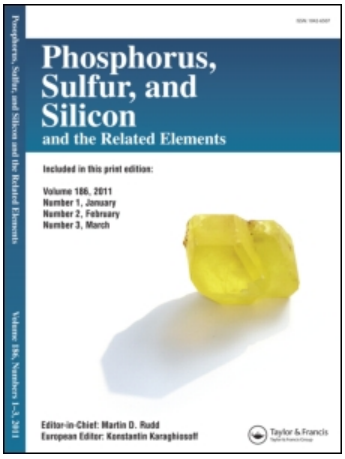

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SYNTHESIS AND LAXS INVESTIGATION OF SOME 1-(D-3-MERCAPTO-2-METHYLPROPIONYL)-L-PROLINE AMORPHOUS COMPLEXES WITH C_0(II), Ni(II), Zn(II), Cd(II)

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SYNTHESIS AND LAXS INVESTIGATION OF SOME 1-(D-3-MERCAPTO-2-METHYLPROPIONYL)-L-PROLINE AMORPHOUS COMPLEXES WITH Co(II), Ni(II), Zn(II), Cd(II)

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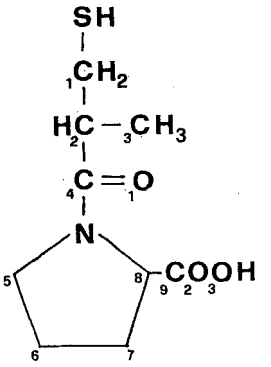
Four amorphous metal complexes with 1-(D-3-mercapto-2-methylpropionyl)-L-proline (L) with general formula $Na_2ML_2 \cdot nH_2O$ (M = Co, n = 14; M = Ni, n = 4; M = Zn, n = 4; M = Cd, n = 7) have been synthesized. LAXS (large angle X-ray scattering) provided information on the local order around the metal(II) ions. A 2:1 ratio between ligand and all examined metal ions was found. A tetrahedral configuration around zinc and cadmium ions has been found with two sulphur and two amidic oxygen atoms bonded to the metals. For nickel and cobalt complexes an octahedral configuration has been found with two water molecules bonded to the metal in axial position and two ligand molecules bonded via sulphur and amidic oxygen in equatorial position.

Key words: 1-(D-3-mercapto-2-methylpropionyl)-L-proline complexes; captopril-metal complexes; large angle X-ray scattering.

INTRODUCTION

1-(D-3-mercapto-2-methylpropionyl)-L-proline (L or captopril see Scheme 1), is an active angiotensin-converting enzyme (ACE) inhibitor. Its synthesis was realized on the basis of the fact that Zn^{2+} ion is the active site of ACE, and an inhibitor should coordinate to it.[1,2] Captopril acts on ACE, which hydrolytically cleaves off dipeptide from angiotensin-I decapeptide to yield the potent vasoconstrictor octapeptide angiotensin-II, inhibiting the formation of the latter whose levels are often elevated in patients affected by hypertension.[3] The mechanism of the action has not been proved, but probably occurs through interaction with active sites of ACE, particularly Zn^{2+}; in fact captopril mobilizes Zn^{2+} from the plasma proteins



SCHEME 1

in vitro. It is interesting to know which of the possible coordination sites of captopril (carboxylate, amino, carbonyl, or mercapto groups) (see Scheme 1) are used in forming coordination bonds to this metal. To gain a deeper insight into captopril side-effects, supposedly related to the complexation of trace elements in vivo,[4] this work has been extended to Cd(II), Ni(II) and Co(II) complexes. Depending on the experimental conditions, different metal-captopril complexes can be obtained: at pH < 6.0 the 1:1 complex is obtained whereas in the pH range between 6.0 and 8.2 the 1:2 complex ($Na_2ML_2 \cdot nH_2O$) is the main product of the synthesis.[4,5]

Investigations on the interactions of captopril with Zn(II) and Cd(II) were carried out using glass electrode potentiometry[4] and two coordination complexes of Zn and captopril have been synthesized and their structure characterized by IR, NMR and XPS spectroscopies.[6] The findings suggested that in the 1:2 complex the carboxylic group is not involved in coordination to the zinc ion and only the mercapto and carbonyl groups participate in the coordination to zinc.

The crystal structure of captopril has been studied by X-ray diffraction.[7] No work has been performed on captopril-nickel complexes.

A DTA investigation on the Co(II) 1:2 complex indicated that captopril is bonded via the sulphur atom and showed that the carboxylic group is not involved in the coordination to the metal ion.

To date no X-ray diffraction studies have been reported on these kinds of complexes. In this work the amorphous captopril metal complexes: $Na_2ZnL_2 \cdot 4H_2O$, $Na_2CoL_2 \cdot 14H_2O$, $Na_2NiL_2 \cdot 4H_2O$, $Na_2CdL_2 \cdot 7H_2O$ (L = captopril^{2-} = $C_9H_{13}NO_3S$) have been synthesized and a large-angle X-ray scattering (LAXS) investigation has been conducted to obtain information on the short range order.

RESULTS AND DISCUSSION

IR

The principal infrared bands of the free ligand and of its examined metal complexes are listed in Table I. Each metal complex shows very similar IR spectra. A strong band at 3400 cm^{-1}, due to the presence of water, is found in the spectra of all metal complexes. The free ligand and the zinc-complex bands are taken from a

TABLE I

Principal I.R. bands (cm^{-1}) for L (captopril) and for the four examined complexes

Compound	Wavenumber	Approximate description
Captopril*	3300-2200 br	Carboxylic ν(OH), hydrogen bonded
	2562 s	ν(SH)
	1742 s 1744**	ν_a(COO)
	1590 s 1648**	Amide ν(CO)
	1446 s	ν_s(COO)
$Na_2ZnL_2 \cdot 4H_2O$*	No bands at 3300-2200	Carboxylic OH absent
	No bands at 2562	SH absent
	1635 sh	ν(CO) of bonded carbonyl amide
	1590 s br	ν_a(COO) of carboxylate sodium salt
	1446 m	ν_s(COO) of carboxylate sodium salt
$Na_2CdL_2 \cdot 7H_2O$	No bands at 3300-2200	Carboxylic OH absent
	No bands at 2562	SH absent
	1590 vs	ν(CO) of bonded carbonyl amide and ν_a(COO) of carboxylate sodium salt
	1445 m	ν_s(COO) of carboxylate sodium salt
$Na_2NiL_2 \cdot 4H_2O$	No bands at 3300-2200	Carboxylic OH absent
	No bands at 2562	SH absent
	1640 sh	ν(CO) of bonded carbonyl amide
	1590 vs	ν_a(COO) of carboxylate sodium salt
	1445 m	ν_s(COO) of carboxylate sodium salt
$Na_2CoL_2 \cdot 14H_2O$	No bands at 3300-2200	Carboxylic OH absent
	No bands at 2562	SH absent
	1615 vs	ν(CO) of bonded carbonyl amide
	1570 s	ν_a(COO) of carboxylate sodium salt
	1445 m	ν_s(COO) of carboxylate sodium salt

* from reference 6

**THF Solution

previous work[6] and shown here for comparison with the other complexes. In the free ligand spectrum the ν(OH) and ν(SH) bands are present at 3300 s and 2562 s cm^{-1}. The ν(CO) amide is found at 1590 cm^{-1} in the free ligand (1648 cm^{-1} in THF solution), at 1635 cm^{-1} in $Na_2ZnL_2 \cdot 4H_2O$, at 1590 cm^{-1} in $Na_2CdL_2 \cdot 7H_2O$, at 1640 cm^{-1} in $Na_2NiL_2 \cdot 4H_2O$ and at 1615 cm^{-1} in $Na_2CoL_2 \cdot 14H_2O$. The ν_a(COO) and ν_s(COO) are found at 1742 and 1446 cm^{-1} in the free ligand, at 1590 and 1446 cm^{-1} in $Na_2ZnL_2 \cdot 4H_2O$, at 1590 and 1445 cm^{-1} in $Na_2CdL_2 \cdot 7H_2O$ and in $Na_2NiL_2 \cdot 4H_2O$ and at 1570 and 1445 cm^{-1} in $Na_2CoL_2 \cdot 14H_2O$.

The shift observed for the amidic ν(CO) band, in the free ligand, from 1590 cm^{-1} (KBr pellet) to 1648 cm^{-1} (THF solution) is due to the loss, in solution, of intermolecular hydrogen bonding which is present in the solid state as already found.[6]

Comparing the IR data of Table I of the amide ν(CO) band for the free ligand and the metal complexes the small shift after coordination is attributable to the contribution of N doublet as a result of the electronic delocalization through the system N═C═O. Hence the decrease of the CO bond order is partially compensated, as found for the zinc complex.[6]

LAXS

$si(s)$ versus s functions (see Experimental) for all examined complexes are shown in Figures 1 and 2. Figures 3, 4 and 7 show the experimental radial distribution functions (Diff(r) = $D(r) - 4\pi r^2\rho_0$).

$Na_2ZnL_2 \cdot 4H_2O$

The Diff(r) function (see Experimental) shows the occurrence of three well-defined peaks at about 2.3, 3.7, 6.0 Å (see Figure 3(a)). Several factors of different origin

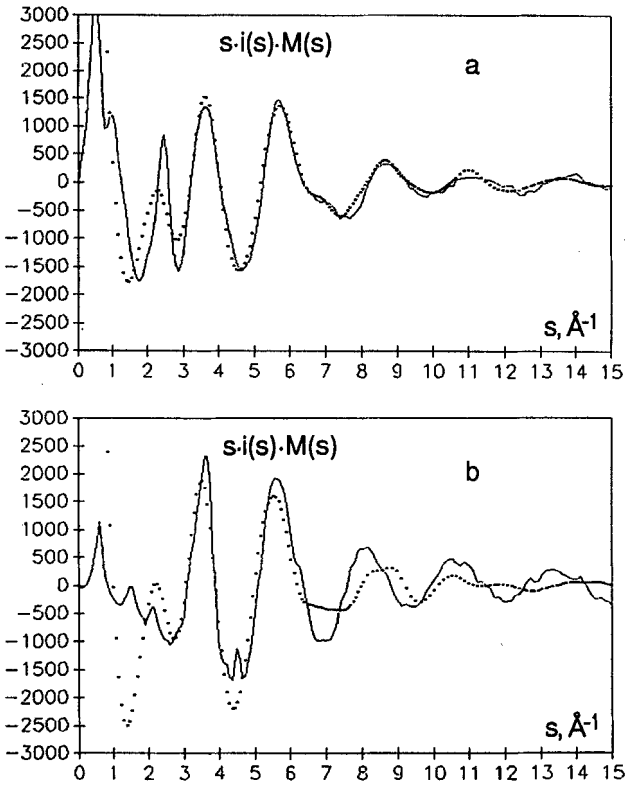


FIGURE 1 Observed (—) and calculated (· · · ·) $s \cdot i(s) \cdot M(s)$ values versus $s = 4\pi\lambda^{-1} \sin\theta$ for the $Na_2ZnL_2 \cdot 4H_2O$ (a) and $Na_2CdL_2 \cdot 7H_2O$ (b) amorphous complexes.

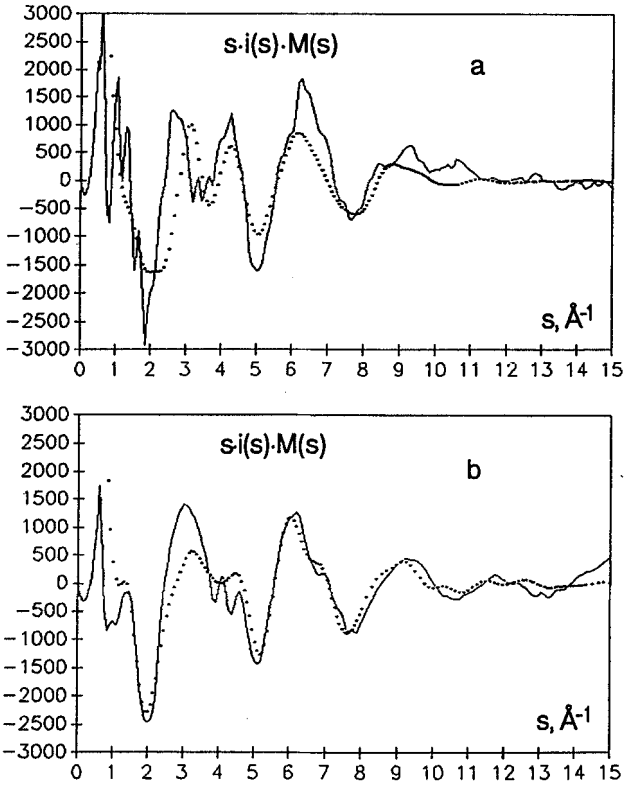


FIGURE 2 Observed (—) and calculated (· · · ·) $si(s)M(s)$ values versus $s = 4\pi\lambda^{-1} \sin\theta$ for the $Na_2CoL_2 \cdot 14H_2O$ (a) and $Na_2NiL_2 \cdot 4H_2O$ (b) amorphous complexes.

contribute to these peaks: Zn-light atom interactions, light atom-light atom interactions and Zn—Zn iteractions. Because the typical distance Zn—O is about 2.1 Å and Zn—S is 2.3–2.4 Å[8] the experimental peak at about 2.3 Å is mainly due to these interactions.

We made preliminary tests on a simple model with Zn tetrahedrally coordinated to two carbonyl oxygens and two S atoms; the good results obtained bear out this hypothesis.

Therefore two captopril molecules were bonded to Zn as shown in Figure 5. It was necessary to make a rotation around the C2—C4 bond, in order to exchange the position of the CH_2—SH group (see Scheme 1) with that of the —CH_3 group, with respect to their position in the free captopril molecule in the crystal.[7]

Only the configuration depicted in Figure 5 gives Zn-light atoms distances in the range 3.4–4.0 Å and therefore reproduces the experimental peak at 3.7 Å.

The synthetic structure function obtained is shown in Figure 1(a) and theoretical peak shapes in Figure 3(a).

Only three mean square deviations (σ) of the interaction distances were used. However, to each distance falling within a preset range (for example 1.0–1.6 Å, 1.6–2.6 Å, 2.6–20.0 Å), the same value of mean square deviation was assigned,

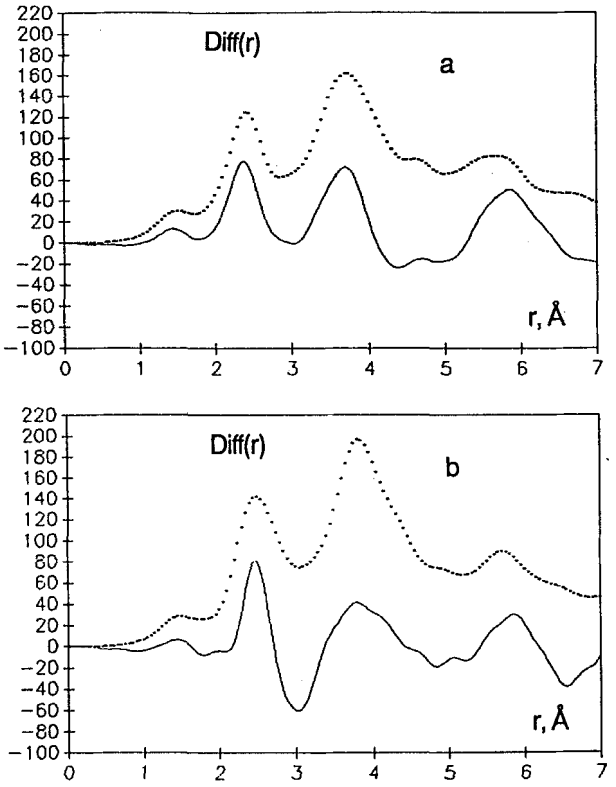


FIGURE 3 The function $D(r) - 4\pi r^2\rho_0$ (——) and the theoretical peak shapes (· · · ·) calculated as described in the paper for the $Na_2ZnL_2 \cdot 4H_2O$ (a) and $Na_2CdL_2 \cdot 7H_2O$ (b) without Na-H_2O interactions.

so that the number of adjusted parameters was much smaller than the number of pair distances existing in the model. The σ values are listed in Table II. The mean square deviation value tends to increase with interatomic distances and the final parameters are consistent with the values obtained for previously studied amorphous compounds.[9]

The theoretical si(s) reproduces the experimental one and the $Diff_{calc}$ shows the same peaks at 2.3 and 3.7 Å.

This model does not completely fit the peak at 6.0 Å and this suggest the existence of correlations between different ZnL_2 complexes with a Zn—Zn distance of 6.0 Å.

$Na_2CdL_2 \cdot 7H_2O$

The Diff(r) function (Figure 3(b)) shows the occurrence of the three peaks at about 2.5 Å, 3.9 Å and 5.9 Å and a small peak at about 1.5 Å. Like zinc the peaks are mainly due to the Cd-light atom interactions in the molecules. The different positions are compared to the zinc complex due to the fact that Cd—O is expected at 2.3 Å[10] and Cd—S at about 2.5–2.6 Å.[11] The coordination model tested for the

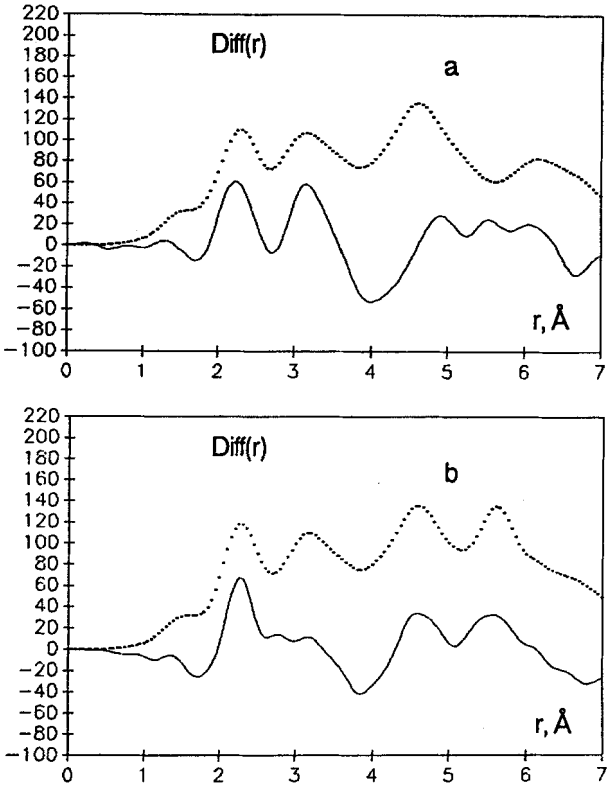


FIGURE 4 The function $D(r) - 4\pi r^2\rho_0$ (—) and the theoretical peak shapes (· · · ·) calculated as described in the paper for the $Na_2CoL_2 \cdot 14H_2O$ (a) and $Na_2NiL_2 \cdot 4H_2O$ (b) without Na-H_2O interactions.

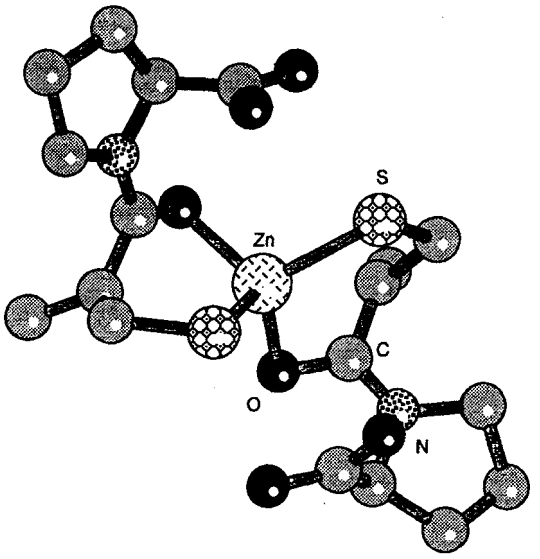


FIGURE 5 Prospective view of the tetrahedral complexes.

TABLE II

The r.m.s. σ_{pq} values used for the model

$1.0 < r \leq 1.6$ Å	$\sigma_1 = 0.05$
$1.6 < r \leq 2.6$ Å	$\sigma_2 = 0.15$
$2.6 < r \leq 20.0$ Å	$\sigma_3 = 0.25$

TABLE III

Distances of all atoms in the complexes from the metal ion

distances in tetrahedral complexes			distances in octahedral complexes	
	Zn	Cd	Co	Ni
C_{1a}	3.366	3.593	3.449	3.449
C_{2a}	2.881	3.114	3.186	3.186
C_{3a}	4.164	4.372	4.509	4.509
C_{4a}	2.554	2.781	2.913	2.913
C_{5a}	4.629	4.867	5.339	5.339
C_{6a}	5.745	5.967	6.411	6.411
C_{7a}	5.450	5.634	6.107	6.107
C_{8a}	4.088	4.258	4.654	4.654
C_{9a}	3.661	3.773	4.461	4.461
S_a	2.370	2.528	2.270	2.270
N_a	3.500	3.723	4.084	4.084
O_{1a}	2.126	2.277	2.100	2.100
O_{2a}	3.787	3.820	4.385	4.385
O_{3a}	3.790	3.913	4.875	4.875
C_{1b}	3.366	3.593	3.449	3.449
C_{2b}	2.881	3.114	3.186	3.186
C_{3b}	4.164	4.372	4.509	4.509
C_{4b}	2.554	2.781	2.913	2.913
C_{5b}	4.629	4.867	5.339	5.339
C_{6b}	5.745	5.967	6.411	6.411
C_{7b}	5.450	5.634	6.107	6.107
C_{8b}	4.088	4.258	4.654	4.654
C_{9b}	3.661	3.773	4.461	4.461
S_b	2.370	2.528	2.270	2.270
N_b	3.500	3.723	4.084	4.084
O_{1b}	2.126	2.277	2.100	2.100
O_{2b}	3.787	3.820	4.385	4.385
O_{3b}	3.790	3.913	4.875	4.875
W_1	–	–	2.000	2.100
W_2	–	–	2.000	2.100

Zn complex fits the experimental data perfectly. Differences between Cd and Zn complexes lie in the distances which are larger in the Cd complex (see Table III). Mean square deviations are the same in both cases.

$Na_2NiL_2 \cdot 4H_2O$

The Diff(r) function (Figure 4(b)) shows a peak at 2.3 Å, 4.5 Å and 5.8 Å. As in the previous cases peaks are due to metal-captopril interactions. Ni—O is expected at 2.1 Å[12] and Ni—S at about 2.3 Å[13]. The shift from 3.7–3.9 Å (as observed for zinc and cadmium complexes respectively) to 4.5 Å suggests that captopril molecules bonded to the metal have a different configuration compared to the previous cases. The Diff(r) function differs substantially from the previous cases and is similar to that of the cobalt complex (see Figures 3 and 4). A first test with the same configuration as the Zn complex was in any case performed but the results were totally unsatisfactory. A molecule with octahedral configuration has been considered with two sulphur and two amidic oxygen in equatorial position and two water molecules in axial position as shown in Figure 6. This model fits the experimental data very well.

$Na_2CoL_2 \cdot 14H_2O$

The Diff(r) function (Figure 4(a)) shows two peaks at 2.3 and 3.2 Å, and at 4.8 and 5.7 Å. Compared with the previous cases the peak at 2.3 Å (due to the contribution of Co—O and Co—S)[14,15] is broader and a very large peak is observed at 3.2 Å. This fact may be due to the large amount of water present in this case. Na^+ coordination with water is then expected, which contributes towards the peak at 2.3 Å (Na-H_2O) and at 3.25 Å (H_2O-H_2O interactions for octahedral configuration) in the Diff(r).[16] Nevertheless the same model used for nickel complex has been tested obtaining a sufficiently good fit of experimental data. The aim of this work was in fact to verify the coordination of the metal with the two captopril molecules.

For the cobalt complex and the cadmium one which contain much larger amounts of water than the Zn and Ni complexes, the contributions of Na-H_2O and H_2O-H_2O were subsequently introduced. The Na-H_2O distance at 2.3 Å, H_2O-H_2O_{cis} at 3.25 Å and H_2O-H_2O_{trans} = 4.6 Å in an octahedral configuration[16] with a mean square deviation (σ) of 0.113 for the last two distances were used for the cobalt complex. The Na-H_2O contribution in a tetrahedral configuration with Na-H_2O

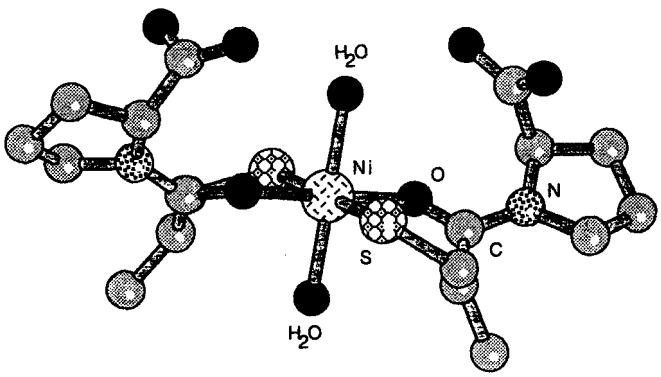


FIGURE 6 Prospective view of the octahedral complexes.

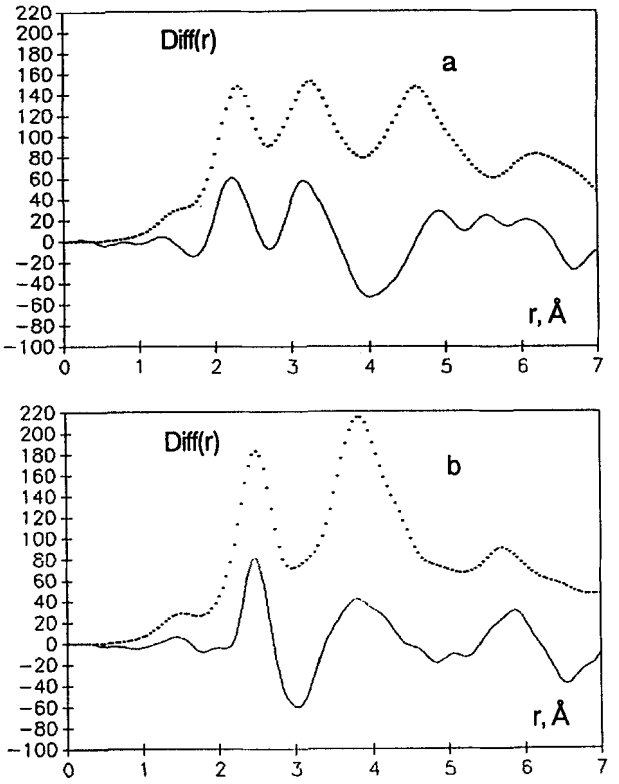


FIGURE 7 The function $D(r) - 4\pi r^2\rho_0$ (—) and the theoretical peak shapes (· · · ·) calculated as described in the paper for the $Na_2CoL_2 \cdot 14H_2O$ (a) and $Na_2CdL_2 \cdot 7H_2O$ (b) with Na-H_2O interactions.

distances = 2.3 Å and H_2O-H_2O = 3.745 Å (σ = 0.255) were considered for the cadmium complex. In both cases a better fit of experimental data was observed: the Diff(r) obtained introducing the Na-H_2O interactions in Cd and Co complexes are shown in Figure 7.

CONCLUSIONS

The aim of this study was to define the local structure of the amorphous metal-captopril complexes. The LAXS analysis provides this information, indicating that the Zn^{2+} ion is bonded to two molecules of captopril through the mercapto and the carbonyl group.

In the zinc and cadmium complexes captopril is coordinated in a tetrahedral structure with two sulphur and two carbonyl oxygen atoms.

In the Ni and Co complexes an octahedral configuration is observed with two captopril molecules bonded via sulphur and carbonyl oxygen atoms and two water molecules in an axial position. The sulphur atoms or carbonyl oxygen atoms lie in a trans-position on the equatorial plane.

EXPERIMENTAL

Materials. Ninety-nine per cent pure captopril was kindly provided by Squibb, Anagni (Italy). Anal. Found (Calc. for $C_9H_{15}NO_3S$): C 50.0 (49.8); H 7.1 (7.0); N 6.5 (6.5); S 14.9 (14.8). The captopril metal complexes were prepared as described below. All reagents were analytical grade and bidistilled water was used for the synthesis.

$Na_2ZnL_2 \cdot 4H_2O$ synthesis. This complex has been synthesized as previously reported.[6] Anal. Found (Calc. for $C_{18}H_{26}N_2O_6S_2Na_2\,Zn \cdot 4H_2O$): C 35.2 (35.2); H 5.7 (5.6); N 4.7 (4.6); S 10.4 (10.4).

$Na_2CdL_2 \cdot 7H_2O$ synthesis. $3CdSO_4 \cdot 8H_2O$ (1.54 gr, 2 mmol) in 10 cm³ of previously ice cooled water and quickly added to an aqueous mixture of captopril (0.87 gr, 4 mmol) and NaOH (8.5 ml of a 1M solution, 8.5 mmol) and ice cooled. 1.2 gr of a white precipitate was filtered and washed with cold water, EtOH and then ether. Anal. Found (Calc. for $C_{18}H_{26}N_2O_6S_2Na_2Cd \cdot 7H_2O$): C 29.2 (29.1); H 5.1 (5.4); N 4.0 (3.8); S 9.0 (8.6).

$Na_2NiL_2 \cdot 4H_2O$ synthesis. $Ni(NO)_3 \cdot 6H_2O$ (0.58 gr, 2 mmol) in 10 cm³ of water was added to an aqueous mixture of captopril (0.87 gr, 4 mmol) and NaOH (8.5 ml of an 1M solution, 8.5 mmol) and ice cooled. A deep dark red colouring was observed. 20 cm³ of EtOH and then 20 cm³ of ether previously cooled were quickly added to precipitate 0.8 gr of product. Anal. Found (Calc. for $C_{18}H_{26}N_2O_6S_2Na_2Ni \cdot 4H_2O$): C 35.3 (35.6); H 5.65 (5.64); N 4.9 (4.6); S 10.7 (10.6).

$Na_2CoL_2 \cdot 14H_2O$ synthesis. $Co(NO_3)_2 \cdot 6H_2O$ (1.16 gr, 2 mmol) in 10 cm³ of water was added to an aqueous mixture of captopril (0.87 gr, 4 mmol) and NaOH (8.5 ml of an 1M solution, 8.5 mmol) and ice cooled. 20 cm³ of EtOH were quickly added to precipitate 1.35 gr of product. Anal. Found (Calc. for $C_{18}H_{26}N_2O_6S_2Na_2Co \cdot 14H_2O$): C 27.47 (27.45); H 6.6 (6.9); N 3.60 (3.60); S 8.0 (8.1).

Chemical analysis. The chemical analyses of all products were performed using a Carlo Erba mod. 1108 instrument.

Infrared spectroscopy. The I.R. spectra of the specimens in the form of KBr pellets were recorded on a Perkin Elmer mod. 983 spectrometer in the range 4000–180 cm^{-1}.

X-ray scattering measurements and data processing. Each sample was very finely ground, introduced into a vessel and pressed at about 9 Kg/cm². The spectrum scattered by the sample irradiated with molybdenum Kα radiation (λ = 0.7107 Å) was obtained using a Siemens D-500 Θ-2Θ automatic diffractometer. The measured intensity was recorded in the s range from 0.6–15 Å, where $s = (4\pi/\lambda)\sin\Theta$. About 100,000 counts were collected for each point. The applied correction and normalization process was the same as those already used.[9] Atomic scattering factors, $f_h(s)$ for all the atoms were taken from international tables.[17] Reduced intensities were calculated with the equation:

$$i(s) = K \cdot I_c(s) - \sum_h n_h[(f_h(s) + \Delta f'_h)^2 + \Delta f''_h + I_{h(\text{inch})}(s) \cdot \text{del}(s)]$$

where K, $I_c(s)$, n_h, $f_h(s)$, $\Delta f'_h$, $\Delta f''_h$, $I_{h(\text{inch})}(s)$ and del(s) have the same meaning reported elsewhere.[9] The radial distribution $D(r)$ can then be written:

$$D(r) = 4\pi r^2\rho_0 + 2r\pi^{-1}\int_0^{s\max} s \cdot i(s)M(s)\sin(rs)\,ds$$

where ρ_0 is the average electronic density of the sample ($\rho_0 = (\Sigma_h n_h f_h(0))^2 \cdot V^{-1}$), V is the stoichiometric unit volume chosen and $M(s)$ a modification function defined by:

$$f_5^2(0)/f_5^2(s)\exp(-0.01s^2)$$

The experimental radial distribution functions is in the form $\text{Diff}(r) = D(r) - 4\pi r^2\rho_0$. Theoretical peaks were calculated by a corresponding Fourier transformation of the theoretical intensities for the pair interactions,

$$i_{pq} = \sum f_p f_q \sin(r_{pq}s)(r_{pq}s)^{-1}\exp(-1/2\sigma_{pq}^2 s^2)$$

using the same sharpening function as for the experimental date and assuming the r.m.s. variation in the distance to be σ_{pq}.

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REFERENCES

1. D. W. Cushman, H. S. Cheng, E. F. Sabo and M. A. Ondetti, *Biochemistry*, **16,** 5484 (1977).
2. M. A. Ondetti, B. Rubin and D. W. Cushman, *Science*, **196,** 441 (1977).
3. K. Sekimoto and H. Tomita, *Nihon Univ. J. Med.*, **28,** 233 (1986).
4. M. A. Huges, G. L. Smith and D. R. Williams, *Inorg. Chim. Acta*, **107,** 247 (1985).
5. P. Bukovec, S. Milicev, N. Bukovec and M. Cepon, *Inorg. Chim. Acta*, **137,** 177 (1987).
6. D. Atzei, D. De Filippo, A. Rossi, A. Lai, G. Saba and R. Bucci, *Spectrochimica Acta*, **48A,** 911 (1992).
7. M. Fujinaga and M. N. G. James, *Acta Cryst.*, **B36,** 3196 (1980).
8. R. F. Baggio and P. K. De Perazzo, *Acta Cryst.*, **B30,** 2166 (1974).
9. R. Caminiti, C. Munoz-Roca, D. Beltran-Porter and A. Rossi, *Z. Naturforsch.*, **43a,** 591 (1988).
10. N. Nardelli, G. F. Gasparri and P. Boldrini, *Acta Cryst.*, **18,** 618 (1965).
11. H. M. Rietveld and E. N. Malsen, *Acta Cryst.*, **18,** 429 (1965).
12. K. Kroqmann and R. Mattes, *Z. Krishahaq.*, **118,** 291 (1963).
13. M. Franzini, *Z. Kristallogr.*, **118,** 393 (1963).
14. F. A. Cotton and R. C. Elder, *Inorg. Chem.*, **4,** 1145 (1965).
15. P. R. H. Alderman, P. G. Owston and J. M. Rowe, *J. Chem. Soc.*, 668 (1962).
16. G. Ferraris and G. Chiari, *Acta Cryst.*, **B26,** 1574 (1970).
17. Int. Tables for X-ray Crystallography, Vol. 4, Keinorh Press, Birmingham 1974.