Ternary Co-ordination Complexes of Copper(II) with L-Histidine and Some selected Amino-acids

By **Madhavan Sivasankaran Nair**,*† **Kora Venkatachalapathi**, and **Muchi Santappa**, Central Leather Research Institute (CSIR), Adyar, Madras-600 020, India
Puliampatti K. Murugan, Department of Physical Chemistry, University of Madras, A.C. College Campus, Madras-600 025, India

The multiple equilibria involved in some ternary systems of copper(II) containing L-histidine (A) and DL-2-aminobutyric acid, DL-3-aminobutyric acid, 4-aminobutyric acid, DL-4-amino-3-hydroxybutyric acid, DL-2,3-diaminopropionic acid, DL-2,4-diaminobutyric acid, or DL-ornithine (B) have been investigated by pH titrimetry in aqueous perchlorate media at 37 °C and I = 0.15 mol dm^{-3} (Na[ClO$_4$]). Ternary complex species of the type [CuAB], [CuABH], and [CuABH$_2$] were detected. In every system studied, greater stability than would be expected statistically is observed. L-Histidine (A) binds in a tridentate manner in all the systems. Among the potentially tridentate secondary ligands (B) used, DL-2,3-diaminopropionic acid, DL-2,4-diaminobutyric acid, and DL-ornithine bind in a tridentate manner, while DL-4-amino-3-hydroxybutyric acid appears to be bidentate. The probable sites of protonation in the [CuABH] and [CuABH$_2$] complexes are discussed in terms of their stability-constant data.

IN recent years considerable attention has been paid to the investigation of copper(II) binary and ternary complexes containing the imidazole group as a ligand, since this is one of the important binding sites for copper in many biological systems. It was shown [1] that histidyl residues in proteins are typically non-chelating. Thus, ternary systems of copper(II) with unsubstituted imidazole as a ligand have been reported by several workers.[1-9] By investigating several ternary systems of copper(II) containing histamine,[7-14] it was concluded that copper(II) complexes containing an imidazole group react preferably with oxygen-donor ligands rather than nitrogen-donor ligands.

Histidine is a potentially tridentate ligand having imidazole, amino-, and carboxylate groups as metal-ion binding sites. Ternary complexes of copper(II) containing L-histidine as a ligand have been studied by many workers.[9,13-17] Kruck and Sarkar [15] suggested that the ternary complex L-histidine–copper(II)–albumin acts as an intermediate in the exchange of copper(II) in blood between a macromolecule such as albumin and a low-molecular-weight substance like an amino-acid. The exchangeable portion of copper(II) in blood plasma was shown to be mainly in the form of the ternary complexes asparaginato(histidinato)-, asparaginato(threoninato)-, and histidinato(threoninato)-copper(II). Baxter and Williams [16] suggested structures for these complexes based on thermodynamics. The stereoselectivity of the ternary complexes of copper(II) containing histidine and amino-acids has been studied by Brookes and Pettit.[17] We have been investigating the ternary complexes containing imidazoles, amino-acids, and dipeptides for some time.[5-8,10-12,18,19] We now report a detailed investigation of some copper(II)–L-histidine(A)–amino-acid(B) systems at 37 °C and $I = 0.15$ mol dm^{-3} (Na[ClO$_4$]) by pH titrimetry. The amino-acids (B) chosen are DL-2-aminobutyric acid (2-aba), DL-3-aminobutyric acid (3-aba), 4-aminobutyric acid (4-aba), DL-4-amino-3-hydroxybutyric acid (ahba), DL-2,3-diaminopropionic acid (dapa), DL-2,4-diaminobutyric acid (daba), and DL-ornithine (orn). The amino-acids 2-aba, 3-aba, and 4-aba are capable respectively of forming five-, six-, and seven-membered chelate rings with copper(II). The ahba ligand is potentially tridentate having amino-, hydroxy-, and carboxylate-donor groups. The aminoethanol moiety, NH_2CH_2CHOH, which it contains is common to several compounds of pharmaceutical and biological importance. The compounds dapa, daba, and orn are diaminocarboxylic acids of general formula $NH_2(CH_2)_n$-$CH(NH_2)COOH$, where $n = 1$ (dapa), $n = 2$ (daba), and $n = 3$ (orn).

EXPERIMENTAL

The ligands used in this work were Fluka products of Puriss quality. The compounds dapa and orn were used in the monoprotonated form, while daba was used in the diprotonated form. The compound Cu[ClO$_4$]$_2$ and the other reagents were prepared and estimated as described earlier.[5-8,10-12,18,19] Doubly distilled water was used for the preparation of all the solutions.

The pH titrations were carried out at 37 °C and at an ionic strength of 0.15 mol dm^{-3} (Na[ClO$_4$]) under a nitrogen atmosphere using a digital pH meter (Electronic Corporation of India Ltd., serial 053, pH 5653; accuracy ±0.01 pH units) having a glass and calomel electrode assembly. The electrode system was calibrated in terms of hydrogen-ion concentrations. The stability constants for the ternary systems were computed from the titrations in which the total concentrations of copper(II), ligand A, and ligand B were in 1 : 1 : 1 and 1 : 2 : 2 molar ratios. Calculations were made with the aid of the MINIQUAD-75 computer program [20] on an IBM-370 computer. The protonation constants for the free ligands, A and B, and the stability-constant data for the parent binary complexes of copper(II) with A and B, estimated at 37 °C and $I = 0.15$ mol dm^{-3} (Na[ClO$_4$]) (Table 1), were held constant in the calculation of the ternary systems. The ionic product of water, *i.e.* the pK_w value of 13.62 at 37 °C, was also treated as a non-refinable parameter. The calculations were restricted to pH values below 8, in order to avoid complications due to the hydrolysis

---

† *Present Address*: Department of Chemistry, Post-Graduate Extension Centre, Madurai Kamaraj University, St John's College Campus, Palayamkottai – 627 022, Tamilnadu, India.

TABLE 1

Stability constants for the proton and copper(II) complexes of 2-aba, 3-aba, 4-aba, ahba, dapa, daba, orn, and L-histidine at 37 °C and $I = 0.15$ mol dm^{-3} (Na[ClO$_4$]). Standard deviations are given in parentheses

	Ligands							
Parameters	2-aba [a]	3-aba [a]	4-aba [a]	ahba [b]	dapa [b]	daba [b]	orn [b]	L-histidine [c]
log β_{HB}	9.43(1)	9.95(1)	10.15(1)	12.88(11)	9.37(2)	9.93(2)	10.22(1)	8.96(3)
log β_{H_2B}	11.54(1)	13.30(1)	14.24(1)	21.91(2)	15.98(3)	18.02(4)	18.85(2)	14.96(5)
log β_{H_3B}				25.78(2)	17.37(5)	19.88(6)	20.99(4)	17.37(9)
log β_{CuBH}					15.37(4)	16.99(3)	17.67(2)	14.38(4)
log β_{CuB}	8.10(2)	7.16(2)	6.07(9)	13.02(9)	10.61(4)	10.94(3)		10.27(2)
log $\beta_{Cu_2B_2}$				28.10(30)				
log $\beta_{CuB_2H_2}$					30.16(5)	32.92(4)	34.32(3)	27.41(21)
log β_{CuB_2H}					25.32(6)	26.89(4)	26.12(6)	23.96(3)
log β_{CuB_2}	15.13(4)	12.90(5)		19.09(24)	20.18(5)	19.15(6)		18.49(4)

[a] Refs. 11 and 19. [b] Ref. 18. [c] Refs. 8 and 11.

TABLE 2

Stability constants for the copper(II)–L-histidine(A)–secondary ligand(B) ternary systems at 37 °C and $I = 0.15$ mol dm^{-3} (Na[ClO$_4$]). Standard deviations are given in parentheses

	Secondary ligands, B						
Parameters	2-aba	3-aba	4-aba	ahba	dapa	daba	orn
log β_{CuAB}	17.65(3)	16.51(8)	16.13(21)	20.80(24)	20.38(19)	20.18(7)	19.52(9)
log β_{CuABH}	21.32(39)		22.60(13)	28.82(15)	25.60(19)	27.14(5)	27.38(4)
log β_{CuABH_2}					29.96(18)	31.23(10)	
log K^{CuA}_{CuAB}	7.38	6.24	5.86	10.53	10.11	9.91	9.25
log K^{CuB}_{CuAB}	9.55	9.35	10.06	7.78	9.77	9.24	
Δ log K_{CuAB}	−0.72	−0.92	−0.21	−2.49	−0.50	−1.03	
log X_{CuAB}	1.68	1.63		4.02	2.09	2.72	
log β_{CuAB} (calc.)	17.11	15.99	15.61	19.09	19.63	19.12	
Δlog β_{CuAB}	0.54	0.52	0.52	1.71	0.75	1.06	
pK^{H}_{CuABH}	3.67		6.47	8.02	5.22	6.96	7.86
log K^{CuA}_{CuABH}					15.33	16.87	17.11
Δlog K_{CuABH}					−0.04	−0.12	−0.56
log X_{CuABH}					2.55	2.87	1.95
log β_{CuABH} (calc.)					24.62	26.00	26.70
Δlog β_{CuABH}					0.98	1.14	0.68
p$K^{H}_{CuABH_2}$					4.36	4.09	
Δlog K_{CuABH_2}					0.21	−0.14	
log X_{CuABH_2}					2.35	2.14	
log β_{CuABH_2} (calc.)					29.08	30.46	
Δlog β_{CuABH_2}					0.88	0.77	

of various complex species at higher pH. The model selected was that which gave the best statistical fit, consistent with chemical logic, to the titration data without giving any systematic drifts in the magnitudes of various residuals, as described elsewhere.[20] The results obtained are listed in Table 2. The charges on all the complex species reported in this paper are omitted for clarity.

RESULTS AND DISCUSSION

The copper(II)-L-histidine(A)-2-aba, -4-aba, -ahba, and -orn(B) systems showed the presence of two ternary species, [CuABH] and [CuAB], while the systems with B = dapa and daba gave rise to the formation of three ternary species, [CuABH$_2$], [CuABH], and [CuAB]. In the system with B = 3-aba only the [CuAB] type of ternary species was detected. Brookes and Pettit[17] who also studied the copper(II)-L-histidine(A)-daba and -orn(B) systems reported [CuABH] and [CuAB] complexes in the system with B = orn; however, they found only one ternary species, [CuABH], in the system with B = daba.

In order to characterise the stability of the ternary complex species in relation to that of the parent binary complexes, the values of Δlog K, the difference in stability between the binary complex and the ternary complex, and log X, the disproportionation constant, were determined (Table 2) for all three types of ternary species, [CuAB], [CuABH], and [CuABH$_2$]. The stabilization constants, Δlogβ, included in Table 2 for various ternary complex species result from the difference between the measured stability constant and that calculated on statistical grounds.[1,21] It has been found from statistics [1,21] that considerably less negative values of Δlog K, and more positive values of log X and Δlog β, indicate greater stabilities of the ternary complexes relative to the binary analogues.

In the case of [CuAB] complexes, the parameters Δlog K and log X are defined by equations (1)—(4). The log X_{CuAB} and Δlog β_{CuAB} values in Table 2 for all the

$$[CuA] + [CuB] \rightleftharpoons [CuAB] + Cu \quad (1)$$

$$\Delta\log K_{CuAB} = \log \beta_{CuAB} - (\log \beta_{CuA} + \log \beta_{CuB}) \quad (2)$$

$$[CuA_2] + [CuB_2] \rightleftharpoons 2[CuAB], \quad X_{CuAB} = \frac{[CuAB]^2}{[CuA_2][CuB_2]} \quad (3)$$

$$\log X_{CuAB} = 2 \log \beta_{CuAB} - (\log \beta_{CuA_2} + \log \beta_{CuB_2}) \quad (4)$$

ternary systems are significantly more positive than those expected on statistical grounds, indicating considerable stabilities. However, the $\Delta\log K_{CuAB}$ values in Table 2 do not deviate much from the statistical values.[21]

The $\log K^{CuB}_{CuAB}$ values in Table 2 are close to the stability constant value of 10.27 for the [CuA], A = L-histidine, binary complex,[8] where L-histidine is tridentate, suggesting that the same type of bonding of L-histidine (A) also occurs in the ternary systems studied. Crystallographic studies have also shown [22] that L-histidine is tridentate in the copper(II) ternary complex systems where the imidazole and primary amino-nitrogens of L-histidine occupy the equatorial positions and the carboxyl group is in the axial position. The $\log \beta_{CuAB}$ and $\log K^{CuA}_{CuAB}$ values for the copper(II)–L-histidine(A)–2-aba, –3-aba, and –4-aba(B) systems decrease in the order B = 2-aba > 3-aba > 4-aba, demonstrating that the decrease in ring size 5 > 6 > 7 found [19] in the corresponding copper(II) binary chelates also holds for the ternary chelate systems containing L-histidine as the primary ligand (A). Thus, the [CuAB] complexes in the copper(II)–L-histidine(A)–2-aba, –3-aba, and –4-aba(B) systems should respectively contain six- and five-, six- and six-, and six- and seven-membered chelate rings in the equatorial positions, in addition to the five membered chelate ring due to the co-ordination of the carboxyl group of L-histidine in the axial position. All these complexes are favoured due to the stability-enhancing effect of the imidazole group [1] of L-histidine (A), since the secondary ligand (B) in all these systems contains an *O*-donor group. The same trends were also reflected in the species-distribution diagrams, where the amounts of total metal complexed in the form [CuAB] in equimolar solutions were 74, 63, and 10% respectively. The smallest value, *i.e.* 10% of the total copper(II), found in the copper(II)–L-histidine(A)–4-aba(B) system may be attributed to steric factors, associated with the presence of six-, seven-, and five-membered chelate rings in the coordination sphere of copper(II), as described above.

It has already been shown [18] that ahba is tridentate in its [CuB] binary complex. Hence, if one expects the same type of binding for the [CuAB] complex in the copper(II)–L-histidine(A)–ahba(B) system, then the value of $\log K^{CuA}_{CuAB}$ in this system must be similar to the $\log \beta_{CuB}$ value in the copper(II)–ahba(B) binary system. However, Tables 1 and 2 show that the former parameter is less than the latter by *ca.* 2.5 log units, suggesting the possibility of bidentate binding of ahba *via* *N*-amino- and *O*-hydroxy-groups in the ternary complex system. The same result is reflected in the $\Delta\log K_{CuAB}$ and $\log K^{CuB}_{CuAB}$ values (Table 2) for this ternary system, *i.e.* the $\Delta\log K_{CuAB}$ value of -2.49 is more negative than that of other ternary systems and the $\log K^{CuB}_{CuAB}$ value is lower than that of other systems by *ca.* 2 log units. This ambiguity may easily be accounted for by the fact that in computing $\Delta\log K_{CuAB}$ [equation (2)] and $\log K^{CuB}_{CuAB}$ values [equation (5)] the value of $\log \beta_{CuB}$ used was that for the tridentate binding of ahba (B) in its [CuB] binary complex, although ahba is bidentate in the [CuAB] ternary complex. This

$$\log K^{CuB}_{CuAB} = \log \beta_{CuAB} - \log \beta_{CuB} \qquad (5)$$

bidentate mode of binding of ahba (B) in the ternary systems is not surprising since in the $[CuB_2]$ binary complex it is also bidentate.[18] A similar mode of bonding for ahba has also been reported [6,10] in the copper(II)–imidazole or histamine(A)–ahba(B) ternary systems. Approximately 35% of the total copper(II) was found to be present in the form of the [CuAB] complex species in a 1 : 1 : 1 solution of the copper(II)–L-histidine(A)–ahba(B) system.

For the [CuAB] complexes of the copper(II)–L-histidine–dapa, –daba, or –orn systems, the $\log K^{CuA}_{CuAB}$ values in Table 2 indicate tridentate bonding of all the secondary ligands (B). Considering [1] the stability-enhancing effect of the imidazole group on the formation of copper(II) ternary complexes provided an *O*-donor ligand is present, it appears more reasonable to suggest structures for these [CuAB] complexes in which the equatorial co-ordination sites are occupied by L-histidine (A) (binding in the histamine-like mode) and dapa, daba, or orn (B) (binding in the glycine-like mode) and the two apical positions by the carboxyl group of L-histidine and the ω-amino-group of dapa, daba, or orn. Thus, all these complexes would have a distorted octahedral geometry and Jahn–Teller effects would be operative. The percentages of the total metal complexed in the form [CuAB] in these systems are, respectively, 84, 82, and 47% at pH 8 in 1 : 1 : 1 molar ratio solutions.

The stability-constant data obtained for the [CuABH] complexes in the copper(II)–L-histidine(A)–2-aba, –4-aba, and –ahba(B) ternary systems are rather confusing. Assuming the likelihood of attachment of the extra proton in [CuABH] to L-histidine (A), considering the fact that the protonated 1 : 1 and 1 : 2 binary complexes were detected only in the copper(II)–L-histidine(A) system and not in the binary systems [11,18,19] with 2-aba, 4-aba, or ahba (B) ligands, then the pK^{H}_{CuABH} values for all three ternary systems should be similar. However, this is not so. Nevertheless, a careful analysis of these values indicates that they follow the same trend as the protonation constant of the amino-group of 2-aba, 4-aba, or ahba (B) (Table 1), suggesting that the site of protonation in the [CuABH] complexes in the copper(II)–L-histidine(A)–2-aba, –4-aba, or –ahba(B) ternary systems is the amino-group of the secondary ligand (B). Surprisingly, the pK^{H}_{CuABH} value obtained in the copper(II)–L-histidine(A)–ahba(B) system is higher than that of the other systems in Table 2, a factor which may be attributed to the influence of neighbouring hydroxy-groups. Thus, since the extra proton in the [CuABH] complexes in the copper(II)–L-histidine(A)–2-aba, –4-aba, and –ahba(B) systems is attached to the ligands B, the parameters $\Delta\log K_{CuABH}$ and $\log X_{CuABH}$ are defined by equations (6)—(9). However, they could not be computed for the [CuABH] monoprotonated ternary complexes in the systems with B = 2-aba, 4-aba, or ahba since stability-constant data for the 1 : 1 and 1 : 2

$$[\mathrm{CuA}] + [\mathrm{CuBH}] \rightleftharpoons [\mathrm{CuABH}] + \mathrm{Cu} \quad (6)$$

$$\Delta\log K_{\mathrm{CuABH}} = \log \beta_{\mathrm{CuABH}} - (\log \beta_{\mathrm{CuA}} + \log \beta_{\mathrm{CuBH}}) \quad (7)$$

$$[\mathrm{CuA_2}] + [\mathrm{CuB_2H_2}] \rightleftharpoons 2[\mathrm{CuABH}],\ X_{\mathrm{CuABH}} = [\mathrm{CuABH}]^2/[\mathrm{CuA_2}][\mathrm{CuB_2H_2}] \quad (8)$$

$$\log X_{\mathrm{CuABH}} = 2 \log \beta_{\mathrm{CuABH}} - (\log \beta_{\mathrm{CuA_2}} + \log \beta_{\mathrm{CuB_2H_2}}) \quad (9)$$

protonated complexes are not available[11,18,19] for the corresponding binary systems. In the ternary system with B = 2-aba, only *ca.* 3% of the total metal was found to be present in the [CuABH] form, while in the systems with B = 4-aba and ahba, the respective percentages were 20 and 50%.

In the copper(II)-L-histidine(A)-dapa, -daba, and -orn(B) systems, the $pK^{\mathrm{H}}_{\mathrm{CuABH}}$ values in Table 2 follow the same trend as the $\log \beta_{\mathrm{CuBH}}$ and $\log \beta_{\mathrm{HB}}$ values in Table 1, suggesting the attachment of the extra proton in the [CuABH] complexes to the ω-amino-group of the secondary ligands (B). This is further confirmed by the fact that the $\log K'$ [equation (10)] values of 16.23, 17.21, and 17.16 in the ternary systems with B = dapa, daba,

$$\log K' = \log \beta_{\mathrm{CuABH}} - \log \beta_{\mathrm{HB}} \quad (10)$$

and orn respectively compare favourably with the $\log \beta_{\mathrm{CuAB}}$ value of 17.65 in the copper(II)-L-histidine(A)-2-aba(B) system (Table 2) suggesting a glycine-like mode of binding of dapa, daba, and orn secondary ligands (B) in the [CuABH] complexes and that the extra proton is attached to the ω-amino-group. However, the $\log K'$ value in the system with B = dapa is lower than that of the other two systems in Table 2. This may be attributed to the possibility of attachment of the extra proton to the α-amino-group as well, as already suggested for the [CuBH] (B = dapa) complex.[18] Thus, the [CuABH] complex in the copper(II)-L-histidine(A)-dapa(B) system would have two equilibrium structures with two different modes of binding of dapa (B): one in which α-amino-carboxyl chelation is involved and the ω-amino-group is protonated; and the other which contains ω-amino-carboxyl chelation with the proton attached to the α-amino-group. Comparison of the $\Delta\log K_{\mathrm{CuABH}}$ values [equations (6) and (7)], $\log X_{\mathrm{CuABH}}$ values [equations (8) and (9)], and the stabilization constants $\Delta\log \beta_{\mathrm{CuABH}}$ in Table 2 for the copper(II)-L-histidine(A)-dapa, -daba, and -orn(B) systems with those values expected on statistical grounds[1,21] indicates that the [CuABH] complexes in all these systems are markedly stable. It is interesting to note that the $\log \beta_{\mathrm{CuABH}}$ values of 26.74 and 27.49 reported by Brookes and Pettit[17] in the copper(II)-L-histidine(A)-daba and -orn(B) systems respectively are in good agreement with the present values of 27.14 and 27.38 (Table 2) after allowing for the different experimental conditions. The respective amounts of the total copper(II) complexed in the ternary systems [CuABH] with B = dapa, daba, and orn are 39, 74, and 70%.

The diprotonated ternary complexes, $[\mathrm{CuABH_2}]$, in both the copper(II)-L-histidine(A)-dapa and -daba(B) systems, were found to be more favoured in solutions of molar ratio 1 : 2 : 2. It is reasonable to suggest that, of the two protons in the $[\mathrm{CuABH_2}]$ species, one would be attached to the L-histidine primary ligand (A), *i.e.* to its primary amino-group as in [CuAH], $[\mathrm{CuA_2H_2}]$, and $[\mathrm{CuA_2H}]$ binary complexes,[8] and the other would reside[18] on the ω-amino-group of the dapa or daba ligands (B). The reactions may be represented by equations (11)—(13). The trends in the $pK^{\mathrm{H}}_{\mathrm{CuABH_2}}$ and $pK^{\mathrm{H}}_{\mathrm{CuABH}}$ values of

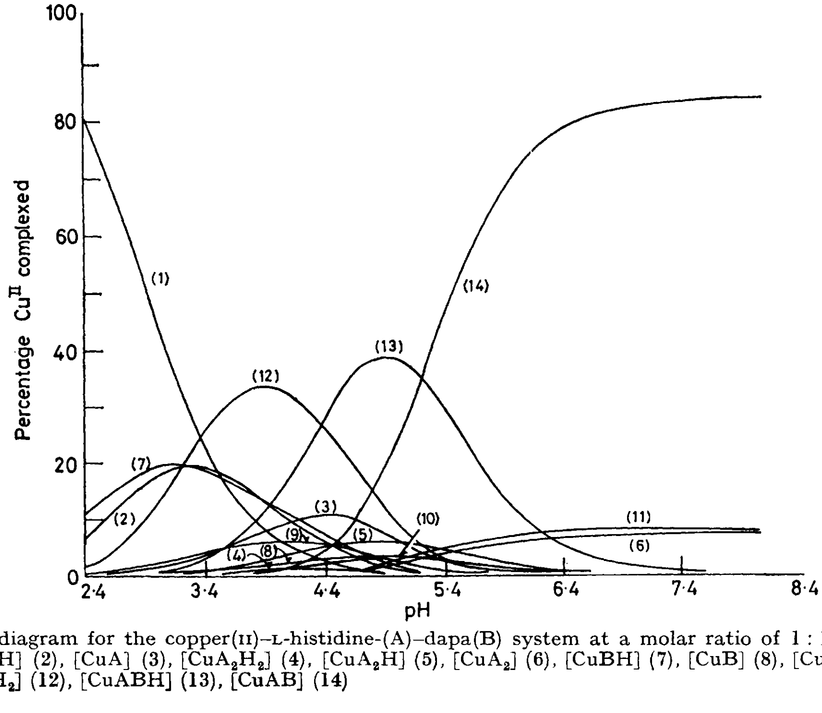

FIGURE 1 Distribution diagram for the copper(II)-L-histidine-(A)-dapa(B) system at a molar ratio of 1 : 1 : 1. Species: unbound copper(II) (1), [CuAH] (2), [CuA] (3), $[\mathrm{CuA_2H_2}]$ (4), $[\mathrm{CuA_2H}]$ (5), $[\mathrm{CuA_2}]$ (6), [CuBH] (7), [CuB] (8), $[\mathrm{CuB_2H_2}]$ (9), $[\mathrm{CuB_2H}]$ (10), $[\mathrm{CuB_2}]$ (11), $[\mathrm{CuABH_2}]$ (12), [CuABH] (13), [CuAB] (14)

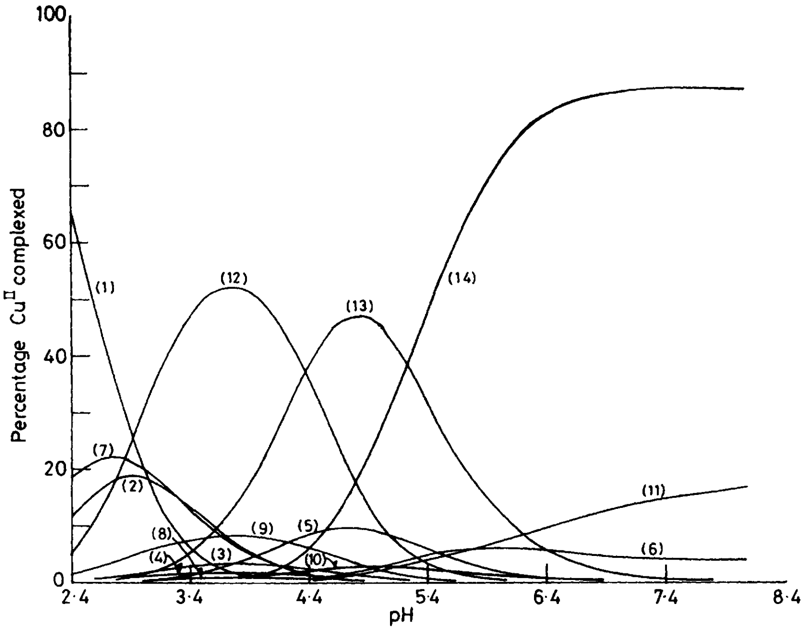

FIGURE 2 Distribution diagram for the copper(II)–L-histidine-(A)–dapa(B) system at a molar ratio of 1 : 2 : 2. Species designation as in Figure 1

$$[\mathrm{CuABH_2}] \xrightleftharpoons{\mathrm{p}K^{\mathrm{H}}_{\mathrm{CuABH_2}} = 4.36} [\mathrm{CuABH}] \xrightleftharpoons{\mathrm{p}K^{\mathrm{H}}_{\mathrm{CuABH}} = 5.22} [\mathrm{CuAB}]\ (\mathrm{A} = \text{L-histidine},\ \mathrm{B} = \text{dapa}) \quad (11)$$

$$[\mathrm{CuABH_2}] \xrightleftharpoons{\mathrm{p}K^{\mathrm{H}}_{\mathrm{CuABH_2}} = 4.09} [\mathrm{CuABH}] \xrightleftharpoons{\mathrm{p}K^{\mathrm{H}}_{\mathrm{CuABH}} = 6.96} [\mathrm{CuAB}]\ (\mathrm{A} = \text{L-histidine},\ \mathrm{B} = \text{daba}) \quad (12)$$

$$[\mathrm{CuABH_2}] \rightleftharpoons [\mathrm{CuABH}] \xrightleftharpoons{\mathrm{p}K^{\mathrm{H}}_{\mathrm{CuABH}} = 7.86} [\mathrm{CuAB}]\ (\mathrm{A} = \text{L-histidine},\ \mathrm{B} = \text{orn}) \quad (13)$$

these reactions demonstrate clearly that the former is for the protonation of L-histidine (A), while the latter denotes the protonation of the dapa, daba, or orn secondary ligands (B). The parameters $\Delta\log K_{\mathrm{CuABH_2}}$ and $\log X_{\mathrm{CuABH_2}}$ computed using equations (15) and (17) for the equilibrium reactions (14) and (16) and also the stabilisation constant, $\Delta\log \beta_{\mathrm{CuABH_2}}$, in Table 2 for the copper(II)–L-histidine(A)–dapa and –daba(B) systems, clearly demonstrate the marked stabilities of the $[\mathrm{CuABH_2}]$ complex species in both systems.

$$[\mathrm{CuAH}] + [\mathrm{CuBH}] \rightleftharpoons [\mathrm{CuABH_2}] + \mathrm{Cu} \quad (14)$$

$$\Delta\log K_{\mathrm{CuABH_2}} = \log \beta_{\mathrm{CuABH_2}} - (\log \beta_{\mathrm{CuAH}} + \log \beta_{\mathrm{CuBH}}) \quad (15)$$

$$[\mathrm{CuA_2H_2}] + [\mathrm{CuB_2H_2}] \rightleftharpoons 2[\mathrm{CuABH_2}],\ X_{\mathrm{CuABH_2}} = [\mathrm{CuABH_2}]^2/[\mathrm{CuA_2H_2}][\mathrm{CuB_2H_2}] \quad (16)$$

$$\log X_{\mathrm{CuABH_2}} = 2\log \beta_{\mathrm{CuABH_2}} - (\log \beta_{\mathrm{CuA_2H_2}} + \log \beta_{\mathrm{CuB_2H_2}}) \quad (17)$$

The species-distribution diagrams in terms of the percentage of the total copper(II) bound as a function of pH were obtained for both 1 : 1 : 1 and 1 : 2 : 2 molar ratio solutions for all the ternary systems studied here. The concentration of the $[\mathrm{CuABH_2}]$ complexes reached a maximum at *ca.* pH 4. As the pH rose the [CuABH] complexes became important and reached their maximum concentration near pH 5. With a further rise in pH, the [CuAB] complexes predominate and there is a steady increase in their concentration with pH. The marked stabilisation of the ternary relative to the binary complexes is reflected in the species-distribution plots, *i.e.* the ternary complexes occur in larger concentrations than the binary complexes in each of the systems studied. The distribution diagrams obtained for the 1 : 1 : 1 and 1 : 2 : 2 molar ratio solutions in the copper(II)–L-histidine-(A)–dapa(B) system are shown in Figures 1 and 2.

[1/320 *Received, 24th February*, 1981]

REFERENCES

[1] 'Metal Ions in Biological Systems,' ed. H. Sigel, Marcel Dekker, New York, 1973, vol. 2.
[2] W. L. Koltum, M. Fried, and F. R. N. Gurd, *J. Am. Chem. Soc.*, 1960, **82**, 233.
[3] R. Driver and W. R. Walker, *Aust. J. Chem.*, 1968, **21**, 671.
[4] M. S. Mohan, D. Bancrott, and E. H. Abbot, *Inorg. Chem.*, 1979, **18**, 1527.
[5] M. S. Nair, M. Santappa, and P. Natarajan, *Inorg. Chim. Acta*, 1980, **41**, 7.
[6] M. S. Nair, M. Santappa, and P. K. Murugan, *Inorg. Chem.*, in the press.
[7] M. S. Nair, M. Santappa, and P. Natarajan, *Indian J. Chem., Sect. A*, 1980, **19**, 1106.
[8] M. S. Nair, M. Santappa, and P. Natarajan, *J. Chem. Soc., Dalton Trans.*, 1980, 1312.
[9] L. G. Sillen and A. E. Martell, *Special Publ.*, The Chemical Society, London, 1964 and 1971, nos. 17 and 25.
[10] M. S. Nair, K. Venkatachalapathi, M. Santappa, and P. K. Murugan, *Inorg. Chem.*, in the press.
[11] M. S. Nair, Ph.D. Thesis, University of Madras, 1979.
[12] M. S. Nair, M. Santappa, and P. Natarajan, *J. Chem. Soc., Dalton Trans.*, 1980, 2138.
[13] D. D. Perrin, I. G. Sayce, and V. S. Sharma, *J. Chem. Soc. A*, 1967, 1955.

[14] A. G. Gergely and I. Sovago, *J. Inorg. Nucl. Chem.*, 1973, **35**, 4355.

[15] T. P. A. Kruck and B. Sarkar, *Can. J. Chem.*, 1973, **51**, 3555.

[16] A. C. Baxter and D. R. Williams, *J. Chem. Soc., Dalton Trans.*, 1975, 1757.

[17] G. Brookes and L. D. Pettit, *J. Chem. Soc., Dalton Trans.*, 1977, 1918.

[18] M. S. Nair and M. Santappa, *J. Chem. Soc., Dalton Trans.*, 1981, 992.

[19] M. S. Nair and M. Santappa, *Indian J. Chem.*, in the press.

[20] P. Gans, A. Vacca, and A. Sabatini, *Inorg. Chim. Acta*, 1976, **18**, 237.

[21] H. Sigel, *Angew. Chem., Int. Ed. Engl.*, 1975, **14**, 394.

[22] H. C. Freeman, J. M. Guss, M. J. Healy, R. P. Martin, C. E. Nocchold, and B. Sarkar, *Chem. Commun.*, 1969, 225.