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Research Article

Chemical Speciation of Complexes of L-phenylalanine and maleic acid with toxic metal ions in Dimethylformamide - Water Mixtures

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Abstract

The formation equilibria of complexes of Pb (II), Cd (II), and Hg (II) with L-phenylalanine and maleic acid were investigated pH metrically in Dimethyl formamide-water mixtures (0-50%v/v) at 303 K and ionic strength of 0.16 moldm^{-3}. The dominant species detected were ML_2, ML_2H, and ML_3 of LPA and MA complexes of Pb(II), Cd(II) and Hg(II) were refined in DMF-water mixtures. The appropriateness of the experimental conditions was verified by introducing errors deliberately. The models containing different numbers of species were refined by using the computer program MINIQUAD75. Selection of the best fit models was based on the statistical parameters. The trend in variation of stability constant of the complexes with dielectric constant of the medium was attributed for the formation and possible structures of the complex species presented. The chemical speciation was explained based on the distribution diagrams drawn using HYSS HYPERQUAD.

Keywords: speciation, complex equilibria, Dimethyl formamide, L-phenylalanine, maleic acid, stability constants, HYSS HYPERQUAD, MINIQUAD75

Introduction

Heavy metals are common in our environment and diet and many of them are essential to living organisms but some of them are highly toxic or become toxic given sufficient exposure and accumulation in the body. Metals such as Hg, Cd, Pb, Sn, Cr and As are generally not required for metabolic activity and are toxic to living organisms even at low concentrations [1]. The mechanism of the toxicity of metals is very complicated. Generally, toxicity of metals results from blocking the essential biological functional groups (-OH, -SH, and –N) or modifying the active conformation of biomolecules (enzyme, DNA, etc.,) through binding and displacing the essential metal ions from their natural binding sites of the bio-molecules with a foreign metal ion. Human civilization and the increase in industrial activity has gradually redistributed many toxic metals from the earth's crust to the environment and increased the possibility of exposure. Lead, cadmium, and mercury are among the various toxic metals especially prevalent in nature due to their high industrial use. These metals serve no biological function and their presence in tissues reflects contact of the organism with its environment [2].

The main sources of lead pollution specially the bones and teeth, the kidneys, and the nervous, cardiovascular, immune and reproductive systems [3,4]. Lead also interferes with the normal metabolism of calcium in cells and causes it to build up within them [5].

The sources of Cd pollution in urban areas are metallurgical plants, Cd plating and battery fabricators. It can also enter the environment through natural causes, such as volcanic activity and forest fires [6]. Human exposure to cadmium mainly occurs through cigarette smoking [7]. but exposure can also occur through contaminated food [8], water or air [9]. Cadmium is a known carcinogen to mammals [10]. Cadmium interacts with calcium in the skeletal system to produce osteodystropies [11]. Due to their similarity in properties, cadmium displaces zincin many metallo-enzymes and many of the symptoms of cadmium toxicity can be traced to a cadmium-induced zinc deficiency [12]. Cd (II) binds strongly with the -SH groups of cysteine residues of enzymes [13], e.g. carbonic anhydrase, dipeptidase, carboxy peptidase etc., and effects the active conformation of bio -molecules due to this strong binding.

Mercury exposure is related to the release of mercury forms (Hg(0), inorganic Hg (II), and organic Hg into the environment by both natural and man -made activities [14]. Mercury is a highly toxic element because of its accumulative and persistent character in the environment and living organisms [15]. It affects the immune system, alters genetics and enzyme systems, damages the nervous affinity for the protonated forms of thiol ligands such as cysteine [16]. So, Hg (II) binds strongly with the thiol group of proteins, enzymes and other bio-molecules in which this binding changes the conformation of bio-molecules in their active site [13, 17].

Speciation studies of toxic and essential metal ion complexes are useful in order to understand the role played by the active site cavities in biological molecules and the bonding behavior of their residues with metal ions. The possible ligand groups in proteins are the amino acid side chains, the terminal amino, carboxyl and thiol groups and, in some cases, the amide group is the peptide backbone [18].

However, the study of metal-protein system may be difficult to construct in simple - like amino acids and peptides but such models may give a tremendous amount of information about the structure of proteins and function of bio-molecules in biological systems [19]. The interaction of metals with amino acids and peptides has been the subject of much research [20], due to the importance of metals in many biochemical processes [21], such as respiration, metabolism and nerve transmission [22]. Investigations of acid-base equilibria of amino acids and peptides and their interaction with metal ions at varying ionic strengths, temperatures and dielectric constant media throw light on the mechanism of enzyme catalyzed reactions. It is known that the polarity of the active site cavities in proteins is lower than that of the bulk but direct measurements of the dielectric constant is not possible.

Comparing the formation constants of acid-base equilibria and/or metal complex equilibria with those at biological centers offers a way to estimate the effective dielectric constant or equivalent solution dielectric constant for the active site cavity [23]. This has brought an important new approach to the study of complex equilibria in aqua-organic mixtures apart from its established utility in understanding solute-solvent interactions, increasing sensitivity of reactions of analytical and industrial importance and solubilizing ligands of their metal complexes.

Chemical speciation of metals is important for an understanding of their distribution, mobility, toxicity, and for setting environmental quality standards [24]. Bioavailability of a particular metal depends on its complex chemical reactions of dissolution, binding and complexation with the constituents of the environmental aquatic media [25]. To reveal the solvent effects on equilibrium processes involving charged species, we have studied the complex formation of L-phenylalanine and maleic acid with Pb (II), Cd (II) and Hg (II) as a good example in modelling of the bonding modes of peptides to toxic metal ions in mixtures containing Dimethyl formamide (DMF) and water.

Materials and Methods

Chemicals and standard solution

All the chemicals used in this experiment were of analytical reagent grade purity. Triple distilled deionized water was used for the preparation of all the solutions. Solutions of 0.1 moldm^{-3} of Pb(II), Cd(II), Hg(II) nitrates (E-Merck, Germany) were prepared maintaining 0.05 mol dm^{-3} nitric acid to suppress the hydrolysis of metal salts. A solution (0.05moldm^{-3}) of L-phenylalanine and maleic acid (GR grade, Loba, India) was prepared by maintaining a 0.05mol dm^{-3} nitric acid concentration to increase its solubility. Dimethylformamide (Qualigens, India) was used as received. Solutions of 0.2 moldm^{-3} nitric acid and 0.4 moldm^{-3} sodium hydroxide (Merck, India) were prepared. A solution of 2.0 moldm^{-3} sodium nitrate (Merck, India) was prepared to maintain the ionic strength in the titrand. All the solutions were standardized by the usual oxalic acid and potassium hydrogen phthalate solutions, while the normality of nitric acid was determined by using the standardized sodium hydroxide and the primary borax solutions [26]. The concentration of the metal ions were determined complexometrically by titrating against a standard solution of EDTA using Xylenol orange indicator and hexamine powder as buffer to maintain the pH at 5-6 [27]. So as to assess the errors that might have crept into the determination of the concentrations, the data were subjected to one-way analysis of variance (ANOVA) by using the computer program, COST [28]. The carbonate contamination in the sodium hydroxide solutions was determined by using the Gran Plot method [29].

Alkalimetric Titrations

The pH measurements of metal-ligand binary systems were carried out in aqueous media containing varying compositions of Dimethylformamide in the range of 0-50% (v/v) maintaining an ionic strength of 0.16 moldm^{-3} with sodium nitrate at 303K by using a digital pH meter ELICO type readability of 0.01 (0-14). The electrode of the cell was calibrated with 0.05 moldm^{-3} potassium hydrogen pthalate solution in the acidic region and with 0.01 moldm^{-3} borax solution in the alkaline region to measure the response in the pH range. The effect of variations in asymmetry potential, liquid junction potential, activity coefficient, sodium ion error and dissolved carbon dioxide on the response of the glass electrode were accounted for in the form of correction factor [30,31]. Mechanical stirring of the solution was carried out by means of a magnetic stirrer. The pH metric titration assembly consisted of a double-walled spotless pyrex glass vessel of 100 mL capacity fitted with a Perspex lid through which the glass combination pH electrode and burette tip were admitted. Free acid titrations were performed before the metal -ligand titrations to calculate the correction factor. In each of the titrations, the titrand consisted of a mineral acid of approximately 1 mmol in a total volume of 50cm^3. titrations with different ratios (1:0.25-1:0.50) of metal to ligand were performed with 0.4 moldm^{-3} sodium hydroxide solution.

Modeling Strategy

The correction factor to be applied to the pH-meter dial readings was calculated with the computer program SCPHD [32]. By using the pH –metric titration data, the binary stability constants were calculated with the computer program MINIQUAD75, which exploits the advantage of the constrained least squares method in the initial refinement and reliable convergence of the Marquardt algorithm [33]. During the refinement of binary stability constants, pKw and the protonation constants [34] of L-phenylalanine and maleic acid were fixed.

Results and discussion

The results of the best fit models that contain the type of species and overall formation constants along with some of the important statistical parameters are given in Table 1. The low standard deviation in log β values indicates the adequacy of the models. The small values of U_{corr} (sum of squares of deviation in concentrations of the metal, ligand and hydrogen ions at all represented by the model). For an ideal normal distribution, the values of kurtosis and skewness should be three and zero, respectively. The kurtosis values in the present study indicate that the residuals form leptokurtic pattern and a few forms a platykurtic pattern. The values of the skewness given in Table 1 are between -0.59 and 3.42 for LPA and in table 2 are between -0.26 and 4.11 for MA. These data evince that the residuals form a part of normal distribution; hence, least squares method can be applied to the present data. The sufficiency of the model is further evident from the low crystallographic R-value recorded [35]. Thus, these statistical parameters support the best fit models which portray the metal-ligand species in DMF-water mixtures.

Effect of systematic errors on best fit model

In order to rely up on the best fit chemical model for critical evaluation and application under varied experimental conditions with different accuracies of data acquisition, an investigation was made by introducing pessimistic errors in the concentrations of alkali, mineral acid, ligand and metal (Table 3). Errors were introduced in the concentrations of the ingredients intentionally to find their effect on the perturbation of stability constants. If the concentrations determined and the experimental conditions maintained by the researcher were appropriate, any variations in the concentrations of the ingredients will affect the magnitudes and statistical parameters of the stability constants. Sometimes even the species shall be rejected. Hence, we have studied the effect of errors in the concentrations of the ingredients on the stability constants. The data show that the order of affecting the magnitudes of the stability constants is alkali > acid > ligand > metal. Some species, were even rejected when the errors were introduced in the concentrations of the components. This shows that any deviation in the stability constants (log β) and also results in the rejection of the species.

Table 3: Effect of errors in influential parameters on M(II)- LPA/MA complex stability constants in DMF-water medium.

Ingredient	% Error	Log β_{mlh}(SD)		
		120	121	130
Pb(II)-LPA 50 % v/v DMF-water mixture				
Acid	0	6.79(24)	14.93(35)	10.15(23)
	-5	8.67(44)	16.99(30)	12.86(27)
	-2	7.28(37)	15.75(25)	11.11(21)
	+2	6.44(12)	Rejected	9.22(18)
	+5	5.99(11)	Rejected	Rejected
Alkali	-5	5.83(12)	Rejected	Rejected
	-2	6.43(11)	Rejected	9.08(21)
	+2	7.24(46)	15.76(27)	11.19(22)
	+5	8.39(29)	Rejected	12.09(30)
Ligand	-5	6.74(45)	15.06(38)	10.46(24)
	-2	6.74(36)	15.03(36)	10.35(23)
	+2	6.74(29)	14.98(33)	10.21(21)
	+5	6.73(24)	14.95(31)	10.10(21)
Metal	-5	6.74(32)	15.00(34)	10.28(22)
	-2	6.77(27)	14.96(35)	10.20(23)
	+2	6.80(22)	14.91(35)	10.10(24)
	+5	6.81(20)	14.87(36)	10.02(25)
Pb(II)-MA 30 % v/v DMF -water mixture				
Acid	0	7.11(17)	12.10(18)	10.51(17)
	-5	Rejected	13.82(09)	12.88(08)
	-2	7.05(60)	12.90(08)	11.50(09)
	+2	6.78(16)	Rejected	9.56(39)
	+5	6.16(21)	Rejected	Rejected
Alkali	-5	5.69(40)	Rejected	Rejected
	-2	6.63(19)	Rejected	9.38(48)
	+2	Rejected	13.04(06)	11.75(05)
	+5	Rejected	14.00(14)	13.33(12)
Ligand	-5	6.82(86)	12.62(12)	11.24(13)
	-2	7.06(28)	12.33(15)	10.81(15)
	+2	7.05(15)	11.85(25)	10.19(22)
	+5	6.98(11)	11.21(73)	9.59(45)
Metal	-5	7.09(20)	12.12(18)	10.61(16)
	-2	7.10(18)	12.11(18)	10.54(16)
	+2	7.10(16)	12.09(17)	10.46(17)
	+5	7.10(15)	12.07(17)	10.40(18)

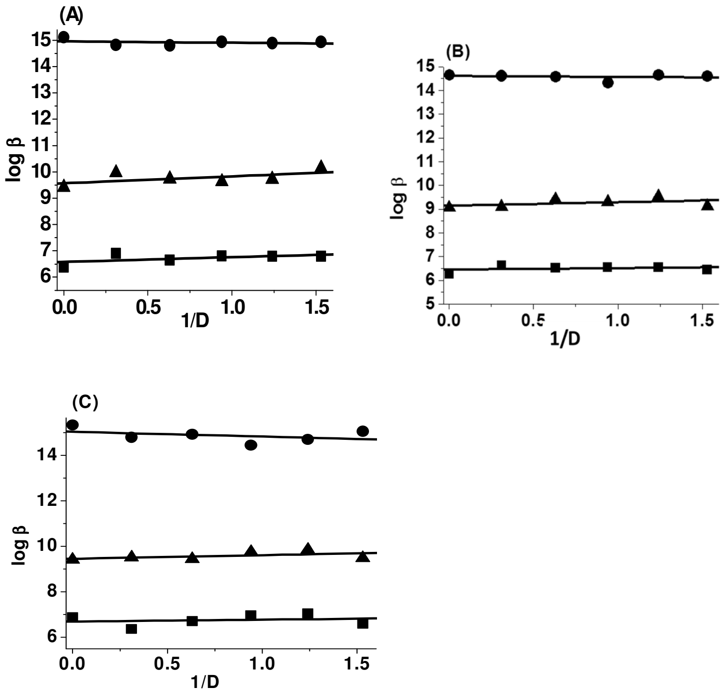

Fig.1: Variation of overall stability constant values of metal-LPA complexes with reciprocal of dielectric constant (1/D) of DMF-water mixtures (A) Pb(II); (B) Cd(II); (C) Hg(II); (■)log β_{ML2}; (▲) log β_{ML3}; (●) log βM_{L2H}.

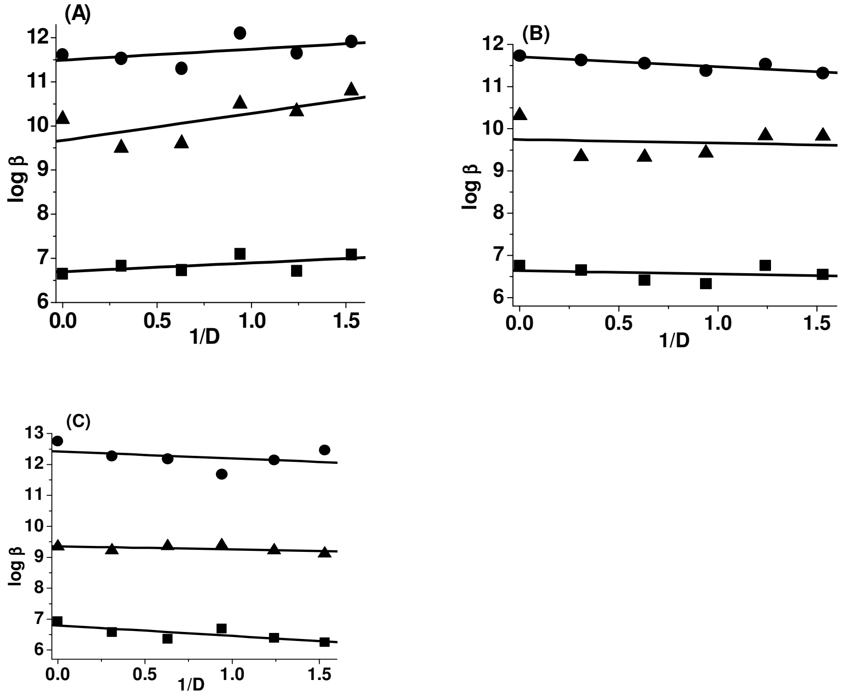

Fig.2: Variation of overall stability constant values of metal-MA complexes with reciprocal of dielectric constant (1/D) of DMF-water mixtures (A) Pb(II); (B) Cd(II); (C) Hg(II); (■)log β_{ML2}; (▲) log β_{ML3}; (●) log β_{ML2H}.

Effect of Solvent

DMF is a polar aprotic solvent. The dielectric constant of DMF-water mixture decreases with increasing concentration of DMF and these solutions are expected to mimic physiological conditions where the concept of the equivalent solution dielectric constant for protein cavities is applicable [36]. The dielectric constants of DMF at different percentages (0.0-50.0 v/v %) of water were taken from literature [37]. The increase in organic solvent content decreases the dielectric constant of the medium. The change in log β values of Pb(II), Cd(II) and Hg(II) complexes of LPA and MA with 1/D (Fig.1-2) is almost linear which indicates that the dielectric constant or long range interactions are responsible for the stability trend in both DMF-water media. The deviation from linearity may be due to some contributions from non- electrostatic forces.

Distribution diagrams

L-phenylalanine is a bidentate ligand that has one dissociable (carboxyl group) and one associable (amino) protons. The form of LPA that exist in the pH region of 1.6 - 11.5 is LH_2^+, LH and L^-. Hence the possible metal-ligand species are ML_2, ML_2H, and ML_3 which are confirmed by MINIQUAD75. The equilibria can be represented as follows:

$$M(II) + LH_2^+ \rightleftharpoons MLH^{2+} + H^+ \quad (1)$$
$$MLH^{2+} \rightleftharpoons ML^+ + H^+ \quad (2)$$
$$M(II) + LH_2^+ \rightleftharpoons ML^+ + 2H^+ \quad (3)$$
$$M(II) + 2LH_2^+ \rightleftharpoons ML_2H_2^{2+} + 2H^+ \quad (4)$$
$$MLH^{2+} + LH_2^+ \rightleftharpoons ML_2H_2^{2+} + H^+ \quad (5)$$
$$ML_2H_2^{2+} \rightleftharpoons ML_2H^+ + H^+ \quad (6)$$
$$MLH^{2+} + LH \rightleftharpoons ML_2H^+ + H^+ \quad (7)$$
$$ML^+ + LH_2^+ \rightleftharpoons ML_2H^+ + H^+ \quad (8)$$
$$ML_2H^+ \rightleftharpoons ML_2 + H^+ \quad (9)$$
$$ML^+ + LH \rightleftharpoons ML_2 + H^+ \quad (10)$$
$$ML_2 + LH \rightleftharpoons ML_3^- + H^+ \quad (11)$$
$$M(II) + 3LH_2^+ \rightleftharpoons ML_3H_3^{2+} + 3H^+ \quad (12)$$
$$MLH^{2+} + 2LH_2^+ \rightleftharpoons ML_3H_3^{2+} + 2H^+ \quad (13)$$
$$ML_3H_3^{2+} \rightleftharpoons ML_3H_2^+ + H^+ \quad (14)$$
$$ML^+ + 2LH_2^+ \rightleftharpoons ML_3H_2^+ + 2H^+ \quad (15)$$
$$ML_3H_2^+ \rightleftharpoons ML_3H^- + H^+ \quad (16)$$
$$ML_3H^- \rightleftharpoons ML_3^{2-} + H^+ \quad (17)$$
$$M(II) + 2LH_2^+ \rightleftharpoons ML_2H^+ + 3H^+ \quad (18)$$
$$M(II) + 2LH_2^+ \rightleftharpoons ML_2 + 4H^+ \quad (19)$$
$$M(II) + 3LH_2^+ \rightleftharpoons ML_3H_2^+ + 4H^+ \quad (20)$$
$$M(II) + 3LH_2^+ \rightleftharpoons ML_3H + 5H^+ \quad (21)$$
$$M(II) + 3LH_2^+ \rightleftharpoons ML_3^- + 6H^+ \quad (22)$$
$$ML_2H_2 \rightleftharpoons ML_2^{2-} + 2H^+ \quad (23)$$
$$ML_3H_3 \rightleftharpoons ML_3H^{2-} + 2H^+ \quad (24)$$
$$ML_3H_3 \rightleftharpoons ML_3^{3-} + 3H^+ \quad (25)$$

Maleic acid is a bidentate ligand that has two dissociable (carboxyl groups) protons. The different forms of maleic acid are XH_2, XH^-, and X^{2-} in the pH range < 4.0, 2.0–7.0 and > 5.0 respectively. Hence, the plausible binary metal-ligand complexes can be predicted from these data. The present investigation reveals the existence of MX_2, MX_2H, MX_3 for Pb(II), Cd(II) and Hg(II).

The present study is confined to pH ranges 2.8-7.8 for Pb(II), 4.0-7.5 for Cd(II) and 4.2-6.5 for Hg(II). The formation of various maleic acid complex species is shown in the following equilibria.

$M(II) + XH_2 \rightleftharpoons MXH^+ + H^+$ (1)
$MXH^+ \rightleftharpoons MX + H^+$ (2)
$M(II) + XH_2 \rightleftharpoons MX + 2H^+$ (3)
$M(II) + 2XH_2 \rightleftharpoons MX_2H_2 + 2H^+$ (4)
$MX_2H_2 \rightleftharpoons MX_2H^- + H^+$ (6)
$MXH^+ + XH^- \rightleftharpoons MX_2H^- + H^+$ (7)
$MX + XH_2 \rightleftharpoons MX_2H^- + H^+$ (8)
$MX_2H^- \rightleftharpoons MX_2^{2-} + H^+$ (9)
$MX + XH^- \rightleftharpoons MX_2^{2-} + H^+$ (10)
$MX_2^{2-} + XH^- \rightleftharpoons MX_3^{4-} + H^+$ (11)
$M(II) + 3XH_2 \rightleftharpoons MX_3H_3^- + 3H^+$ (12)
$MXH^+ + 2XH_2 \rightleftharpoons MX_3H_3^- + 2H^+$ (13)
$MX_3H_3^- \rightleftharpoons MX_3H_2^{2-} + H^+$ (14)
$MX + 2XH_2 \rightleftharpoons MX_3H_2^{2-} + 2H^+$ (15)
$MX_3H_2^{2-} \rightleftharpoons MX_3H^{3-} + H^+$ (16)
$MX_3H^{3-} \rightleftharpoons MX_3^{4-} + H^+$ (17)
$M(II) + 2XH_2 \rightleftharpoons MX_2H^- + 3H^+$ (18)
$M(II) + 2XH_2 \rightleftharpoons MX_2^{2-} + 4H^+$ (19)
$M(II) + 3XH_2 \rightleftharpoons MX_3H_2^{2-} + 4H^+$ (20)
$M(II) + 3XH_2 \rightleftharpoons MX_3H^{3-} + 5H^+$ (21)
$M(II) + 3XH_2 \rightleftharpoons MX_3^{4-} + 6H^+$ (22)
$MX_2H_2 \rightleftharpoons MX_2^{2-} + 2H^+$ (23)
$MX_3H_3^- \rightleftharpoons MX_3H^{3-} + 2H^+$ (24)
$MX_3H_3^- \rightleftharpoons MX_3^{4-} + 3H^+$ (25)

Distribution diagrams were drawn for various complex species using the formation constants of the best-fit models as shown in Fig 3-4. These diagrams indicate that the percentage of ML species of Pb(II),Cd(II) and Hg(II) increases and then decreases with the increase of pH. Depending upon the active sites in the ligand and the nature of the metal ions, the structures were proposed for the species detected as shown in Fig 5-6.

Amino nitrogen and carboxyl oxygen of L-phenylalanine participate in bonding with metal ions. This argument supports the structures of complexes proposed in Fig.5

Maleic acid acts as a bidentate ligand by using its two oxygen donor sites and the chelation results in highly stable seven membered rings (Fig.6). Octahedral structures are proposed to the complexes of all the metal ions.

Table 1: Parameters of best fit chemical models of Pb(II), Cd(II) and Hg(II)- LPA complexes in DMF- water mixtures.

% of DMF	log β_{mlh} (SD)			pH-Range	NP	U_{corr} $\times 10^8$	χ^2	Skewness	Kurtosis	R-factor
	ML_2	ML_2H	ML_3							
Pb(II)										
0.0	6.38(39)	15.03(06)	9.25(18)	7.0-9.1	30	9.44	1.52	-0.02	4.92	0.0162
10	6.90(92)	14.82(88)	9.97(04)	7.3-8.3	27	9.28	2.18	-0.01	2.90	0.0322
20	6.64(66)	14.80(83)	9.73(25)	7.7-8.9	31	6.67	3.92	1.23	5.02	0.0623
30	6.80(83)	14.94(95)	9.63(25)	7.6-8.9	30	2.61	2.93	-0.24	3.17	0.0491
40	6.79(74)	14.89(88)	9.72(21)	7.6-8.9	37	10.00	6.25	0.03	2.65	0.0372
50	6.79(76)	14.93(94)	10.15(21)	7.0-8.9	30	3.53	5.87	0.63	3.79	0.0223
Cd(II)										
0.0	6.27(28)	14.65(67)	9.06 (09)	7.0-9.1	41	3.33	5.95	-0.52	3.00	0.0352
10	6.64(67)	14.62(63)	9.10 (17)	7.3-9.1	43	1.00	1.35	3.42	5.49	0.0511
20	6.52(55)	14.58(59)	9.42(05)	7.3-9.3	43	1.5	6.16	2.01	2.78	0.0302
30	6.55(56)	14.33(36)	9.30(21)	7.3-9.3	41	7.78	7.13	0.62	3.01	0.0301
40	6.55(57)	14.65(64)	9.53(07)	7.3-9.5	40	1.76	1.33	0.23	7.96	0.0141
50	6.45(47)	14.60(62)	9.13(24)	7.3-9.5	47	2.86	2.80	-0.61	4.23	0.0161
Hg(II)										
0.0	6.88(89)	15.34(35)	9.42(07)	6.0-9.4	44	5.71	1.33	0.21	4.41	0.0242
10	6.37(39)	14.80(82)	9.52(21)	6.0-8.4	34	5.45	7.52	-0.59	4.41	0.0232
20	6.71(73)	14.93(91)	9.45(07)	6.0-8.4	26	1.54	2.00	0.13	2.53	0.0132
30	6.97(98)	14.45(46)	9.76(29)	6.0-8.4	21	4.44	9.76	-0.53	4.12	0.0223
40	7.05(07)	14.70(72)	9.85(03)	6.0-8.4	27	1.42	8.14	-0.31	4.12	0.0141
50	6.59(62)	15.06(07)	9.49(03)	6.0-8.4	22	1.11	8.85	-0.54	3.63	0.0052

Table 2: Parameters of best fit chemical models of Pb(II), Cd(II) and Hg(II)-MA complexes in DMF - water mixtures.

% of DMF	log β_{mlh} (SD)			pH-Range	NP	U_{cor4r} $\times 10^8$	χ^2	Skewness	Kurtosis	R-factor
	MX_2	MX_2H	MX_3							
Pb(II)										
0.0	6.65(66)	11.61(62)	10.15(16)	2.8-7.8	44	2.11	16.41	4.11	2.90	0.0493
10	6.83(84)	11.53(54)	9.50(51)	3.6-5.8	48	0.66	5.85	0.05	4.66	0.0083
20	6.73(74)	11.30(31)	9.60(62)	3.6-5.2	48	6.66	10.59	0.60	3.18	0.0244
30	7.10(12)	12.10(12)	10.50(51)	3.9-5.1	44	2.00	3.46	-0.14	2.62	0.0132
40	6.71(73)	11.65(66)	10.33(34)	4.1-5.2	46	0.66	9.41	0.76	5.95	0.0292
50	7.08(09)	11.91(92)	10.80(82)	3.8-5.1	77	6.00	6.58	-0.26	3.69	0.0243
Cd(II)										
0.0	6.76(77)	11.73(72)	10.32(33)	4.0-7.2	72	3.18	5.11	0.26	3.14	0.0154
10	6.65(66)	11.63(65)	9.34(35)	4.0-7.5	73	6.087	1.69	3.61	4.04	0.0265
20	6.41(43)	11.55(54)	9.33(36)	4.2-7.4	44	4.58	5.02	1.37	5.78	0.0226
30	6.33(35)	11.38(40)	9.43(44)	4.2-7.3	88	3.04	1.64	1.52	7.43	0.0197
40	6.76(77)	11.53(54)	9.84 (85)	4.2-7.4	88	6.84	9.64	0.25	5.39	0.0299
50	6.55(56)	11.32(33)	9.83(82)	4.2-7.4	90	4.21	3.82	-0.03	2.72	0.0221
Hg(II)										
0.0	6.93(94)	12.75(76)	9.35(36)	4.2-6.4	100	7.22	3.92	1.14	5.11	0.0292
10	6.58(61)	12.27(29)	9.22(23)	4.4-6.4	22	24.54	23.67	0.05	5.82	0.0583
20	6.36(37)	12.18(19)	9.36(35)	4.2-6.5	34	8.50	8.33	1.34	6.36	0.0344
30	6.69(70)	11.68(67)	9.39(40)	4.2-6.4	36	10.52	3.82	1.23	3.21	0.0375
40	6.39(40)	12.14(15)	9.22 (23)	4.2-6.4	77	5.26	38.00	1.95	2.12	0.0456
50	6.25(31)	12.46(47)	9.12(13)	4.5-6.4	65	8.23	4.00	1.16	3.45	0.0323

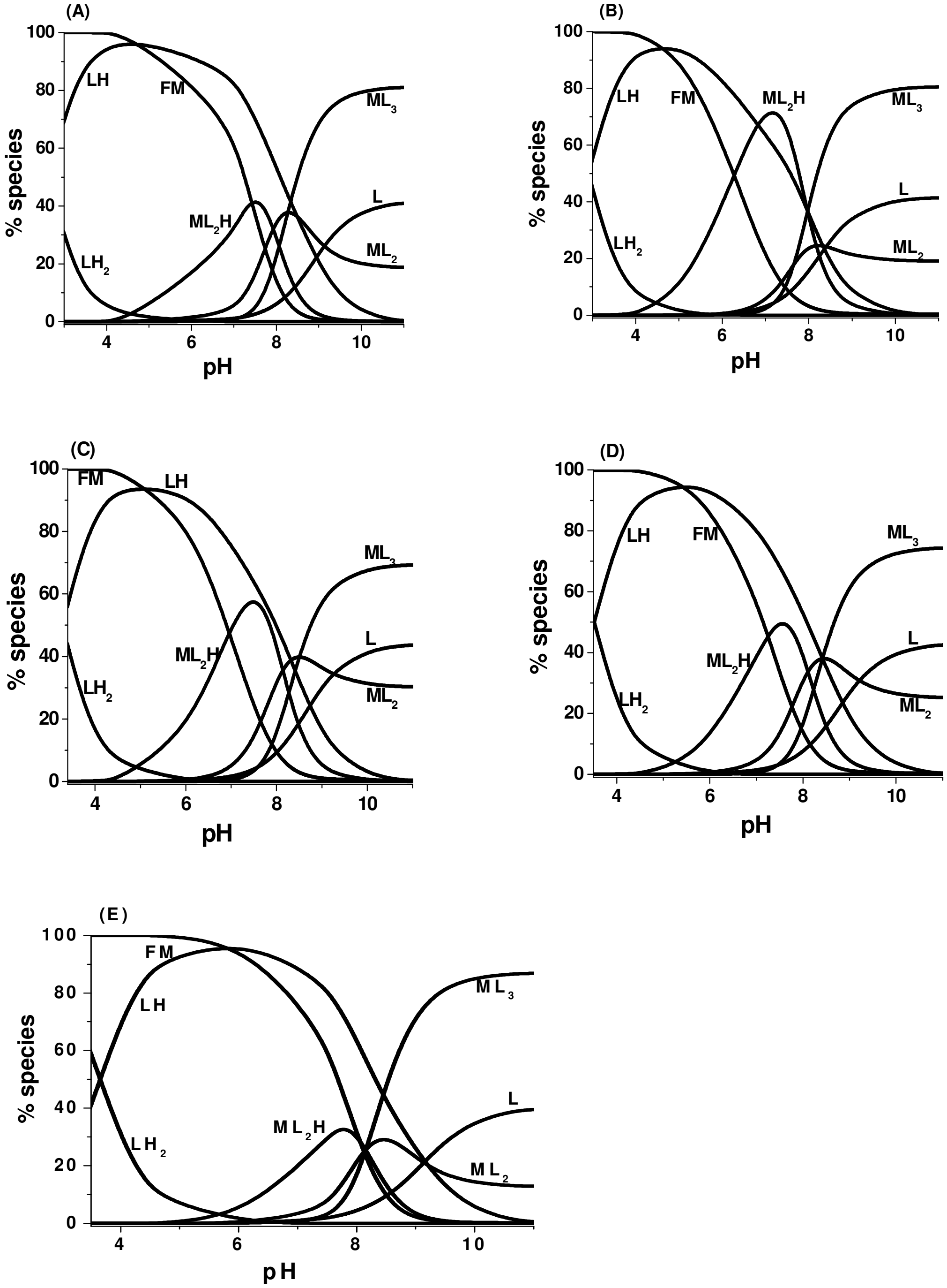

Fig.3: Distribution diagrams of Pb- LPA in DMF-water mixtures % v/v. (A) 10, (B) 20, (C) 30, (D) 40, and (E) 50.

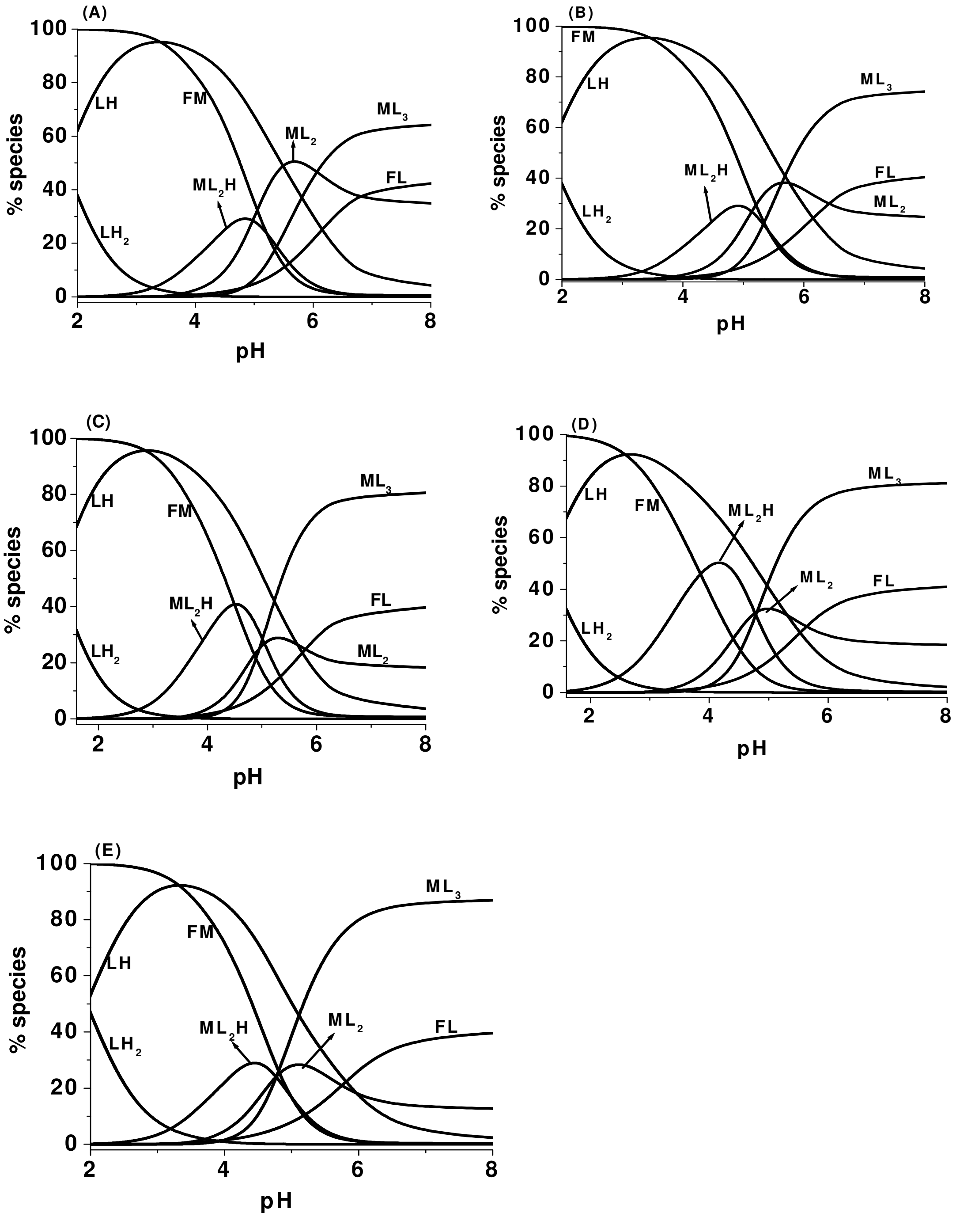

Fig.4: Distribution diagrams of Cd-MA in DMF-water mixtures % v/v. (A) 10, (B) 20, (C) 30, (D) 40, and (E) 50.

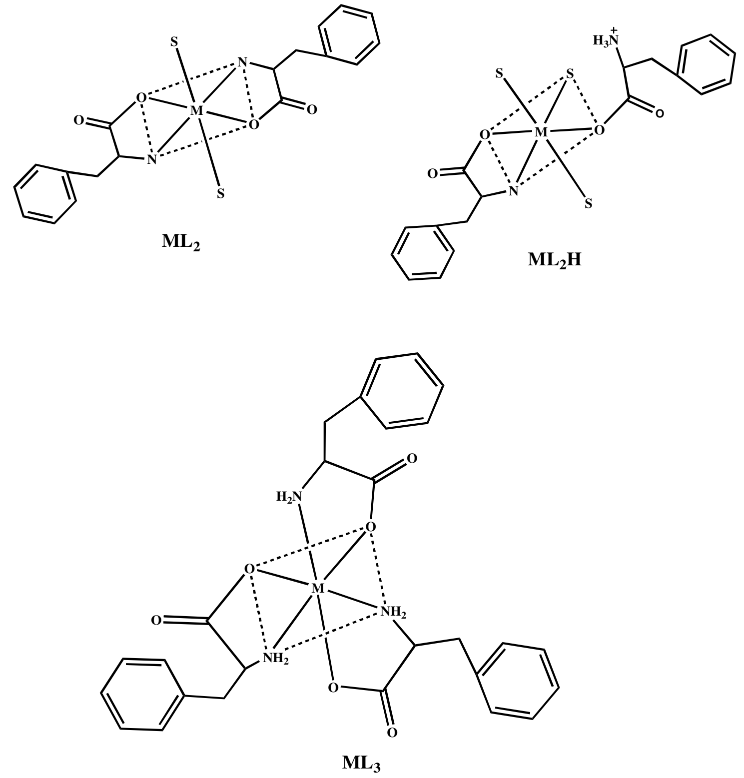

Fig.5: Speculative structures of LPA complexes with Pb(II), Cd(II) and Hg(II). where S is either solvent or water molecules.

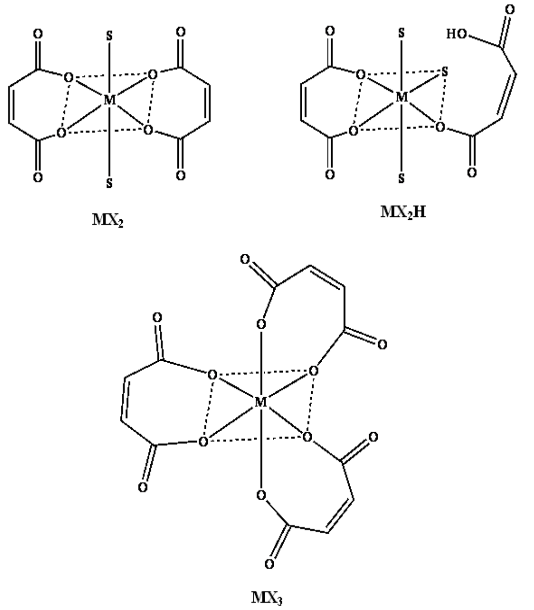

Fig.6: Speculative structures of MA complexes with Pb(II), Cd(II) and Hg(II) where S is either solvent or water molecules.

CONCLUSIONS

The common species formed due to interaction of LPA with the toxic metal ions ML$_2$, ML$_2$H, and ML$_3$ in the DMF media and For MA complexes of

Pb(II), Cd(II) and Hg(II) the species MX_2, MX_2H, MX_3 are refined in DMF-water mixtures.

The linear variation of stability constants of LPA and MA complexes with the reciprocal of dielectric constant of DMF-water mixtures indicates the dominance of electrostatic forces over non-electrostatic forces in case of Pb(II) & Hg(II) and non-linear trend in case of Cd(II). A linear increasing trend with DMF content supports the predominance of the structure forming nature of DMF over its complexing ability in case of Pb(II), Cd(II) and Hg(II) indicates the dominance of electrostatic forces.

The order of ingredients in influencing the magnitudes of stability constants due to incorporation of errors in their concentrations is alkali > acid > ligand > metal.

At higher pH values, the high concentrations of chemical species indicate that the metals are more amenable for transportation at higher pH values.

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