NMR and CD Studies of Palladium(II) Complexes with S-methyl-L-cysteine Containing Peptides

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The studies on Pd(II) complexes with Gly-SMC, SMC-Gly and SMC-SMC have shown that S-methyl-L-cysteine as a residue in dipeptide ligands binds palladium ions by {N,S} donor set, creating a new chirality center on sulfur atom. The conformation of SMC in the formed complexes seems to be different when it acts as a dipeptide residue, as compared to that found in PdSMC complex. The presence of vicinal N-terminal residue (e.g. Gly in PdGly-SMC) stablizes the δ conformer of the SMC chelate ring, as well as changing the kinetics of the sulfur inversion in palladium complexes. The formation of the metal thioether sulfur bond enriches considerably the UV region of the CD spectra where the S → Pd(II) charge transfer (as well as intra sulfur transition) could be observed.

Introduction

Recent studies on metal ion coordination to S-methyl-L-cysteine have shown very interesting stereochemical implications of the metal–sulfur bond formation in various complexes [1–8]. In this communication we present further NMR and CD studies of the Pd(II) inteaction with small peptides containing S-methyl-L-cysteine as a residue. The aim of this study is to find whether the specific binding of sulfur donor to metal may be influenced by the vicinal amino acid residues of peptide molecule, and *vice versa*. It is also of interest to study the relation between the formation of the new chirality center on sulfur and the CD spectra of the formed complexes.

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Experimental

Glycyl-S-methyl-L-cysteine Gly-SMC, S-methyl-L-cysteyl-glycine SMC-Gly, and S-methyl-L-cysteyl-S-methyl-L-cysteine SMC-SMC dipeptides were synthesized by coupling of two amino acids *via* N-hydroxy succinimide [9].

^{1}H NMR spectra were recorded on 80 (WP 80) and 250 MHz (WM 250) Bruker spectrometers with peptide concentration 0.05 *M* at 300 ± 2 K. ^{13}C NMR spectra were recorded on a JEOL JMN-PS-100 spectrometer at 25 MHz with ligand concentration 0.1 *M*. The temperature effect on ^{1}H NMR spectra was measured on a 60 MHz Bruker spectrometer model WP 60 in the 276–350 K range. Analysis and simulation of the proton ABC spectra of the SMC residue were carried out on a JEC-6 computer.

CD spectra were recorded on a Mark III Jobin-Yvon Dichrographe in the 800–200 nm region, with metal ion concentration 5×10^{-3} *M*.

Results and Discussion

^{1}H NMR parameters for Gly-SMC, SMC-Gly and SMC-SMC are presented in Table I. The distribution of the rotamer population in SMC residue around the C_α–C_β bond (Fig. 1) is more or less similar to that found in S-methyl-L-cysteine [10], except for some stabilization of isomer III at higher pH observed for SMC residue on the C-terminal of the peptide molecule (Table II).

In CD spectra of SMC containing peptides it is possible to observe the absorption of the thioether chromophore in the 190–250 nm region [11]. In the peptides studied in this work we observed for some pH values a broad positive band around 225

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TABLE I. ^{1}H NMR Parameters for Gly-SMC, SMC-Gly and SMC-SMC Peptides and Pd Gly-SMC Complex. Chemical Shifts are related to DSS standard.

Compound	pH	ν_A	ν_B	ν_C	ν_A[a]	ν_B[a]	ν_C[a]	ν_{SCH_3}	ν_{SCH_3}[a]	$\nu_{CH_2\text{-Gly}}$	J_{ABCH_2}
Gly-SMC	0.27				2.975	3.096	4.720		2.152	3.921 (A_2)	
	6.2				2.886	3.036	4.434		2.143	3.889 (A_2)	
	12.55				2.898	3.025	4.372		2.139	3.378 (A_2)	
Pd(II)Gly-SMC	12.2 (1)				3.112	3.375	4.115			3.719 (A_2)	
1:1	(2)				3.286	3.194	4.145		2.528	3.726 3.624(AB)	16.9
C H proton decoupled										3.780 3.653(AB)	17.0
∝	12.2 (1)				3.107	3.375					
	(2)				3.112	3.376					
	(3)				3.287	3.192					
SMC-Gly	0.56	3.014	3.157	4.311				2.181		4.094 (A_2)	
	6.32	2.986	3.127	4.209				2.179		3.915 3.749(AB)	16.8
	13.27	2.77	2.873	3.636				2.128			
SMC-SMC	0.97	3.021	3.184	4.332	2.986	3.176	4.695	2.181	2.160		
	6.86	2.958	3.146	4.155	2.905	3.036	4.415	2.170	2.151		
	12.34	2.785	2.905	3.669	2.798	3.045	4.420	2.144	2.135		

[a]Results for C-terminal SMC residue.

TABLE II. Rotamer Populations[b] and Coupling Constants for SMC Residue in Gly-SMC, SMC-Gly and SMC-SMC Peptides and Pd Gly-SMC Complex.

Compound	pH	J_{AB}	J_{AC}	J_{BC}	J_{AB}[a]	J_{AC}[a]	J_{BC}[a]	p_I	p_{II}	p_{III}	p_I[a]	p_{II}[a]	p_{III}[a]
Gly-SMC	0.27				13.7	8.3	4.6				0.21	0.54	0.25
	6.2				13.8	8.9	3.9				0.14	0.60	0.26
	12.55				14.1	9.0	2.3				0.00	0.61	0.39
Pd(II)Gly-SMC	12.2 (1)				11.4	6.6	2.6				0.02	0.38	0.60
1:1	(2)				14.0	7.2	2.3				0.00	0.44	0.56
SMC-Gly	0.56	14.4	8.4	4.9				0.23	0.55	0.22			
	6.32	14.4	8.5	4.9				0.23	0.56	0.21			
	13.27	13.7	8.0	4.8				0.22	0.51	0.27			
SMC-SMC	0.97	14.6	7.6	3.9	14.5	8.7	5.5	0.14	0.47	0.39	0.28	0.58	0.14
	6.86	14.3	8.7	4.5	14.1	8.5	4.1	0.19	0.58	0.23	0.16	0.56	0.28
	12.34	13.9	7.6	4.8	14.3	7.1	5.0	0.22	0.48	0.30	0.24	0.43	0.33

[a]Results for C-terminal SMC residue. [b]Populations are calculated according to the Martin approach [29].

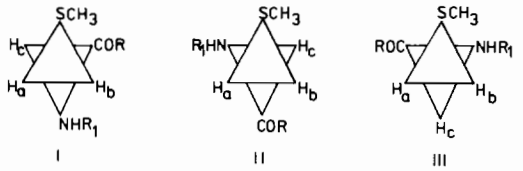


Fig. 1. Rotamer notation of SMC residue.

nm for SMC-SMC and SMC-Gly, which can be tentatively assigned as the transition on sulfur atom dissymmetrically perturbed by the asymmetric center C_α. In the absorption spectra of those peptides the intrasulfur transitions are usually overlapped with the other intraligand transitions centered at 210 nm, except for Gly-SMC where the 257 nm band ($\epsilon \sim 300$–$500\ M^{-1}\ cm^{-1}$) is well resolved. This band is observed as a shoulder for SMC-SMC at 250 nm.

The variation of the proton chemical shift in Gly-SMC molecules upon the Pd(II) ion coordination (Table I) clearly shows that the binding sites of Pd(II) in ligand molecules in pH range 2–13 are two nitrogens (NH_2, N^-) and sulfur donor (*vide infra* for ^{13}C NMR data). At pH below 9, strongly low field shifted S-CH_3 proton resonances (0.369–0.387 ppm) give two signals at 2.53 and 2.512 ppm, which derive from two diastereoisomers formed after Pd(II) coordination to sulfur (slow inversion at sulfur center). These two signals coalesce when the pH increases above 10. The interesting region of the proton spectrum in Pd(II) Gly-SMC complex is that of the CH_2 glycine protons (Fig. 2). In this complex, glycine methylene protons exhibit three different spectra: one of A_2 and two of AB type. All these proton resonances are upfield shifted (0.1–0.25 ppm) as compared to the zwitterionic form of Gly-SMC (Table I) due to Pd(II) coordination to the NH_2 group. These different types of spectra may suggest that glycine chelate ring may be present in more than one conformation in the formed PdGly-SMC complex. On the other hand, however, the unequivalence of glycine protons may derive from different conformations of the SMC chelate ring (*vide infra*).

In the spectra of the SMC residue the $C_\alpha H$ proton exhibits one broad quartet in the whole pH region studied. The methylene resonances consist of two (or three when $C_\alpha H$ proton is decoupled) AB multiplets at pH > 10 (Table I, Fig. 3). At pH < 9, the methylene proton region is difficult to analyse even in 250 MHz spectrum due to overlapping of probably more than two poorly-resolved AB multiplets. The complication of low pH spectra is most likely caused by the slow exchange between two diastereoisomers *i.e.* in NMR scale, slow inversion at the sulfur center [2].

The variety of the observed spectra in the Pd Gly-SMC complex seems to be derived from the presence

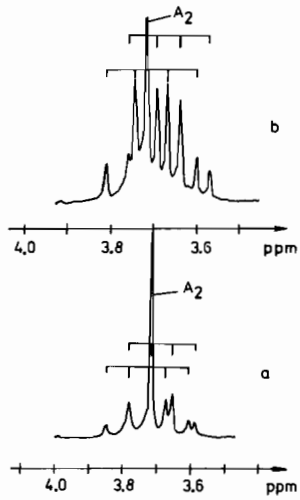


Fig. 2. NMR spectra of CH_2Gly protons at pH 4.76 (a) and 12.2 (b).

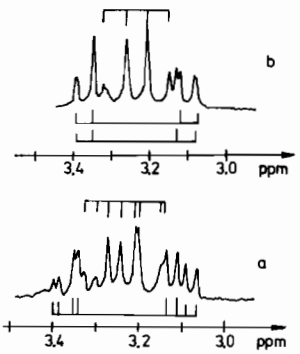


Fig. 3. NMR spectra of SMC residue CH_2CH protons for non-decoupled (a) and decoupled at C_α H proton (b).

of the SMC residue and metal–sulfur coordination. In the similar Pd(II) dipeptide complexes without SMC, the glycine residue protons usually exhibit one spectrum of A_2 type if dipeptide is tridentately bound to metal ions or one spectrum of AB type if peptide is bidentately bound to metal [12–15].

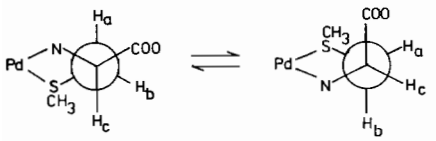
As has been already found earlier [1–8, 30], the metal ion coordination to thioether sulfur creates a new chirality center on the sulfur donor. At pH < 9 (slow inversion on sulfur) both diastereoisomers formed due to such binding may lead to two different spectra of SMC protons [1]. The presence of three different glycine signals (as well as several SMC methylene proton signals even for fast inversion at sulfur) suggest, however, that chelate rings may assume different conformations not necessarily related to the absolute configuration at the sulfur center.

Another interesting structural feature found in Gly-SMC molecules after metal ion coordination

TABLE III. ^{13}C NMR Chemical Shifts of Gly-SMC and Pd Gly-SMC[a] in D_2O Solutions. The values are given in ppm in relation to dioxane standard.

Compound	pH	ν_{CH_2Gly}	ν_{C_α}	ν_{C_β}	ν_{CO}	ν_{COO^-}	ν_{SCH_3}
Gly-SMC	7.1	−25.8	−12.4	−30.8	100.6	110.2	−51.8
Pd(II) Gly-SMC	6.4 (1)	−15.5 (10.3)	−3.2 (9.2)	−18.4 (12.4)	114.9 (14.3)	111.0 (0.8)	−45.6 (6.2)
1:1	(2)	−16.0 (9.8)	−4.7 (7.6)	−21.6 (9.2)	114.4 (13.8)	109.9 (−0.2)	−47.4 (4.4)
	12.4 (1)	−15.8 (10.0)	−4.4 (8.0)	−19.0 (11.8)	113.7 (13.1)	111.3 (1.1)	−46.2 (5.6)
	(2)	−16.1 (9.7)	−5.5 (6.9)	−22.2 (8.6)	113.3 (12.7)		−47.4 (4.4)

[a]The chemical shift changes upon Pd(II) coordination are given in parentheses.



λ δ

Fig. 4. λ and δ conformer equilibrium of SMC chelate ring.

is a strong increase in population of the SMC rotamer III (Table II, Fig. 1). Stabilization of the 'gauche' isomer in the Pd Gly-SMC complex may suggest equilibrium between λ and δ conformations [16–18] of {NS} bonded SMC chelate rings (Fig. 4).

Very high population of rotamer III in the studied complex (~0.6) means that δ conformer of the SMC chelate ring with axial carboxylate could predominate. Our earlier study of PdSMC complexes has shown that in this case metal ion coordination via NS donors does not stabilize rotamer III, and rotamer II predominates considerably over the two other ones [1]. If our assumption about $\lambda \rightleftharpoons \delta$ equilibria in NS bonded SMC residue is reasonable, in PdSMC complexes the λ conformer with equatorial carboxylate should be predominant with only a minor (if any δ isomer population. X-ray studies of metal SMC or SMC derivative complexes have shown that in fact the λ conformation is usually found when SMC amino acid is NS bonded to metal [3, 8, 19, 20, 30]. It should be noted, however, that envelope-like conformations are also possible in metal complexes with simple derivatives of SMC [4]. It should be noted that the X-ray studies of metal complexes with SMC and its derivatives also revealed that the dihedral angle χ around C_α–C_β bond is near to the 'normal' values found for free amino acids and lies within the limits 52–60° [4, 19, 30, 33]. These values of χ angle show that the analysis presented above of rotamer populations derived from vicinal proton coupling constants may be treated as semiquantitative, especially in solutions where 5-membered rings become flexible.

At pH < 9 the increase of temperature of the sample causes a coalescence of methyl SCH_3 protons as a result of the inversion on sulfur center as found earlier for Pd(II) SMC complexes [1, 10]. The coalescence point in Pd(II) Gly-SMC complex strongly depends on pH (315 K for pH = 4.5, 290 K for pH = 9.7, 276 K for pH> 10) and it is considerably lower than that in PdSMC molecules (347.5 K [10]). The latter difference derives most likely from stronger *trans* effect caused by NH_2 groups in PdGly-SMC, as compared to that caused by Cl^- or H_2O molecule in PdSMC complexes. The influence of pH on inversion kinetics may suggest an important role of OH^- in such process.

No such discussion could be present for the other two peptide complexes since both ^1H and ^{13}C NMR spectra were poorly resolved. The only conclusion which could be reached is that sulfur donor is a binding site in all palladium complexes formed with SMC-Gly and SMC-SMC peptides.

The ^{13}C NMR spectra (Table III) generally support conclusions reached from ^1H NMR studies. PdGly-SMC complex exhibits two sets of ^{13}C signals which could derive either from the formation of two diastereoisomers [2] or from the different chelate ring conformations.

The ^{13}C chemical shift changes upon the metal ion coordination show (in agreement with ^1H NMR data) that coordination sites of metal ion in Gly-SMC molecule are NH_2, N^- and S donors (see considerable downfield chemical shifts of the vicinal carbons, Table III). The slight change of ^{13}C chemical shift of carboxylate indicates no involvement of this group in a direct coordination to metal ion (Table III and ref. 2).

An increase of pH or temperature has some slight effect on ^{13}C chemical shifts of the formed complex. The increase of pH from 6.4 to 12.4 mostly affects signals of S-CH_3 carbon resonances. The two S-CH_3 signals derived from both isomers become closer when pH increases and the difference decreases from 1.8 to 1.2 ppm, due mostly to faster exchange on sulfur atoms at higher pH. Similar

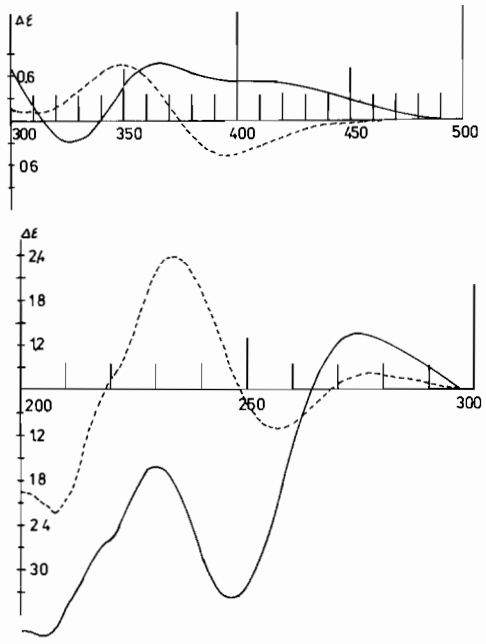


Fig. 5. CD spectra of PdSMC complex at pH 1.3 (dotted line) and 6.7 (solid line).

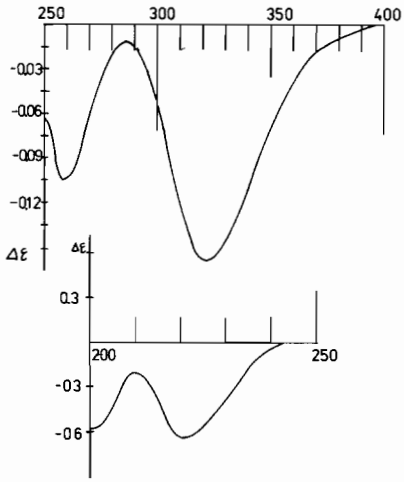


Fig. 6. CD spectra of Pd Gly-SMC complex at pH 6–12.

variations (though slightly smaller) are observed also for C_α carbon resonances (Table III).

The considerable differences between C_β carbon signals observed in the whole pH range for both isomers (3.2 ppm) seem to support the conclusion reached from ^1H NMR spectra that the SMC chelate ring may be present in at least two different conformations *e.g.* λ and δ (see above).

The comparison of the NMR data obtained for PdSMC complex [1, 2, 10] with those obtained in this work clearly shows the important influence of vicinal amino acid (even so simple as glycine) on conformation of coordinated SMC residue. In PdGly-SMC complexes, glycine residue also influences the population ratio of two diastereoisomers which varies from 2·1 in PdSMC to 1.2:1 in PdGly-SMC.

In CD spectra of the systems studied one can distinguish two regions: 600–300 nm and 300–200 nm.

Spectral Region 600–300 nm

In this range of wavelengths, the complex displays Cotton effects due to d–d transition within a metal ion [21–25]. In the CD spectrum of PdSMC complexes, one observes at pH < 2 two extrema at 395 nm ($\Delta\epsilon$ = –0.48,A) and 350 nm ($\Delta\epsilon$ = +0.76,E), and at pH 5–7 three Cotton effects at 400 nm ($\Delta\epsilon$ = +0.52), 365 nm ($\Delta\epsilon$ = +0.76) and 327 nm ($\Delta\epsilon$ = –0.27) (Fig. 5). The latter two bands could derive from the splitting of E transitions due to D_{4h} symmetry lowering in the PdSMC complex in the higher pH range. The absorption spectra exhibit only one d–d band, at 380 nm (ϵ = 860 M^{-1} cm^{-1}), in the pH range 1.5–7.0.

In the PdGly-SMC complex, the CD spectrum in d–d region is simpler and in the whole pH range one observed a negative Cotton effect at 340 nm ($\Delta\epsilon$ = –0.12; pH < 6) or 324 nm ($\Delta\epsilon$ = –0.16, pH > 7) (Fig. 6). Whatever the pH one observes a considerable broadening due to the overlapping of A and E d–d transitions. The increase of pH shifts the CD band but does not change the value of $\Delta\epsilon$. The shifting of the d–d band with the pH increase is also observed in the absorption spectra from 335 nm (ϵ = 1040 M^{-1} cm^{-1}, pH < 6) to 312 nm (ϵ = 954 M^{-1} cm^{-1}, pH = 12.0). The d–d transition shift derives from the variation on the fourth coordination site of PdGly-SMC complex occupied by Cl^-, H_2O or OH^- [26, 31].

The CD pattern for the d–d transitions of the PdSMC-Gly complexes is similar to that observed for the low pH PdSMC complex. It consists of two extrema, a negative at about 400 nm and a positive at about 350 nm (Table IV). Increase of pH in the solutions containing Pd(II) and SMC-Gly causes a decrease of both $\Delta\epsilon$ and energy of the negative Cotton effect at 400 nm (A transition) and an increase of $\Delta\epsilon$ and energy of E transition. Thus, the CD spectra of the latter system show that at pH < 4, Pd(II) ion binds SMC residue in SMC-Gly ligand in the same way as it does in the PdSMC complex, *i.e. via* {NS} donors. The d–d band observed at 377 nm (ϵ = 660 M^{-1} cm^{-1}, pH < 4) in absorption spectra seems to support {NS} coordination of this ligand in low pH region. At higher pH this band becomes much broader and is centered at ~360 nm for pH > 6 (ϵ = 900 M^{-1} cm^{-1}). The energy increase of E band

TABLE IV. CD Spectra of Pd(II) Complexes with SMC Containing Ligands.

Compound	pH	λ, nm	Δε	Compound	pH	λ, nm	Δε
Pd(II)SMC	1.34	395	−0.48	Pd(II)SMC-Gly	3.14	395	−0.22
		349	+0.76	1·1		352	+0.67
		277	+0.42			277	+0.7
		256	−1.03			247	−3.2
		236	+3.58			228	−2.7
		210	+3.33			200	+1.2
	6.77	400	+0.52		7.15	408	−0.35
		365	+0.76			348	+1.45
		327	−0.27			295	+0.65
		276	+1.51			256(sh)	−9.1
		246	−5.54			241	−11.0
		220(sh)	−3.94			208	+0.6
		205	−6.67				
				Pd(II) SMC-SMC	1.69	411	+1.1
Pd(II)Gly-SMC	5.35	340	−0.12	1:1		346	−6.2
1:1		269	−0.14			289	+1.82
		232	−0.07			259	−17.2
	12.26	323	−0.16			235	−22.2
		259	−0.11			207	+9.6
		221	−0.64		10.07	410	−0.17
						360	+0.57
						318	−1.81
						261	−14.8
						230	+9.84
						207	−8.0

from 350 to about 335 nm could suggest that the metal ion also coordinates to a nitrogen donor from another SMC-Gly, and its stronger ligand field effect leads to more splitting in the d orbital system [27]. Although the species formed in the latter solutions are difficult to define, it seems that the main difference between Gly-SMC and SMC-Gly ligands could be similar to those found in analogous methionine containing systems [28] (*i.e.* formation of polymeric species). The very broad ^{1}H and ^{13}C NMR spectra at all temperatures, could also suggest the formation of polymeric complexes at higher pH, and their more detailed description seems to be quite difficult with the results obtained in this work.

For the 1:1 PdSMC-SCM system, the CD spectra of low pH (<4) exhibit maxima near 410 nm (A) ($\Delta\epsilon$ = +1–+0.4) and minima near 345 nm (E). Though the Cotton effects are of opposite sign, these spectra resemble those of PdSMC and PdSMC-Gly involving NS coordination of SMC residue. The increase of pH shifts E signal to 320 nm, *i.e.* to the energy found for E transition in PdGly-SMC complex with {NNS} coordination mode. In absorption spectra the d–d transition at pH > 6 shifts to 329 nm and its molar absorbance is considerably higher than that observed for other studied solutions *i.e.* ϵ = 1950 M^{-1} cm^{-1}. It strongly suggests the involvement of two sulfur donors in metal ion coordination. ^{1}H NMR data show that sulfur donors of both SMC residues are involved in metal coordination over the whole pH range, hence it seems very likely that at higher pH each metal ion binds two sulfur and two nitrogen donors. This coordination mode should lead to the formation of polymeric planar complexes.

Spectral Region 300–200 nm

This region seems to be very complicated for the assignment of the CD bands observed in the studied systems. Besides the intra ligand π–π^* and n–π^* transitions in amide chromophore, one observes most likely S → metal charge transfer transitions [23, 24, 34] as well as the transitions induced on sulfur atom by C_α center and/or metal ion coordination, since the Pd(II)–S bond formation creates a new chirality center at sulfur (see *e.g.* [32]).

PdSMC solutions exhibit mostly three CD signals (Table IV, Fig. 5), near 275 (+), 250 (–) and 235 (+) nm, and a group of peaks above 220 nm. The latter signal bands seem to correspond to intraligand amide transitions [11]. The other three signals result from the formation of the Pd(II) complexes with SMC

ligand. It is clear that 275 nm (*i.e.* lowest energy band) corresponds to $\pi S \rightarrow Pd(II)$ charge transfer transition [23, 24, 34]. Even if the origin of the 235 nm band is also the $S \rightarrow Pd(II)$ charge transfer transition from σ orbitals centered on sulfur donor [23, 24], the 250 nm signal could probably be derived from the intraligand transition centered on sulfur atoms. Intrasulfur transition in free Gly-SMC and SMC-SMC is observed very close to 250 nm in their absorption spectra (see above). In absorption spectra of PdSMC complexes the strong band consisting of both $S \rightarrow Pd(II)$ and intrasulfur transitions are observed at ~250 nm and 228 nm ($\epsilon \sim 10000$ M^{-1}, pH = 2.6). It should be mentioned that no such transition was observed in PdAla complex with {NO} coordination set. The lowest energy band in the latter case was centered at 210 nm ($\Delta\epsilon = -2.4$). The assignment of the 275 and 235 nm bands as the CT transitions from π and σS orbitals to Pd(II) metal ions, respectively, agrees well with that proposed recently by Miskowski and Schugar [34] for the copper thioether complexes, if one takes into account the larger splitting of d orbitals in palladium ion.

Much simpler CD spectra are found in 1:1 PdGly-SMC complex solutions (Fig. 6). In the considered region only two additional bands come into sight when metal ion coordinates dipeptide molecule (*i.e.* near 260 (–) and 223 nm (–): Table IV)). The shift of $\pi S \rightarrow Pd(II)$ CT band from 275 (PdSMC) to 260 nm (PdGly-SMC) is caused by stronger ligand field splitting in the latter case ({NNS} as compare to {N,S}).

The 1:1 PdSMC-Gly complex spectra solutions at pH < 4 display three bands which could be assigned to complex molecule, *i.e.* near 275 (+), 245 (–) and 230 nm (–). This spectrum is similar again to that of the PdSMC complex (Table IV), and its assignment could be the same.

The spectra of low pH PdSMC-SMC solutions are similar to those of PdSMC and PdSMC-Gly, though $\Delta\epsilon$ values for corresponding extrema are very different (Table IV). The latter change is caused by the fact that two sulfur donors are present in a ligand molecule. Increase of pH complicates the coordination equilibria but the CD spectrum becomes somewhat simpler. It consists of two bands derived from Pd(II)–S bond formation at 260 (–) and 230 nm (+) (Table IV).

Thus, the metal ion coordination to thioether sulfur leads to the creation of several important transitions in the UV region, which is extremely important in the studies of the biomolecules (including those containing metal ions). For this reason the more detailed description of the spectral features of metal–thioether sulfur bond, especially the relation between the creation of a new chirality center on sulfur and its optical activity, seems to be necessary.

Conclusions

S-methyl-L-cysteine as a residue binds palladium ion by {NS} donor set, as was found for this ligand acting as a simple amino acid. The coordination of thioether sulfur to metal ions leads to creation of a new chirality center on the sulfur atom, which leads to formation of two diastereoisomers observed in complex solutions.

The conformation of SMC in the formed complexes is very different when it acts as a residue in peptide ligand as compared to that found in M-SMC (M-metal ion) complexes. The vicinal N-terminal amino acid (*e.g.* Gly in PdGly-SMC complex) stabilizes considerably the δ conformer of the SMC chelate ring, and also changes the kinetics of the sulfur inversion in the palladium complex. Also, SMC residue influences the conformation features of the chelate ring formed by the vicinal amino acid residue.

The formation of the metal–thioether bond enriches considerably the UV region of the CD spectra which are extremely important in the study of the biomolecules. The coordination of metal ion to thioether sulfur creates a new chirality center on the sulfur atom, which may influence the optical activity of the ligand molecule *e.g.* the CD active transition within sulfur donor. Also charge transfer transitions from π and σ orbitals of sulfur to metal ions may play an important role in the interpretation of the spectral data of the biomolecules containing metal ions. The problem of the CD spectra of the systems with the metal–thioether sulfur bonds is still open, and needs further detailed studies to be solved in a more unambiguous manner.

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References

1 H. Kozłowski, Z. Siatecki, B. Jeżowska-Trzebiatowska and A. Allain, *Inorg. Chim. Acta, 46*, L25 (1980).
2 B. Jeżowska-Trzebiatowska, A. Allain and H. Kozłowski, *Inorg. Nucl Chem. Letters, 15*, 279 (1979).
3 A. Allain, M. Kubiak, B. Jeżowska-Trzebiatowska, H. Kozłowski and T. Glowiak, *Inorg. Chim. Acta, 46B1*, 127 (1980).
4 M. Kubiak, A. Allain, B. Jeżowska-Trzebiatowska, T. Glowiak and H. Kozłowski, *Acta Cryst., B36*, 2246 (1980).

5 T. Isago, K. Igi and J. Hidaka, *Bull. Chem. Soc. Japan, 52,* 407 (1979).
6 W. J. Jackson and A. M. Sargeson, *Inorg. Chem., 17,* 2165 (1978).
7 T. Isago, K. I. Okamoto, M. Ohmasa and J. Hidaka, *Chem. Letters Japan,* 319 (1980).
8 G. J. Gainsford, W. G. Jackson and A. M. Sargeson, *Chem. Comm.,* 802 (1979).
9 G. W. Anderson, J. E. Zimmerman and F. M. Callaham, *J. Am. Chem. Soc., 85,* 3039 (1963).
R. G. Hiskey, L. M. Beacham, V. G. Math, J. N. Smith, E. B. Williams Jr., A. M. Thomas and E. T. Walters, *J. Org. Chem., 36,* 488 (1971).
10 B. Jeżowska-Trzebiatowska, A. Allain and H. Kozłowski, *Bull. Acad. Polon. Sci. Ser. Sci Chi., 25,* 971 (1977).
11 C. Toniolo and G. M. Bonora, *Can. J. Chem., 54,* 70 (1976), and references therein.
12 H. Kozłowski and M. Jezowska, *Chem. Phys. Letters, 47,* 452 (1977).
H. Kozłowski, G. Formicka-Kozłowska and B. Jeżowska-Trzebiatowska, *Org. Magn. Resonance, 10,* 145 (1977).
13 H. Kozłowski, M. Jeżowska and H. Szyszuk, *J. Mol. Struct., 50,* 73 (1978).
14 H. Kozłowski and B. Jeżowska-Trzebiatowska, *J. Mol. Struct., 45,* 159 (1978).
15 H. Kozłowski and B. Jeżowska-Trzebiatowska, *Chem. Phys. Letters, 42,* 246 (1976).
16 C. J. Hawkins and R M. Peachey, *Aust. J. Chem., 29,* 33 (1976)
17 C. J. Hawkins, R. M. Peachey and C. L. Szoredi, *Aust. J Chem., 31,* 973 (1978).
18 C. J. Hawkins and J. A. Palmer, *Aust. J. Chem., 31,* 1689 (1978).
19 L. P. Battaglia, A. B. Corradi, C. G. Palmieri, M. Nardelli and E. Tani, *Acta Cryst., B29,* 762 (1973).
20 L. J. Nicholls and W. A. Freeman, *Acta Cryst., B35,* 2392 (1979).
21 E. W. Wilson Jr., and R. B. Martin, *Inorg. Chem., 9,* 528 (1970).
22 R. B. Martin, in 'Metal Ions in Biological Systems', H. Sigel ed., N. Y Basel, vol. 91, Chap. 4 (1974) and references therein.
23 H. Lam-Thanh, K. Lintner, M. Mannot, F. Piriour and S. Fermandjian, *J Chim. Physique, 75,* 755 (1978).
24 H. Lam-Thanh and S. Fermandjian, *J Chim. Physique, 74,* 361 (1977).
25 L. E. Nance, A. F. Schreiner and H. G. Frye, *Bioinorg Chem., 3,* 135 (1974).
26 M. C. Lim and R. B. Martin, *J Inorg. Nucl. Chem., 38,* 1911 (1976).
27 B. Jeżowska-Trzebiatowska, G. Formicka-Kozłowska and H. Kozłowski, *Bull. Acad Polon Sci , ser. sci chim., 26,* 561 (1978) and references therein.
28 B. Jeżowska-Trzebiatowska, T. Kowalik and H. Kozłowski, *Bull. Acad. Polon Sci., ser. sci. chim., 26,* 223 (1978).
29 R. B. Martin, *J. Phys. Chem., 83,* 2404 (1979).
30 N. Hadjiliadis, V. Theodoron, I. Photaki, R. W. Geller and R. Bau, *Inorg. Chim. Acta* (in press).
31 R. F. Coley and D. S Martin, Jr., *Inorg. Chim. Acta, 7,* 573 (1973).
32 K. Yamanaki, J. Hidaka and Y. Shimura, *Bull. Chem. Soc. Japan, 50,* 2299 (1977).
33 P. de Meester, D. J. Hodgson, H. C. Freeman and C. J. Moore, *Inorg. Chem., 16,* 1494 (1977).
34 V. M. Miskowski, J. A. Thich, R. Solomon and H. J. Schugar, *J. Am. Chem. Soc., 98,* 8344 (1976).