.66	83.88	0.0288
6	————	12.80 (12)	15.19 (13)	8.30	-0.31	5.47	12.73	0.0092
7	8.26 (13)	12.50 (09)	14.74 (13)	4.97	0.41	2.62	3.76	0.0071

Table 2. Statistical measures of best suitable systems of Co^{II}, Ni^{II} and Cu^{II}-met complexes in TX 100-water mixture.

% v/v TX 100	log β_{mlh} (SD)			NP	U_{corr}	Skewness	Kurtosis	χ^2	R-factor
	MLH	ML	ML_2						
Co^{II} (pH: 1.69–9.5)									
0.0	10.53 (13)	3.28 (20)	5.65 (37)	86	7.92	-0.27	3.78	53.01	0.0220
0.5	11.54 (31)	4.03 (14)	6.71 (09)	79	2.25	0.20	3.13	43.52	0.0116
1.0	11.67 (19)	4.16 (11)	7.38 (12)	118	1.25	-0.01	3.10	99.56	0.0133
1.5	13.48 (38)	5.27 (48)	8.97 (36)	132	1.60	0.08	2.43	18.34	0.0240
2.0	13.66 (12)	5.51 (11)	9.09 (24)	100	9.44	-0.63	3.34	37.12	0.0127
2.5	15.19 (12)	6.82 (11)	9.78 (26)	99	1.29	-1.01	8.77	93.98	0.0137
Ni^{II} (pH: 1.69–9.5)									
0.0	11.56 (06)	5.59 (08)	8.98 (12)	126	0.98	0.09	5.56	64.50	0.0097
0.5	12.39 (11)	5.73 (16)	9.20 (28)	112	5.70	0.01	3.90	40.86	0.0054
1.0	12.01 (08)	5.76 (11)	9.85 (14)	117	1.89	0.07	4.84	82.80	0.0116
1.5	12.66 (27)	5.81 (23)	9.59 (33)	94	1.03	-0.12	3.82	49.88	0.0131
2.0	13.55 (25)	5.85 (11)	10.72 (13)	107	3.90	-0.77	2.97	67.51	0.0146
2.5	15.13 (22)	6.18 (02)	11.63 (38)	33	3.56	0.29	6.77	42.17	0.0180
Cu^{II} (pH: 1.63–5.2)									
0	11.18 (08)	7.19 (13)	13.56 (12)	134	2.56	-0.19	3.38	26.7	0.0154
0.5	12.50 (09)	8.26 (13)	14.74 (13)	44	4.97	0.41	2.62	3.76	0.0071
1.0	13.01 (21)	8.63 (12)	15.07 (13)	125	1.50	0.16	3.22	6.46	0.0116
1.5	13.54 (23)	9.11 (36)	16.13 (10)	77	3.87	-0.54	4.99	19.98	0.0189
2.0	13.65 (11)	9.39 (14)	16.18 (20)	124	1.86	-0.40	2.64	33.25	0.0029
2.5	14.07 (08)	9.54 (29)	17.02 (28)	82	4.58	0.47	3.36	11.76	0.0083

Ucorr = U/(NP-m) $x10^8$; NP = Number of experimental points; m = number of formation constants; SD = Standard deviation.

Table 3. Comparison of experimental data with literature by various techniques.

Transition Metal ion	Chemical Species	Experimental value	Literature value	Ionic Strength	Temperature	Instrumental Technique	References
Co(II)	MLH	10.53	————	0.10 mol/dm^3 $NaNO_3$	308K	Paper Ionophoretic Technique	[35]
	ML	3.28	4.40				
	ML_2	5.65	4.20				
Ni(II)	MLH	11.56	———	0.16 mol/dm^3 $NaNO_3$	303K	Potentiometry	[36]
	ML	5.59	5.03				
	ML_2	8.98	9.72				
Cu(II)	MLH	11.18	———	0.16 mol/dm^3 $NaNO_3$	303K	Potentiometry	[36]
	ML	7.19	7.71				
	ML_2	13.56	13.98				

5. Effect of surfactant

Dielectric constant is an important property of a solvent, which can alter the equilibrium of a reaction mixture by surfactants. The concentration and dielectric constant of a solvent are inter related inversely. If the concentration of the solvent increases, the dielectric constant of the medium decreases as well as micellar size increases. The anisotropic bulk water dispersion in micellar media causes uneven dispersion in polarity, viscosity and degree of hydration inside the structure of the micelle in micro level [49, 50]. According to Born's classical treatment [51] and previous studies [52] represent system dielectric constant influenced by electrostatic forces. These factors cause accountable changes in the magnitude of formation constants in binary complexes with concentration (here 0.0–2.5% (v/v)) of the micelle and the linear and non-linear

Table 4. Effect of errors in influential measures on the stability constants of Ni^{II}-met complexes in 0.5% (v/v) TX 100-water intermediate.

Ingredient	% of error	log β_{mlh} (SD)		
		MLH	ML	ML_2
	0	12.39 (11)	5.73 (16)	9.20 (28)
Alkali	-5	11.76 (20)	4.59 (28)	6.84 (21)
	-2	12.16 (16)	5.30 (22)	8.36 (48)
	+2	12.63 (17)	6.15 (21)	9.99 (26)
	+5	13.11 (25)	6.91 (27)	11.23 (28)
Acid	-5	14.42 (52)	7.23 (52)	11.13 (52)
	-2	13.03 (31)	6.54 (33)	10.33 (37)
	+2	11.91 (16)	5.12 (21)	8.28 (43)
	+5	Rejected	4.14 (25)	6.93 (79)
Ligand(L)	-5	12.05 (13)	5.46 (17)	8.98 (29)
	-2	12.26 (14)	5.62 (19)	9.11 (32)
	+2	12.55 (19)	5.87 (26)	9.33 (34)
	+5	12.84 (29)	6.13 (31)	9.56 (40)
Metal	-5	12.48 (18)	5.82 (23)	9.46 (31)
	-2	12.43 (17)	5.77 (21)	9.31 (31)
	+2	12.37 (19)	5.71 (20)	9.11 (32)
	+5	12.33 (20)	5.66 (19)	8.97 (33)
log F	-5	12.57 (19)	5.9 (23)	9.38 (33)
	-2	12.47 (17)	5.8 (21)	9.28 (32)
	+2	12.33 (15)	5.68 (20)	9.15 (31)
	+5	12.24 (15)	5.6 (19)	9.06 (31)

trends in log β values with surfactant concentration purely depends on two opposing factors namely electrostatic with non-electrostatic forces operated by the substrate with the medium. The results of the present experimental study indicates log β values of the binary complexes linearly growing as the concentration of the surfactant increases incrementally by 0.5 % (v/v) showing electrostatic forces are dominative. Moreover, the stabilization of the binary complexes can be explained by dielectric constant of the non-ionic surfactant medium (TX 100-water

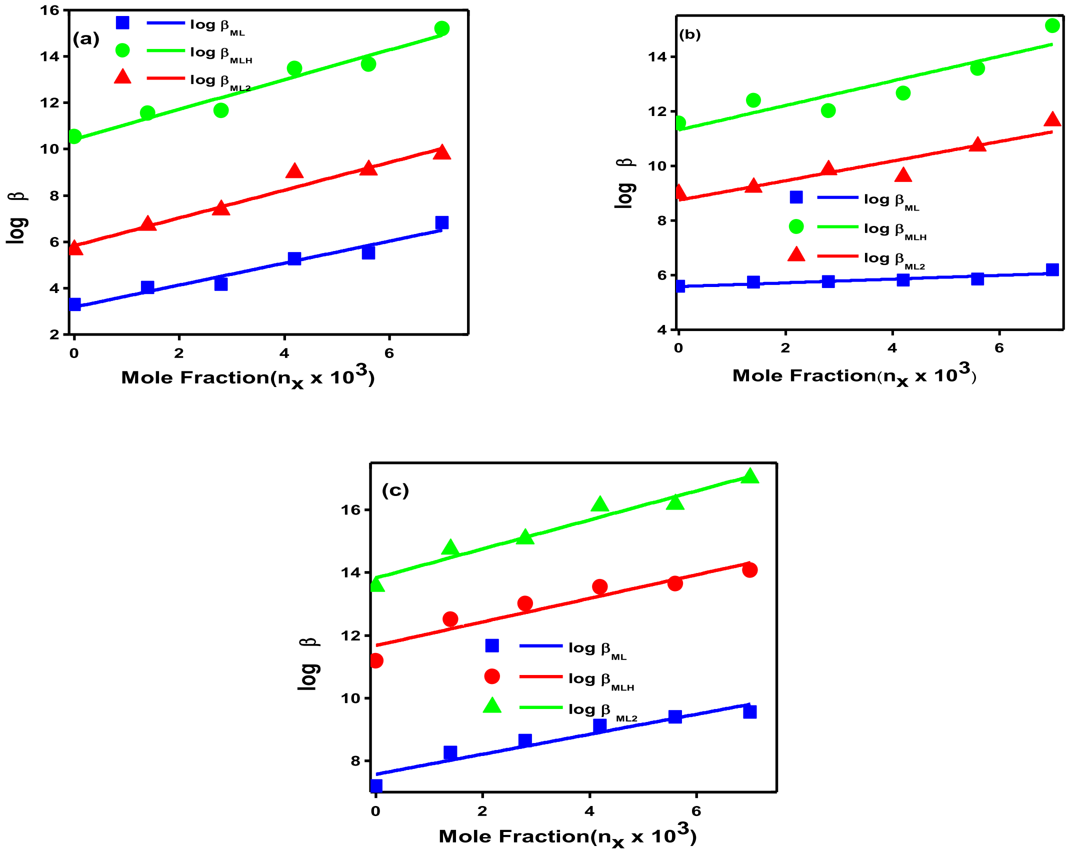

Figure 1. Change in stability of Metal-Met complexes in TX 100-water system: (a) Co^{II}, (b) Ni^{II}, and (c) Cu^{II}

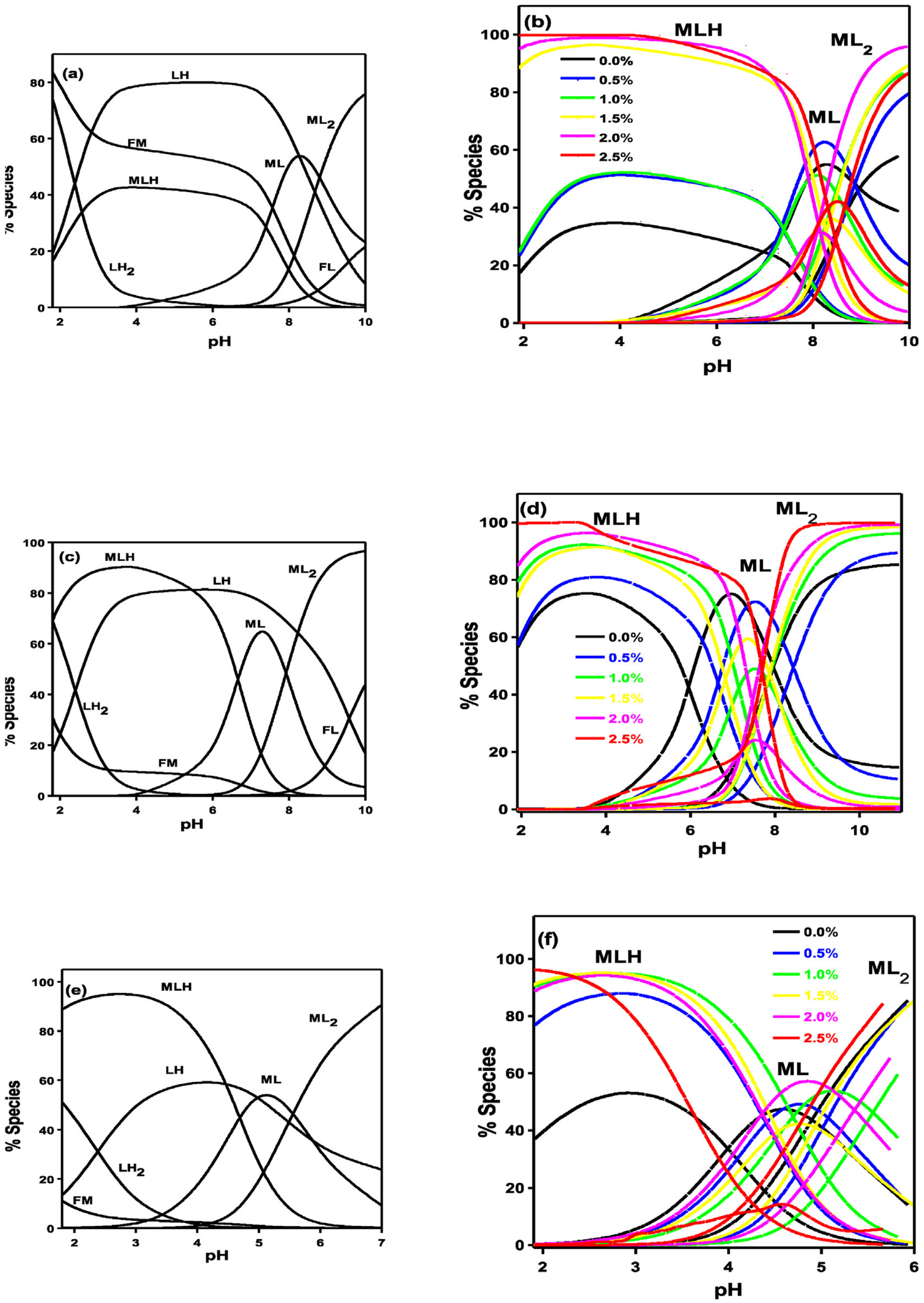

Figure 2. Distribution diagrams of L-Met Complexes of (a) Co^{II}, (c) Ni^{II} and (e) Cu^{II} in 1.0% (v/v) and (b) Co^{II}, (d) Ni^{II} and (f) Cu^{II} in 0.0–2.5% (v/v) TX 100-water mixture.

mixture) is lesser compared to pure water. TX-100, a non-ionic surfactant which destabilizes the charged particles in the stern bilayer of the micelle, as a result charged ions get repelled and availability of vacant orbital present in H^+ ions and metal ions becomes the competents to the ligand have lone pair of electrons residing at donor atoms. Increase in surfactant concentration reduces the accepting ability of proton and particularly to that of the metal ion increases by the ligand. Since the lone pair donation becomes easy to the vacant atomic orbital of the metal ion, forming a dipolar bond between metal ion and ligand. As a result there is a raise in binding capacity of the metal complexes with concentration of surfactant; hence the magnitude of the stability constants increases. The effects of composition of surfactant on stability of metal complex species of L-methionine are presented in Figure 1 are in good agreement with this concept. Effect of co-solvent interactions in molecular levels can be investigated by this study [53, 54, 55, 56].

5.1. Distribution diagrams

LH_2^+, LH and L^- are the active forms of protonated L-methionine in the pH region 2.0–4.0, 2.0–11.0 and 6.0–11.0 due to the involvement of protonated amino and deprotonated carboxylic acid groups. In this study MLH, ML and ML_2 are the three dominant species investigated for the met complexes of these three transition metal ions. The remaining species ML_2H_2 & ML_2H (equilibrium (4) & (7)) are generated by free metal ion binded with 2 moles of active met and also ML_3H_3, ML_3H_2, ML_3H and ML_3 (equilibrium (8), (9), (10) & (11)) are produced by 3 moles of met coordinated with free metal ion, but these species are not found to be in considerable amount (<10%). The generation of possible different chemical species is listed by the given equilibria [36, 43, 57]:

$$M(II) + LH_2^+ \rightleftharpoons MLH^{2+} + H^+ \text{[36]} \quad (1)$$

$$MLH^{2+} \rightleftharpoons ML^+ + H^+ \text{[36]} \quad (2)$$

$$M(II) + LH_2^+ \rightleftharpoons ML^+ + 2H^+ \text{[57]} \quad (3)$$

$$M(II) + 2LH_2^+ \rightleftharpoons ML_2H_2^{2+} + 2H^+ \text{[36, 43, 57] (minor process)} \quad (4)$$

$$ML_2H_2^{2+} \rightleftharpoons ML_2 + 2H^+ \text{[57]} \quad (5)$$

$$M(II) + 2LH_2^+ \rightleftharpoons ML_2 + 4H^+ \text{[36]} \quad (6)$$

$$M(II) + 2LH_2^+ \rightleftharpoons ML_2H^+ + 3H^+ \text{[43] (minor process)} \quad (7)$$

$$M(II) + 3LH_2^+ \rightleftharpoons ML_3H_3^{2+} + 3H^+ \text{[43] (minor process)} \quad (8)$$

$$M(II) + 3LH_2^+ \rightleftharpoons ML_3H_2^+ + 4H^+ \text{[43] (minor process)} \quad (9)$$

$$M(II) + 3LH_2^+ \rightleftharpoons ML_3H + 5H^+ \text{[43] (minor process)} \quad (10)$$

$$M(II) + 3LH_2^+ \rightleftharpoons ML_3^- + 6H^+ \text{[43] (minor process)} \quad (11)$$

Distribution diagrams gives a clear picture, how the concentration of complex species distributed in the solution as a measure of pH and also informs the key optimization pH, where the maximum species formed with percentage can be obtained from SIM refined data drawn by using Origin Pro 8. Interplay of free metal ion and LH_2^+ at lower pH forms MLH species (equilibrium (1)). Species ML can be generated either by deprotonation of MLH (equilibrium (2)) or by the binding affinity of the free metal ion with the active LH_2^+ form (equilibrium (3)). Due to the deprotonation of $ML_2H_2^+$ or active LH_2^+ form react with free metal ion (equilibrium (5) &(6)) forming ML_2 species. The depletion of metal ion concentration with pH shows the reaction tendency towards the ligand forming different complexes.

From Figure 2 (a) and (b), in Co^{II}-met system, predominant species are observed in the pH region 2.0–8.5 for MLH, 5.0–9.0 for ML and 7.9–9.0 for ML_2. The maximum % of species is found at pH 2.2–6.0, 8.0 and 9.0 for MLH, ML and ML_2 respectively. Interestingly rise in surfactant concentration favours MLH, ML_2 formation nearly 100% and simultaneously decrease in ML species concentration. The observed dominative species are MLH in acidic region and ML and ML_2 in basic region.

From Figure 2 (c) and (d), in Ni^{II}-met system, MLH, ML and ML_2 species are appeared between 2.0-7.0, 4.5–10.0 and 7.0–10.0 pH ranges respectively. The highest % of species appeared at pH 3.9, 7.9 and 8.9 for MLH, ML and ML_2 sequentially. More over gain in concentration of MLH, ML_2 and lose in concentration of ML with increase in micellar concentration is noticed. MLH and ML_2 with nearly 100% formation are appeared in this system.

In Cu^{II}-met system, from Figure 2 (e) and (f), have 2.0–5.0 pH for MLH, 3.5–5.5 pH for ML and 4.0–5.7 pH for ML_2 successively. All the species are found in acidic region only, in which MLH and ML_2 are dominative. So this study illustrates the species formation with a particular composition, apart from this, it gives information of bioavailability of the species with physiological pH conditions.

5.2. Proposed structures for metal complexes

The proposed structures for Co^{II} and Ni^{II} complexes were found to be octahedral geometry in literature by various authors. But apart from these complexes, Cu^{II} complexes have been suggested geometry of square planar or distorted octahedral. This distortion is caused by the effect of Jahn-Teller distortion [10, 28]. In addition to this, residing nitrogen donor sites at amino group have high affinity towards accepting electron

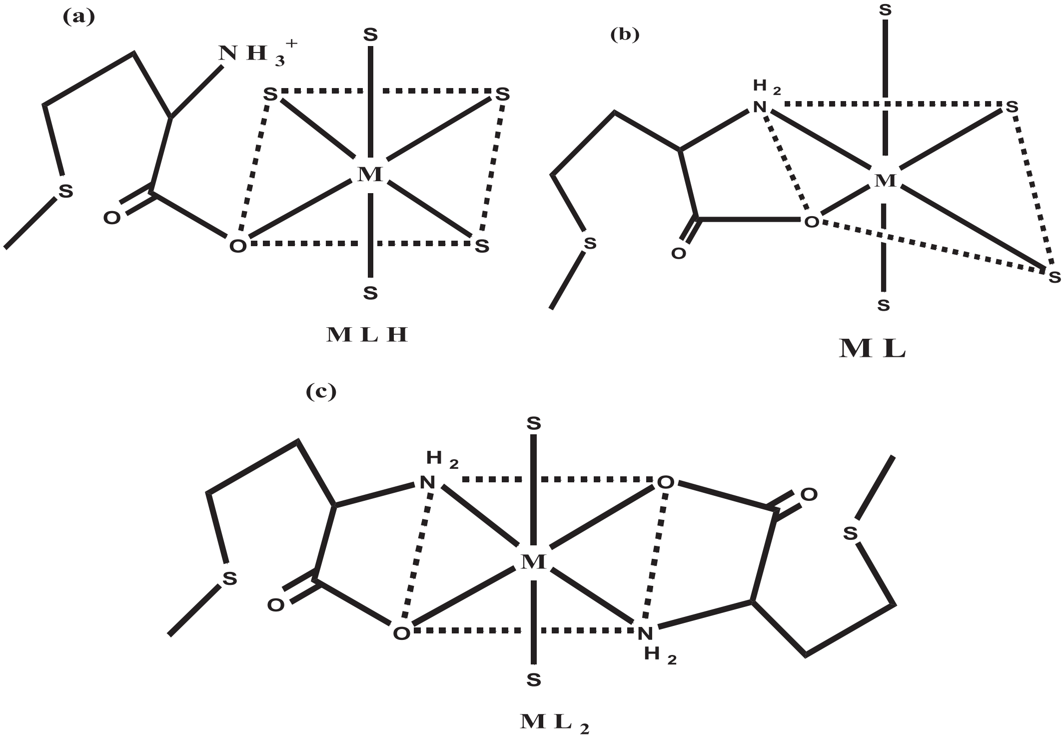

Figure 3. Schematic representation of L-Met complexes with Co^{II}, Ni^{II} and Cu^{II} (S is either solvent or water molecules)(a) MLH, (b) ML and (c) ML2.

pair in the physiological pH region. Thus metal ions become the opponents to the protons (H^+) in binding the ligand sites, consequently forming protonated and deprotonated species accompanied in the solution equilibria of the metal-methionine complexes.

From literature, the two active sites of Met are binded via carboxylate (-COO^-) and amino (-NH_2) groups through the respective donor atoms of "O" and "N" with these metal ions create a five membered stable cyclic rings, in which Met acted as a bidentate chelate ligand [29, 30, 31, 32, 33, 34]. At lower pH, the carboxylate "O" of Met can donate the electron pair to the metal ion forming protonated species, MLH and retaining lone pair of electrons in amino group contributed to the proton. At higher pH, the active sites amino and carboxylate bind through the donor atoms 'N' and 'O' of met with the metal ion, thereby forming deprotonated species, ML and ML_2. Also with the knowledge of valence shell electron pair repulsion theory, the binary complexes of M(Co^{II}, Ni^{II} and Cu^{II})-Met systems must be octahedral in shape [28], due to the availability of six electron pairs in its outer most shell, which suggests the schematic structures in Figure 3 [29–34].

6. Conclusions

The present study investigates L-Methionine forms protonated (MLH) and deprotonated (ML and ML_2) species, where the formation of protonated species at lower pH becomes deprotonated species with increase in pH by the addition of alkali in potentiometric titration. Influential parameters such as concentration of alkali and acid can affect significantly the magnitude of stability of binary complexes more compared to that of the other parameters like ligand, metal and correction factor. The formation constants (log β) fluctuated linearly with concentration (0.0–2.5% (v/v)) of TX 100-water mixtures predict that electrostatic forces are dominative than non-electrostatic forces. M (Co^{II}, Ni^{II} and Cu^{II})-Met systems stability constants follows the Irving-William order $Co^{II} < Ni^{II} << Cu^{II}$ and the extra stability attained by copper complexes due to the effect of Jahn-Teller Distortion.

Declarations

Author contribution statement

Robbi Neeraja: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Gandham Hima Bindu: Conceived and designed the experiments; Analyzed and interpreted the data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

[1] B.R. Raju, K.V.S. Devi, G.N. Rao, Formation of binary complexes of Co(II), Ni(II) and Cu(II) with L-DOPA in dioxan-water mixtures, Bull. Chem. Soc. Ethiop. 21 (1) (2011).

[2] R.J. Reeder, M.A. Schoonen, A. Lanzirotti, Metal speciation and its role in bioaccessibility and bioavailability, Rev. Mineral. Geochem. 64 (1) (2006) 59–113.

[3] L. Prashanth, K.K. Kattapagari, R.T. Chitturi, V.R.R. Baddam, L.K. Prasad, A review on role of essential trace elements in health and disease, J. Dr. Ntr Univ. Health Sci. 4 (2) (2015) 75–85.

[4] A. Aroor, A. Aroor, Medical Biochemistry, Amino Acid Metabolism, 2011, p. 336, chapter 11.

[5] S. Muthusamy, R. Natarajan, Pharmacological activity of a few transition metal complexes: a short review, J. Chem. Bio. Ther. (2016) 1000108.

[6] A.M. Al-Mohaimeed, A.A. Alothman, Characterization by potentiometric procedures of the stability constants of the binary and ternary complexes of Cu(II) and duloxetine drug with amino acids, J. Chem. (2019), 1064942.

[7] N. Rodríguez-Laguna, L.I. Reyes-García, R. Moya-Hernández, A. Rojas-Hernández, R. Gómez-Balderas, Chemical speciation of the system Cu(II)-Indomethacin in ethanol and water by UV-vis spectrophotometry, J. Chem. (2016), 9804162.

[8] F. Polat, H. Atabey, H. Sari, A. Cukurovali, Potentiometric study of equilibrium constants of a novel triazine–thione derivative and its stability constants with Hg2+ , Cu2+ , Ni2+ , Pb2+ , and Zn2+ metal ions in ethanol and water mixed, Turk. J. Chem. 37 (2013) 439–448.

[9] G.H. Bindu, G.N. Rao, Chemical speciation of L-glutamine complexes with Co(II), Ni(II) and Cu(II) in cationic micellar medium, Bull. Chem. Soc. Ethiop. 26 (3) (2012).

[10] R. Srinivasu, G.A. Atnafu, P. Shyamala, G.N. Rao, Mononuclear binary complex formation equilibria of L-ornithine with biologically essential metals in TBAB micellar media, Asian J. Chem. (2019).

[11] P. Sharmila, A. Ranjana, A. Rupali, Spectrophotometric study on the stability constant of complex Cu^{+2} - Arsenazo-III, Rasayan J. Chem. 2 (1) (2009) 120.

[12] P.S. Halman, D.D. Perrin, E. Ann. Watt, The computed distribution of copper(II) and zinc(II) ions among seventeen amino acids present in human blood plasma, Biochem. J. 121 (3) (1971).

[13] S. Raju, B.A. Kumar, K.B.K. Naik, G.N. Rao, Effect of dielectric constant of medium on chemical speciation of L-histidine complexes of Co(II), Ni(II) and Cu(II), Bull. Chem. Soc. Ethiop. 26 (2) (2012).

[14] N.V.V. Simhadri, K.B. Rao, N.V. Kumar, T.S. Rao, G.N. Rao, Speciation of Glutathione complexes of Pb(II), Cd(II) and Hg(II) in propylene Glycol-Water Mixtures, Int. J. Advan. Resear. Chem. Sci. 2 (5) (2015) 15.

[15] P.A. Azeez, B.A.K. Prusty, E.P. Jagadeesh, Chemical speciation of metals in environment, its relevancy to ecotoxocological studies and the need for biosensor development, J. Food Agric. Environ. 4 (3/4) (2006).

[16] D.M. Templeton, F. Ariese, R. Cornelis, L.G. Danielsson, H. Muntau, H.P. van Leeuwen, R. Lobinski, Guidelines for terms related to chemical speciation and fractionation of elements. Definitions, structural aspects, and methodological approaches, Pure Appl. Chem. 72 (8) (2000) 1453–1470.

[17] P. Sujatha, G.H. Bindu, P.S. Sunitha, Y. Vamsi Kumar, Speciation of binary complexes of Cd(II) and Pb(II) with L-Glutamine in cationic micellar medium, Int. J. Pharm. Drug. Anal. 5 (11) (2017) 423. https://ijpda.com/index.php/journal/article/view/310.

[18] P.S. Prasad, Micelle mediated extraction of calcium species in aqueous biphasic systems: a mechanism steered by aggregation number, Kamilika Sen, J. Mol. Liq. 276 (2019) 861–866.

[19] S.A.A. Sajadi, A comparative investigation of interaction between metal ions with L-methionene and related compounds such as alanine, leucine, valine, and glycine in aqueous solution, Adv. Biosci. Biotechnol. 1 (1) (2010).

[20] A.N. Belkher, A.A. Al-abbas, M. Zidan, Potentiometric studies on stability constant of the complexes of some essential transition metal ions with L-Valine, J. Pure and. Appl. Sci. 18 (3) (2019) 59.

[21] P. Bhushanavathi, G.N. Rao, Effect of solvent on chemical speciation of binary complexes of Co(II), Ni(II) and Cu(II) with L-proline, J. Inf. Comput. Sci. 10 (1) (2020) 49.

[22] S. H van Rijt, P.J. Sadler, Current applications and future potential for bioinorganic chemistry in the development of anticancer drugs, Drug Discov. Today 14 (23-24) (2009) 1089–1097.

[23] S. Clarke, Homocysteine in Health and Disease, 2001, pp. 63–78.

[24] J.E. Katz, M. Dlakić, S. Clarke, Automated identification of putative methyltransferases from genomic open reading frames*S, Mol. Cell. Proteomics 2 (8) (2003) 525–540.

[25] M. Mohammadi, A. Ghorbani-Choghamarani, L-Methionine-Pd complex supported on hercyniteas a highly efficient and reusable nanocatalyst for C-C cross-coupling reactions, New J. Chem. 44 (2020) 7.

[26] R.M. Aguiar, R.A. Leão, A. Mata, D. Cantillo, C.O. Kappe, L.S. Miranda, R.O. de Souza, Continuous-flow protocol for the synthesis of enantiomerically pure intermediates of anti epilepsy and anti tuberculosis active pharmaceutical ingredients, Org. Biomol. Chem. 17 (2019) 6.

[27] M.P. Latha, V.M. Rao, T.S. Rao, G.N. Rao, Determination of Protonation constants of L-Glutamic acid and L-Methionine in 1,2-Propanediol-Water Mixtures, Acta Chim. Slov. 54 (2007) 1.

[28] P.L. Kishore, V.T. Rao, G.N. Rao, Chemical speciation of binary complexes of Co(II), Cu(II) and Ni(II) with L-Dopa in Acetonitrile-Water and DMF-Water mixtures, Int. J. Res. Anal. Rev. 6 (1) (2019) 858.

[29] A. Dogan, E. Kilic, Potentiometric studies on the stability constants of some -amino acid-copper(II) and Ni(II) systems in ethanol-water mixture, Indian J. Chem. 42A (2003) 1632. http://nopr.niscair.res.in/handle/123456789/20689.

[30] G.R. Lenz, A.E. Martell, Metal chelates of some sulfur-containing amino acids, Biochemistry 3 (6) (1964) 745.

[31] C. McAuliffe, S. Murray, Metal complexes of sulphur-containing amino acids, Inorg. Chim. Acta. Rev. 6 (c) (1972) 103.

[32] C. Mcauliffe, J. Quagliano, L. Vallarino, Metal complexes of the amino acid DL-methionine, Inorg. Chem. 5 (11) (1966) 1996.

[33] V. Shtyrlin, E. Gilyazetdinov, N. Serov, Stability, lability, spectral parameters and structure of complexes and stereoselective effects in the nickel(II) – l/d/dl-histidine – l/d/dl-methionine systems, Inorg. Chim. Acta. 477 (2018) 135.

[34] J. Murphy, A. Gaertner, T. Williams, Stability constant determination of sulfur and selenium amino acids with Cu(II) and Fe(II), J. Inorg. Biochem. 195 (2019) 20.

[35] B.B. Tewari, Studies on complexation in solution with a paper electrophoretic technique [the system copper(II)/Cobalt(II)−Methionine−Penicillamine], J. Chem. Eng. Data 55 (5) (2010) 1779–1783.

[36] M.P. Latha, V.M. Rao, T.S. Rao, G.N. Rao, Chemical speciation of Pb(II), Cd(II), Hg(II), Co(II), Ni(II), Cu(II) AND Zn(II) binary complexes of L-methionine in 1,2-propanediol–water mixtures, Bull. Chem. Soc. Ethiop. 21 (3) (2007) 363.

[37] D. Koley, A.J. Bard, Triton X-100 concentration effects on membrane permeability of a single HeLa cell by scanning electrochemical microscopy (SECM), Proc. Natl. Acad. Sci. Unit. States Am. 107 (39) (2010) 16783–16787.

[38] I. Budin, N.K. Devaraj, Membrane assembly driven by a biomimetic coupling reaction, J. Am. Chem. Soc. 134 (2) (2012) 751–753.

[39] A.L. Vogel, G.H. Jeffery, Vogel's Textbook of Quantitative Chemical Analysis, Wiley, 1989.

[40] G. Gran, Determination of the equivalence point in potentiometric titrations, Part II, Analyst 77 (1952) 920.

[41] G. Gran, Equivalence volumes in potentiometric titrations, Anal. Chim. Acta 206 (1988) 111–123.

[42] G.N. Rao, Complex Equilibria of Some Biologically Important Metal Ions in Aquo-Organic Media, Ph. D. thesis, Andhra University, Visakhapatnam, India, 1989.

[43] C.N. Rao, M. Ramanaiah, B.B.V. Sailaja, Speciation of binary complexes of Pb(II) and Cd(II) with L-asparagine in dimethyl sulfoxide - water mixtures, Bull. Chem. Soc. Ethiop. 30 (1) (2016).

[44] P. Gans, A. Sabatini, A. Vacca, An improved computer program for the computation of formation constants from potentiometric data, Inorg. Chim. Acta. 18 (1976) 237–239.

[45] G.H. Bindu, G.N. Rao, Effect of anionic micelles on speciation of L-glutamine in presence/absence of metals, Chem. Speciat. Bioavailab. (2011) 88–95.

[46] M. Ramanaiah, P. Seetharam, M. Balakrishna, B.R. Raju, Potentiometric studies of complex equlibria of CaII, MgII and ZnII with 5-sulphosalicylic acid in cationic micelles of CTAB, Heliyon 5 (8) (2019), E02157.

[47] V.U. Sagar, G. Himabindu, K.G. Sudarsan, G.N. Rao, Speciation studies of binary complexes of nickel(II) with L-arginine and L- histadine in micellar medium, J. Indian Chem. Soc. 82 (2005) 7.

[48] G.H. Bindu, G.N. Rao, Protonation and complexation equilibria of L-glutamine in Non-ionic micellar medium, Proc. Natl. Acad. Sci. India Sect. A (Phys. Sci.) 82 (2012) 2.

[49] Z. Yuanqin, The effect of surfactant micelles on the dissociation constants and transition points and transition intervals of acid–base indicators, Talanta 56 (4) (2002) 705–710.

[50] A.L. Undereood, Dissociation of acids in aqueous micellar systems, Anal. Chim. Acta 140 (1) (1982) 89–97.

[51] M. Born, Volumen und hydratationswärme der ionen, Z. Physik. (1920) 45–48.

[52] C.A. Bunton, L.S. Romsted, L.A. Sepulveda, A quantitative treatment of micellar effects upon deprotonation equilibriums, J. Phys. Chem. (1980) 2611–2618.

[53] Y. Obata, K. Takayama, Y. Maitani, Y. Machida, T. Nagai, Effect of ethanol on skin permeation of nonionized and ionized diclofenac, Int. J. Pharmaceutics. 89 (3) (1993) 191–198.

[54] J.M. Miller, A. Beig, B.J. Krieg, R.A. Carr, T.B. Borchardt, G.E. Amidon, A. Dahan, The solubility–permeability interplay: mechanistic modeling and predictive application of the impact of micellar solubilization on intestinal permeation, Mol. Pharm. (2011).

[55] A.V. Solomonov, Y.S. Marfin, E.V. Rumyantsev, E. Ragozin, T.S. Zahavi, G. Gellerman, A. Miyawaki, Self-assembled micellar clusters based on Triton-X-family surfactants for enhanced solubilization, encapsulation, proteins permeability control, and anticancer drug delivery, Mater. Sci. Eng. C (2019) 1848–1856.

[56] B. Srikanth, P.S. Rao, V.S.S. Rao, C.K. Sastry, G.N. Rao, Effect of micelles on the chemical speciation of binary complexes of Co(II), Nii(II), Cu(II) and Zn(II) with succinic acid, J. Serb. Chem. Soc. 74 (7) (2009) 745–754.

[57] V.G. Kumari, M. Ramanaiah, B.B.V. Sailaja, Speciation of binary complexes of Co(II), Ni(II), and Cu(II) with L-phenylalanine in anionic micellar medium, Chem. Speciat. Bioavailab. 27 (3) (2015) 121.