Complexes of Doubly Chelating Ligands. Part IV.† Nickel(II), Zinc(II), Magnesium(II), and Uranyl(VI) Complexes of L-β-(3,4-Dihydroxyphenyl)-alanine (DOPA)

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The interactions of DOPA with nickel(II), zinc(II), magnesium(II), and uranyl(VI) ions in aqueous solution have been investigated at 25° ± 0·01° and 1·0M-ionic strength (KNO_3) by potentiometric and spectrophotometric methods. The stoicheiometry and nature of the chelate reactions have been established and stability constants are reported for the nickel, zinc, and magnesium cases. Mixed metal complex systems have also been studied for the DOPA–uranyl–copper system. Interpretation of these systems was limited by precipitation and olation reactions of the complexes.

MIXED ligand complexes of metal ions are well known, and several authors have reported stability constants for such systems.[1-10] Experimental data have usually indicated that the proportion of mixed complex is significantly larger than that predicted,[7,9] but the reasons for this are by no means clear, and we considered that the similar problem of mixed metal chelations by a doubly chelating ligand might clarify some aspects of the phenomenon. (The mixed metal case is simpler in that chelation at one ligand site does not, in the type of molecule studied here, greatly affect chelation constants at the other site.) Here we report the interactions of DOPA with the metal ions mentioned above and some preliminary work on mixed metal complex systems.

The terminology introduced to cover the equilibrium studies reported in this paper is as in Part I;[11] other ligand abbreviations are as follows.

DBA = 3,4-dihydroxybenzoic acid
DPAA = 3,4-dihydroxyphenylacetic acid
DPPA = 3,4-dihydroxypropionic acid
L^a = Ligand co-ordinated at amino-acid site
L^c = Ligand co-ordinated at catechol site
} for DOPA

The stability constants for the proton complexes of the DOPA zwitterion that are used in calculations of metal ion constants here, have been reported in Part I of this series.[11]

RESULTS

Spectrophotometric methods were used to determine the site at which nickel and uranyl ions are chelated to DOPA; typical spectra for DOPA, glycine, and catechol complexes of these two metal ions are shown in Figure 1. Difficulties with the slight oxidation of the solutions in the optical cells make us regard the measurements as qualitative only, and hence no stability-constant calculations have been made from these data. It can be clearly seen, however, that nickel(II) ions are chelated by the alanine site and uranyl ions by the catechol site; this was to be expected, of course, from the related constants for the glycine and catechol complexes of these ions.

Potentiometric titrations, using the glass–calomel system

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† Part III, J. E. Gorton and R. F. Jameson, preceding paper.

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previously described, enabled stability constants for 1 : 1 and 2 : 1 complexes of DOPA and nickel(II) ions to be determined. See Table 1 and Figure 2. As can be seen in Figure 3, these values fit in very well with similar amino-acid complexes in an Irving–Rossotti type plot, although the agreement may be fortuitously good in view of the range of experimenters and conditions. No higher complexes than 2 : 1 could be observed.

TABLE 1

Equilibrium constants for the reactions of metal ions with DOPA, measured at 25° and an ionic strength of 1·00M

Reaction	log (equilibrium constant)	Spread	Standard deviation
$Ni + L^a \rightleftharpoons NiL^a$	4·96	0·03	0·014
$NiL^a + L^a \rightleftharpoons NiL_2^a$	4·20	0·03	0·010
$Zn + L^c \rightleftharpoons ZnL^c$	9·94	0·09	0·039
$ZnL^c + L^c \rightleftharpoons ZnL_2^c$	8·12	0·15	0·064
$Mg + L^c \rightleftharpoons MgL^c$	4·71	0·08	0·038

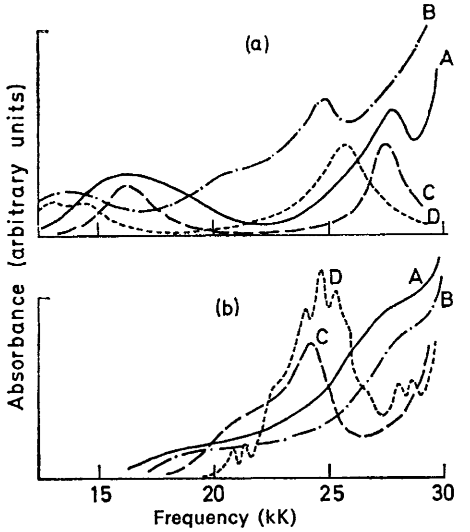

FIGURE 1 Spectra of (a) nickel(II) and (b) uranyl(VI) complexes of DOPA (A), catechol (B), glycine (C), and water (D)

Although several workers have treated uranyl complexes in a satisfactory quantitative manner,[12–16] we have not as yet been able to interpret our data in a similar fashion. This is due to the complexity of the olation reactions and the early onset of precipitation (*ca.* pH 5). Spectra of the mixed complex system copper(II), uranyl, DOPA (1 : 1 : 2 molar ratios) show the uranyl–catechol, and copper–amino-acid absorption maxima (16 kK); in addition copper amalgam electrode data show that the copper(II) ions are undergoing a two-stage reaction. An attempt to extend the range of computational approaches towards the elucidation of these reactions is at present under way.

As is to be expected, the zinc and magnesium complexes do not exhibit large differences in spectra from the component metal ion and ligand. However in titrations using a glass electrode, the ionization of the amine group proton (K_3^H) was observed to be unchanged from the ligand. We concluded that both these metal ions formed catechol-type complexes, as predicted by the constants for the glycine and catechol complexes.

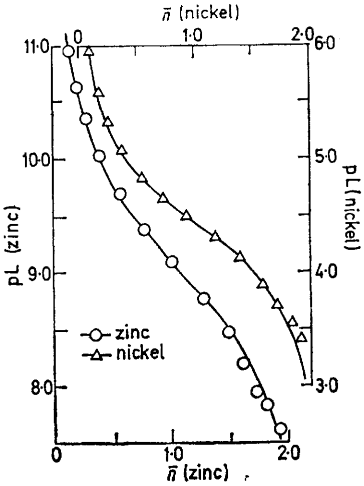

FIGURE 2 Formation curve for nickel(II) and zinc–DOPA complexes

In the zinc system 1 : 1 and 2 : 1 complexes were observed Figure 2 and the values of the relevant constants are in Table 1. Figure 4 shows an Irving–Rossotti type plot for these and related complex systems. Similar comparison of 1 : 1 magnesium complexes is given in Table 3. Only slight evidence for the 2 : 1 complex was observed for magnesium; however good evidence for a protonated complex was obtained in the region $\bar{n} < 0{\cdot}1$ (see Figure 5).

Schwartzenbach [17] reports a similar complex for the Tiron-magnesium system, and it may well be that complexing occurs with one phenolic proton initially retained.

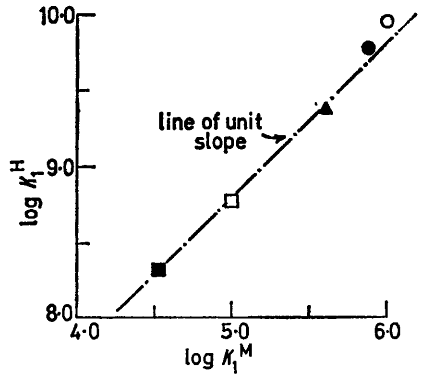

FIGURE 3 Correlation plot for nickel(II)–amino-acid complexes (data from refs. 18 and 19 and K. P. Anderson, W. O. Greenholgh, and E. A. Butler, *Inorg. Chem.*, 1967, **6**, 1056 and N. C. Li, E. Doody, and J. M. White, *J. Amer. Chem. Soc.*, 1957, **79**, 5859): alanine = ○, glycine = ●, phenylalanine = ▲, DOPA = □, glycylglycine = ■

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DISCUSSION

Calculations of the expected degree of complex formation were made from the stability constants of the glycine and catechol complexes.[18-21] These clearly indicated that nickel(II) ions should form amino-acid-type complexes with DOPA, and this was found to be the case. No such simple prediction could be made from the zinc(II) complex calculations although catechol-type complexes were preferred. It is interesting to note, therefore (Figures 3 and 4), that DOPA forms stronger zinc(II) complexes than comparable ligands, thus giving preference to catechol-type chelation. The nickel(II) complexes, on the other hand, are weaker than those of most other amino-acids. Since both correlation plots are good straight lines we attribute these differences to differences in the strength of the proton complexes of the ligands. Because precipitation frustrated our attempts to form a mixed nickel–zinc complex we are considering the use of stronger chelating ligands to lower the pH range in which the complexes form.

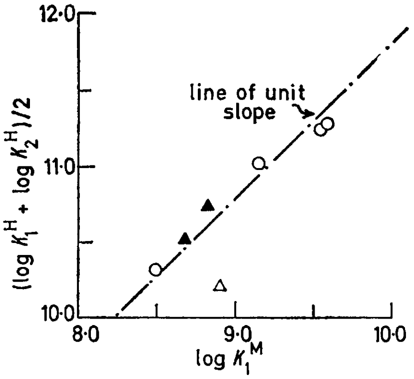

FIGURE 4 Correlation plot for zinc complexes of catechols (data from refs. 20 and 21 and V. T. Athavole, L. H. Prabhu, and D. G. Vartak, *J. Inorg. Nuclear Chem.*, 1966, **28**, 1237. (Note result of difficulty in measuring the second proton dissociation constant for catechol): DOPA = ●, catechol = ○, DPAA = ▲, DBA = △

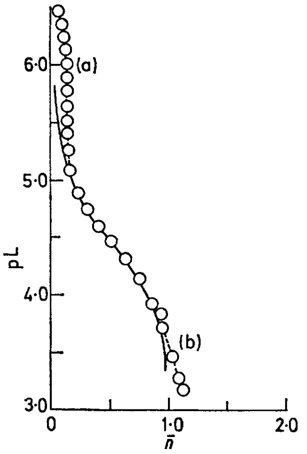

FIGURE 5 Formation curve for magnesium–DOPA complexes showing evidence for (a) the monoprotonated complex, and (b) the attachment of a second ligand

TABLE 2

Comparison of stability constants of magnesium complexes

Ligand	$\log K_1^H$	$\log K_2^H$	$\log K^*$	$\log K_1^M$	$\log K_2^M$	Ref.
Tiron	12·6	7·66	1·98	6·86		17
DBA	11·74	8·67		5·67	4·17	*a*
DPAA	12·0	9·44		4·94		*a*
DPPA	11·6	9·36		4·90		*a*
DOPA	13·40	9·74	*ca.* 1	4·71	*ca.* 2	Present work

(K^* is the formation constant for the protonated metal complex.)

[a] V. T. Athavale, L. H. Prabhu, and D. G. Vartak, *J. Inorg. Nuclear Chem.*, 1966, **28**, 1237.

Further calculations are being performed on the uranyl systems for we feel that although the titrations end in precipitation at pH ≃ 5 better use can be made of the relatively reliable low pH data.

EXPERIMENTAL

The titration apparatus and its calibration have been described previously.[11] DOPA was Koch–Light Puriss grade; determinations of the purity of this ligand are described in Part I.[11] The metal-ion salts were nitrates and of AnalaR grade. Uranyl nitrate was analysed by the oxide method.[22] Nickel nitrate was analysed by the dimethylglyoxime method.[22] Stock solutions of the zinc and magnesium salts were analysed by passing aliquots through an ion-exchange column and titrating the liberated protons.

A Unicam SP 700 spectrophotometer was used. Data were processed on the 4130 computer at the University.

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