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Metal Complexes of Amino Acids. VII.[1] The *trans*(*N*) and *cis*(*O*)*cis*(*N*) Isomers of the Type $[Co(aa)_2phen]X$ and $[Co(aa)_2dipy]X$

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Fourteen complexes of the type $[Co(aa)_2phen]X$ and $[Co(aa)_2dipy]X$ (where aa is the anion of glycine, β-alanine, L-serine, or L-proline) were newly prepared. Two geometrical isomers (*trans(N)* and *cis*(*O*)*cis*(*N*)) for the glycinato and β-alaninato complexes, four geometrical and/or diastereomeric isomers ($(+)_D$- and $(-)_D$-*trans*(*N*) and -*cis*(*O*)*cis*(*N*)) for the L-serinato complexes, and two diastereomers ($(+)_D$- and $(-)_D$-*trans*(*N*)) for the L-prolinato complex were separated. These complexes were characterized by absorption, circular dichroism spectra, and ^1H and ^{13}C NMR spectra. The absolute configurations of the L-serinato and L-prolinato complexes were assigned as Λ and Δ for the $(+)_D$- and $(-)_D$-isomers, respectively.

In our previous study[2] one of the three possible geometrical isomers for the type $[Co(aa)_2(diimine)]X$ (where aa is the anion of amino acid and diimine is 1,10-phenanthroline or dipyridyl) was separated. It was concluded that this isomer has the *trans*(*N*) (C_2 symmetry) structure with respect to the amino groups. Matsuoka and coworkers succeeded in separating the three geometrical isomers for $[Co(gly)_2en]^+$ and for $[Co\ ox(gly)_2]^-$ complex ions,[3] and the six geometrical and/or diastereomeric isomers for $[Co\ ox(L\text{-}ser)_2]^-$ complex ion[4] by a column chromatographic method. Analogous separations of the six geometrical and/or diastereomeric isomers for the $[Co(L\text{-}aspH)_2en]^+$ complex ion have been performed by Kojima and Shibata.[5]

In the present paper two geometrical isomers of the type $[Co(aa)_2(diimine)]X$ which were newly separated are characterized on the basis of the absorption, ^1H and ^{13}C NMR, and circular dichroism (CD) spectra.

Experimental

Preparation and Separation of Four Isomers of the $[Co(L\text{-}ser)_2\text{-}phen]Br$ *Complex.* Four isomers were obtained by modifying the method reported in the previous paper.[2]

To an aqueous solution containing $CoCl_2\cdot 6H_2O$ (4.8 g, 0.02 mol) and L-serine (4.2 g, 0.04 mol) in 50 ml of water was added PbO_2 (10 g, excess), and the mixture was stirred for about 15 min. To the mixture was added gradually 1,10-phenanthroline (3.9 g, 0.02 mol) with stirring, and the solution was heated at 65 °C for 15 min. The resulting purple solution was allowed to stand at room temperature overnight and filtered. The filtrate was diluted with 100 ml of water and poured into a column containing cation-exchange resin (Dowex 50W×8, 200—400 mesh, K-form, ϕ3.5 cm×60 cm). Purple and pink solutions (neutral complexes) were swept out with water in that order and then the purple solution of the bis(L-serinato)diaquo complex ions was swept out with a 0.025 M aqueous solution of KBr. The brownish-orange ($(+)_D$-*trans*(*N*)), the scarlet ($(-)_D$-*cis*(*O*)*cis*(*N*)), the brownish-orange ($(-)_D$-*trans*(*N*)), and the scarlet ($(+)_D$-*cis*(*O*)*cis*(*N*)) bands were eluted with a 0.1—0.5 M aqueous solution of KBr in that order. Each eluate was concentrated at below 35 °C under reduced pressure, and a large amount of methanol was added to the concentrated solution. Each crude complex was recrystallized by dissolving it in a small amount of warm water, by adding methanol–acetone (1 : 2) mixture to the concentrated solution, and by keeping in a refrigerator overnight.

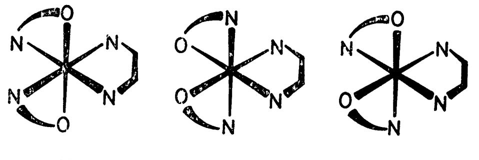
Four isomers ($(+)_D$- and $(-)_D$-*trans*(*N*) and -*cis*(*O*)*cis*(*N*)) of $[Co(L\text{-}ser)_2dipy]Br$ and two geometrical isomers (*trans*(*N*) and *cis*(*O*)*cis*(*N*)) of $[Co(gly)_2phen]Br$, $[Co(\beta\text{-}ala)_2phen]Br$ and $[Co(gly)_2dipy]Br$ were obtained as described above for the $[Co(L\text{-}ser)_2phen]Br$. The *cis*(*O*)*cis*(*N*) isomers have lower solubility in water than the *trans*(*N*) isomers. Only two diastereomers ($(+)_D$- and $(-)_D$-*trans*(*N*)) were separated for the $[Co(L\text{-}pro)_2phen]Br$.

The elemental analyses for the newly prepared complexes are shown in Table 1.

Measurements. The absorption spectra were measured with a Hitachi Model EDS-3T spectrophotometer. The CD data were obtained by using a JASCO Model ORD/UV-5 spectrophotometer. The measurements of the ^1H and ^{13}C NMR spectra were made by a JEOL MH-100 spectrometer (with pulsed Fourier transform/proton noise decoupled mode for the ^{13}C NMR measurements) in D_2O solutions. DSS and cyclohexane were used as an internal standard for ^1H NMR and as an external standard for ^{13}C NMR, respectively. The chemical shifts of the carbon resonances are shown relative to TMS using the relation $\delta_{TMS}=\delta_{cyclohexane}-27.5$.

Results and Discussion

For either $[Co(L\text{-}aa)_2phen]X$ or $[Co(L\text{-}aa)_2dipy]X$, six geometrical and/or diastereomeric isomers (Λ- and Δ-*trans*(*O*) (C_2 symmetry), Λ- and Δ-*trans*(*N*) (C_2 symmetry), and Λ- and Δ-*cis*(*O*)*cis*(*N*) (C_1 symmetry)) are possible, as shown in Fig. 1. In our previous study[2] the *trans*(*N*) isomers for the $[Co(aa)_2\text{-}(diimine)]X$ (where aa is the anion of glycine, L-alanine, L-hydroxyproline, or *allo*-L-hydroxyproline, and diimine is phen or dipy) complexes were separated and characterized. In this study the separations of the three geometrical isomers (six isomers for the L-amino acid) were tried repeatedly by the column chromatographic method, but unfortunately only two geometrical isomers were obtained. This result suggestes that the stereoselectivity of the two amino acidato



trans(*O*) (C_2) *trans*(*N*) (C_2) *cis*(*O*)*cis*(*N*) (C_1)

Fig. 1. Three possible isomers (all Δ) for the $[Co(aa)_2(diimine)]^+$ ion.

ligands for the complexes containing phen or dipy is different from that for the corresponding ethylenediamine and oxalato complexes.[3,4)]

Absorption Spectra. The absorption curves of the two geometrical isomers of the $[Co(gly)_2phen]^+$ and $[Co(\beta\text{-ala})_2phen]^+$ ions are shown in Fig. 2. The new geometrical isomer (isomer eluted late) of the glycinato complex does not show any splitting in the first band as was also found[2)] for the *trans*(*N*) isomer (complex eluted early). The *trans*(*O*) isomer is expected to show large splitting of the bands, as observed for other $trans(O)_2(N)_4$ type complexes.[3,5)] The first band maximum ($\nu = 19610\ \text{cm}^{-1}$, $\log \varepsilon = 2.10$) of the new isomer has higher intensity and occurs at lower energy, as compared with that ($\nu = 20660\ \text{cm}^{-1}$, $\log\varepsilon = 2.02$) of the *trans*(*N*) isomer. The greater dipole strength and greater band width of the first band of the isomer eluted late are consistent with the lower symmetry (C_1) of the *cis*(*O*)*cis*(*N*) isomer in comparison to the *trans*(*N*) isomer. The sharpest bands are expected for the *trans*(*N*) isomer for which the effective field along each axial direction (amine *N*–amine *N* and two imine *N*–*O*) should be most nearly the same. For geometrical isomers one might expect a lower crystal filed strength, indicated by lower energy of the first band, and one might also expect a lower stability. In fact, the new isomer is easily decomposed in the aqueous solution on heating, as compared with the *trans*(*N*) isomer. Therefore, the geometrical structure of the new isomer is concluded to be *cis*(*O*)*cis*(*N*) (C_1 symmetry). This assignment agrees with the results of ^{1}H NMR (*vide infra*).

The geometrical structures of the isomers for the $[Co(\beta\text{-ala})_2phen]X$ (Fig. 2), $[Co(gly)_2dipy]X$ (not shown), $[Co(\text{L-ser})_2phen]X$ (Fig. 3), and $[Co(\text{L-ser})_2dipy]X$ (Fig. 4) are assigned by comparing their first bands with those of the *trans*(*N*) and *cis*(*O*)*cis*(*N*) isomers for the $[Co(gly)_2phen]X$ complex. The structural assignments of these complexes are indicated in Table 1. The absorption spectra of the diastereomeric L-prolinato complexes correspond to that of *trans*(*N*)-$[Co(gly)_2phen]X$ (Fig. 5).

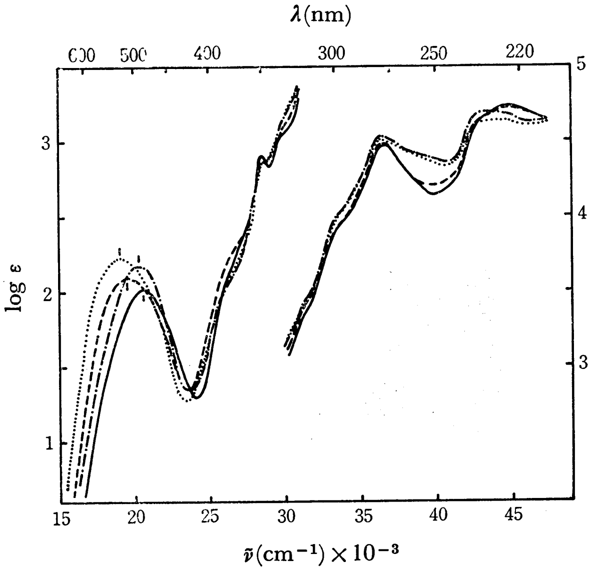


Fig. 2. Absorption curves of (——) *trans*(*N*)- and (----) *cis*(*O*)*cis*(*N*)-$[Co(gly)_2phen]^+$, and (-·-·-) *trans*(*N*) and (······) *cis*(*O*)*cis*(*N*)-$[Co(\beta\text{-ala})_2phen]^+$ ions.

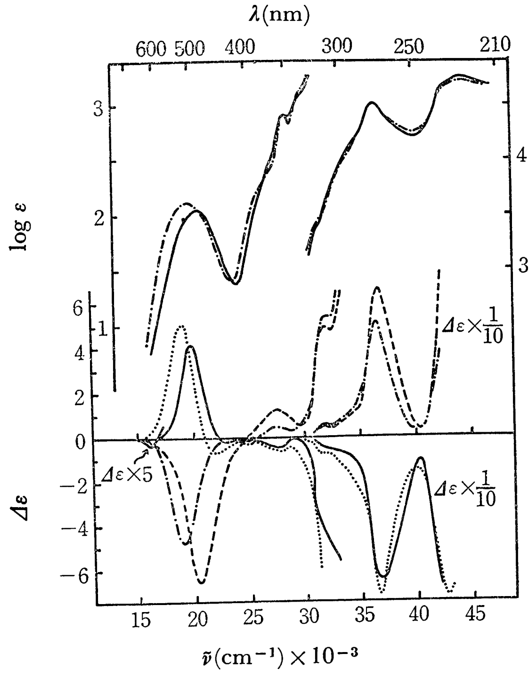


Fig. 3. Absorption and CD curves of (——) $(+)_D$-*trans*(*N*)-, (----) $(-)_D$-*trans*(*N*)-, (······) $(+)_D$-*cis*(*O*)*cis*(*N*)- and (-·-·-) $(-)_D$-*cis*(*O*)*cis*(*N*)-$[Co(\text{L-ser})_2phen]^+$ ions.

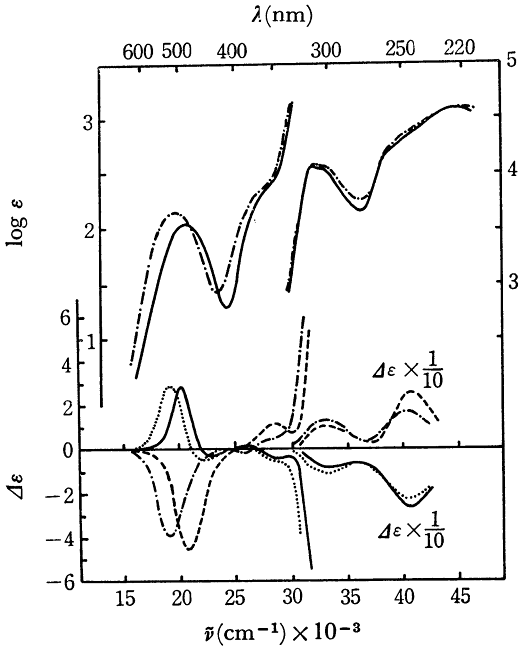


Fig. 4. Absorption and CD curves of (——) $(+)_D$-*trans*(*N*)-, (----) $(-)_D$-*trans*(*N*)-, (······) $(+)_D$-*cis*(*O*)*cis*(*N*)- and (-·-·-) $(-)_D$-*cis*(*O*)*cis*(*N*)-$[Co(\text{L-ser})_2dipy]^+$ ions.

Circular Dichroism (CD). The CD spectra of the $[Co(\text{L-ser})_2phen]^+$, $[Co(\text{L-ser})_2dipy]^+$ and $[Co(\text{L-pro})_2phen]^+$ ions are shown in Figs. 3—5. The CD spectra of the $(+)_D$- and $(-)_D$-*trans*(*N*)-$[Co(\text{L-ser})_2$-

Table 1. Analytical data of [Co(aa)$_2$(diimine)]X type complexes

Complex	$[M]_D$ (°)	C, % Found(Calcd)	H, % Found(Calcd)	N, % Found(Calcd)
cis(*O*)*cis*(*N*)-C_1-[Co(gly)$_2$phen]Br·2H_2O		38.24(38.18)	4.12(4.01)	11.12(11.14)
trans(*N*)-C_2-[Co(*β*-ala)$_2$phen]Br·4H_2O		38.33(38.10)	5.03(4.98)	9.64 (9.88)
cis(*O*)*cis*(*N*)-C_1-[Co(*β*-ala)$_2$phen]Br·2H_2O		40.54(40.68)	4.67(4.56)	10.20(10.55)
$(-)_D$-*trans*(*N*)-C_2-[Co(L-pro)$_2$phen]Br·3.5H_2O	−2110	43.38(43.28)	4.97(5.13)	9.12 (9.18)
$(+)_D$-*trans*(*N*)-C_2-[Co(L-pro)$_2$phen]Br·1.5H_2O	+1930	46.03(46.00)	4.64(4.75)	9.80 (9.76)
$(+)_D$-*trans*(*N*)-C_2-[Co(L-ser)$_2$phen]Br·H_2O	+773	39.81(39.64)	4.22(4.07)	10.17(10.28)
$(-)_D$-*cis*(*O*)*cis*(*N*)-C_1-[Co(L-ser)$_2$phen]Br·H_2O	−5732	39.97(39.64)	4.30(4.07)	10.16(10.28)
$(-)_D$-*trans*(*N*)-C_2-[Co(L-ser)$_2$phen]Br·H_2O	−3370	39.81(39.64)	4.11(4.07)	10.24(10·28)
$(+)_D$-*cis*(*O*)*cis*(*N*)-C_1-[Co(L-ser)$_2$phen]Br·2H_2O	+3300	38.45(38.37)	4.30(4.30)	9.84 (9.94)
cis(*O*)*cis*(*N*)-C_1-[Co(gly)$_2$bipy]Cl		41.97(42.17)	4.11(4.05)	14.02(14.05)
$(+)_D$-*trans*(*N*)-C_2-[Co(L-ser)$_2$bipy]Br·3H_2O	+245	34.52(34.47)	4.71(4.71)	10.05(10.05)
$(-)_D$-*cis*(*O*)*cis*(*N*)-C_1-[Co(L-ser)$_2$bipy]Br·1.5H_2O	−4950	36.19(36.23)	4.57(4.38)	10.63(10.57)
$(-)_D$-*trans*(*N*)-C_2-[Co(L-ser)$_2$dipy]Br·1.5H_2O	−2470	36.33(36.23)	4.49(4.38)	10.21(10.57)
$(+)_D$-*cis*(*O*)*cis*(*N*)-C_1-[Co(L-ser)$_2$bipy]Br·H_2O	+2220	36.69(36.86)	4.18(4.27)	10.66(10.75)

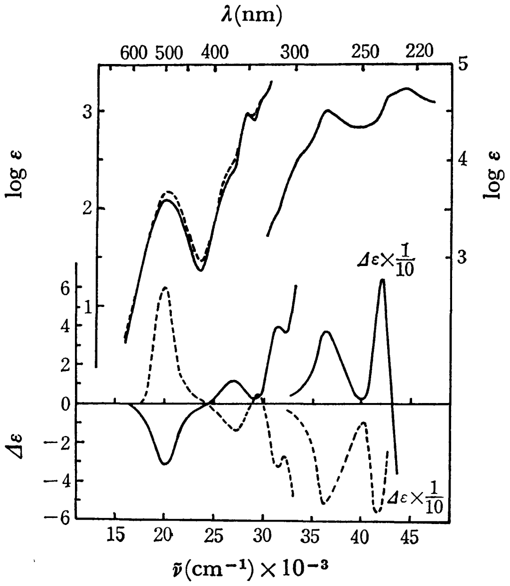


Fig. 5. Absorption and CD curves of (----) $(+)_D$- and (——) $(-)_D$-*trans*(*N*)-[Co(L-pro)$_2$phen]$^+$ ions.

phen]$^+$ ions are quite similar to those of the corresponding [Co(L-ala)$_2$phen]$^+$ ions reported in our previous paper.[2)] The $(+)_D$- and $(-)_D$-*cis*(*O*)*cis*(*N*) isomers show also CD spectra of the same form as those of the corresponding *trans*(*N*) isomers, although the main CD peaks in the first band region shift to lower energy (Figs. 3 and 4). Therefore, the absolute configurations of these complexes can be assigned as *Λ* and *Δ* for the $(+)_D$- and $(-)_D$-*trans*(*N*) and -*cis*(*O*)*cis*(*N*) isomers, from the sign of the main CD band in the first band region.[6)] The same comparisons can be made for the *trans*(*N*)- and *cis*(*O*)*cis*(*N*)-[Co(L-ser)$_2$dipy]$^+$ ions (Fig. 4). The diastereomers of the *trans*(*N*)-[Co(L-pro)$_2$-phen]$^+$ ion show also CD curves quite similar to those of the corresponding L-hydroxyprolinato complex previously reported.[2)] The absolute configurations of these isomers can also be assigned as *Λ* and *Δ* to the $(+)_D$- and $(-)_D$-isomers, respectively. The same assignments of the absolute configuration can also be made from CD spectra in the region of the phen or bipy ligand *π*-*π** transition (ultraviolet).[2,7)] In this case the *Λ*-configuration is assigned to the isomer having an intense negative CD peak in this region (*ca.* 37000 and 33000 cm^{-1} for the phen and bipy complexes, respectively).

^1H and ^{13}C NMR Spectra. The ^1H NMR spectra of two isomers for the [Co(gly)$_2$phen]$^+$ ion are shown in Fig. 6. The methylene proton resonance of the chelated glycinate ion for the isomer eluted early (*trans*(*N*)) shows a typical single AB pattern expected for the C_2 symmetry. On the other hand, the isomer eluted late shows the methylene resonances of two AB patterns in 3.2—4.2 ppm region. This split pattern is attributed to the low symmetry (C_1) and supports the conclusion that this isomer takes the *cis*(*O*)*cis*(*N*) structure, in agreement with the interpretation of the absorption spectra.

The ^{13}C NMR spectroscopy has been applied to

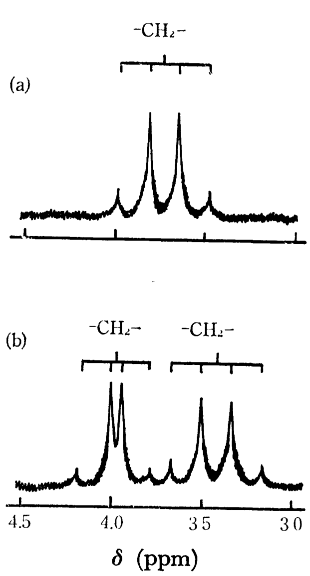


Fig. 6. ^1H NMR spectra of (a) *trans*(*N*)- and (b) *cis*(*O*)*cis*(*N*)-[Co(gly)$_2$phen]$^+$ ions in D_2O solutions.

the determination of the structure for a large number of organic compounds.[8,9] Recently, Fuhr and Rabenstein pointed out that ^{13}C NMR study is more useful than ^{1}H NMR for elucidating the binding of metal ions by peptides and proteins.[10]

The ^{13}C NMR spectra of two isomers of the $[Co(\beta\text{-ala})_2phen]^+$ ion are shown in Fig. 7. The sharp carbon resonances of ethylene and carboxyl groups of the chelated β-alaninate ions, and phenanthroline are observed in the ranges of 33—41, 128—155 and 182—185 ppm, respectively. The resonances of the *cis*(*O*)-*cis*(*N*) isomer show complicated patterns as compared with those of the *trans*(*N*) isomer, as expected from the symmetry. In particular, each signal for a single carbon resonance of the latter isomer (C_2 symmetry) appears as a doublet for the former isomer of lower (C_1) symmetry. This ascertainment of the geometrical structure of two isomers of $[Co(\beta\text{-ala})_2phen]^+$ ion from ^{13}C NMR spectra supports the conclusion which was obtained from their absorption spectra.

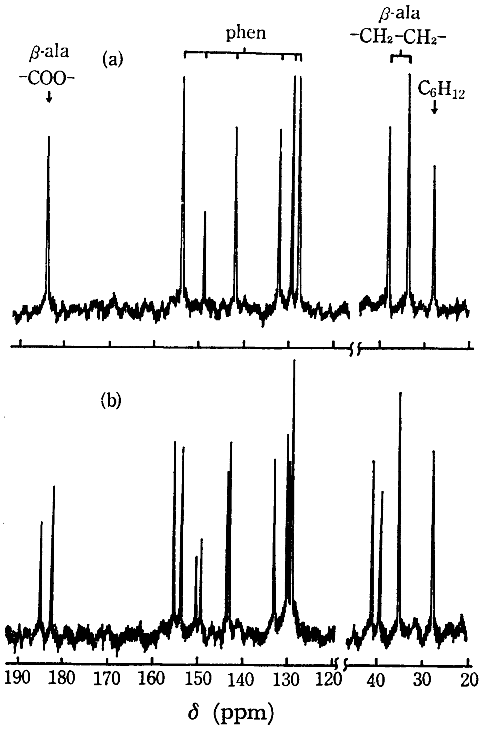


Fig. 7. ^{13}C NMR spectra of (a) *trans*(*N*)- and (b) *cis*(*O*)*cis*(*N*)-$[Co(\beta\text{-ala})_2phen]^+$ ions in D_2O solutions.

Formation Ratios of Isomers. Kojima and Shibata[5] separated six isomers for $[Co(\text{L-aspH})_2en]^+$ and $[Co(\text{L-aspH})_2(\text{l-pn})]^+$ using activated carbon in the preparation. They showed that the yields decrease in the order of Λ-*trans*(*O*)>Δ-*cis*(*O*)*cis*(*N*)>Δ-*trans*(*O*)≃Λ-*trans*(*N*)>Λ-*cis*(*O*)*cis*(*N*)≫Δ-*trans*(*N*) for the former complex and Λ-*trans*(*O*)>Δ-*cis*(*O*)*cis*(*N*)>Δ-*trans*(*O*)>Λ-*trans*(*N*)=Λ-*cis*(*O*)*cis*(*N*)≫Δ-*trans*(*N*) for the latter complex. These results suggest that the *trans*(*N*) isomer is less favored in this type of complex and for these preparative conditions. Similar results were obtained by Matsuoka *et al.* for the type $[Co(aa)_2en]^+$.[3,4]

For the complexes reported here the formation ratios of Λ-, Δ-*trans*(*N*), Δ- and Λ-*cis*(*O*)*cis*(*N*) isomers were 5.1 : 2.3 : 1.6 : 1.0 for $[Co(\text{L-ser})_2phen]^+$ ion, and 9.4 : 4.1 : 2.1 : 1.0 for $[Co(\text{L-ser})_2bipy]^+$ ion. On the other hand, the formation ratios of *trans*(*N*) and *cis*(*O*)*cis*(*N*) isomers were 2.6 : 1.0 for $[Co(gly)_2phen]^+$ and 4.4 : 1.0 for $[Co(gly)_2bipy]^+$, and these ratios also agree with those of the L-serinato complexes (2.8 : 1.0 for phen and 4.3 : 1.0 for bipy). From the preparation using activated carbon, however, only one geometrical isomer, *trans*(*N*) was identified. These results suggest that the *trans*(*N*) isomer in the phen and bipy complexes is more easily formed and more stable in aqueous solution than the *cis*(*O*)*cis*(*N*) and *trans*(*O*) isomers.

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References

1) Part VI of this series: T. Yasui, H. Kawaguchi, Z. Kanda, and T. Ama, This Bulletin, **47**, 2393 (1974).

2) T. Yasui and B. E. Douglas, *Inorg. Chem.*, **10**, 97 (1971).

3) N. Matsuoka, J. Hidaka, and Y. Shimura, This Bulletin, **40**, 1868 (1967).

4) N. Matsuoka, J. Hidaka, and Y. Shimura, *Inorg. Chem.*, **9**, 719 (1970).

5) Y. Kojima and M. Shibata, *ibid.*, **12**, 1009 (1973).

6) A. J. McCaffery and S. F. Mason, *Mol. Phys.*, **6**, 359 (1963); *J. Chem. Soc.*, **1965**, 5094.

7) J. Hidaka and B. E. Douglas, *Inorg. Chem.*, **3**, 1180 (1964).

8) G. C. Levy and G. L. Nelson, "Carbon-13 Nuclear Magnetic Resonance for Organic Chemists," Wiley-Interscience, New York (1972).

9) L–R. F. Johnson and W. C. Jankowski, "Carbon-13 NMR Spectra," Wiley-Interscience, New York (1972).

10) B. J. Fuhr and D. L. Rabenstein, *J. Amer. Chem. Soc.*, **95**, 6944 (1973).