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Preparation and Characterization of *uns-cis*-Trimethylenediamine-*N*,*N'*-diacetato Cobalt(III) Complexes with Several L-Amino Acids

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Five *uns-cis-mer* and two *uns-cis-fac* complexes of (trimethylenediamine-*N*,*N'*-diacetato)(L-amino carboxylato)cobalt(III) were prepared, where L-amino carboxylate denotes L-alaninate, L-valinate, L-prolinate, L-hydrogen aspartate, or L-hydrogen glutamate ion. The complexes were separated into the fourteen isomers, Δ-, Λ-*uns-cis-mer* for the L-alaninato, L-valinato, and L-prolinato complexes, and Δ-, Λ-*uns-cis-mer* and Δ-, Λ-*uns-cis-fac* for the L-hydrogen aspartato and L-hydrogen glutamato complexes. They were characterized by their proton magnetic resonance, absorption and circular dichroism spectra. Each of the *uns-cis-mer* and *uns-cis-fac* isomers showed the characteristic CD behavior in the second absorption band region. The Λ-*uns-cis-mer* and Δ-*uns-cis-fac* isomers of the L-aspartato and L-glutamato complexes were stereoselectively formed, the formation ratios of the isomers being estimated spectrophotometrically.

Cobalt(III) complexes with the trimethylenediamine-*N*,*N'*-diacetate ion (tmdda) have been investigated in the past few years.[1,2] The trimethylenediamine-*N*,*N'*-diacetate ion is an O–N–N–O type ligand and similar to the ethylenediamine-*N*,*N'*-diacetate ion (edda) except that the former has a longer diamine moiety. The tmdda complexes were obtained only in *uns-cis* geometry except the ethylenediamine complex[3] while the edda complexes have been isolated in both geometries, *uns-cis* and *s-cis*.[4–16] In these circumstances, a synthetic work of the complexes containing tmdda, which forms a six-membered diamine backbone, and an L-amino carboxylate ion is significant for the stereoselective formation of the complexes[17] and CD behavior in the d-d transition band region.[18,19]

In the present study, the *uns-cis*-tmdda-Co(III) complexes containing the L-aspartate, L-glutamate, L-prolinate, L-valinate, or L-alaninate ion in the remaining two coordination sites were prepared and their isomers, Δ-, Λ-*uns-cis-mer* and Δ-, Λ-*uns-cis-fac* types for L-aspartato and L-glutamato complexes and Δ-, Λ-*uns-cis-mer* types for L-alaninato, L-valinato and L-prolinato complexes were chromatographically separated. The stereoselectivity of the complex with the L-aspartate or L-glutamate ion is discussed on the basis of the formation ratios of their isomers. Absorption and proton magnetic resonance spectra of the complexes are discussed in relation to their structures. The configurational CD contribution of the isomers was separated from the vicinal CD contribution due to the optically active ligand and the CD spectra are discussed in relation to their configurations.

Experimental

Preparation and Separation of Isomers of uns-cis-*(Trimethylenediamine*-N,N'-*diacetato) (L-hydrogen aspartato)cobalt(III), [Co(tmdda)(L-aspH)].* A solution containing 1.00 g (3.05×10^{-3} mol) of hydrogen dichloro(trimethylenediamine-*N*,*N'*-diacetato)cobaltate(III) hemihydrate,[1] H[Co(tmdda)Cl_2]$\cdot 0.5H_2O$ in 50 cm^3 of water was heated at *ca.* 65 °C for 20 min. The color of the solution turned from green to blue and finally violet. To the solution was added a solution containing 0.50 g (3.79×10^{-3} mol) of L-aspartic acid in 100 cm^3 of water. The pH of the solution was adjusted to 8.0 by addition of 1 mol dm^{-3} NaOH aqueous solution. After 0.5 g of activated charcoal had been added to the solution, the mixture was mechanically stirred at *ca.* 65 °C for 20 min. The charcoal and insoluble material were removed by filtration and washed with hot water until the washings became colorless. The combined filtrate and washings were concentrated to *ca.* 50 cm^3 with a rotary evaporator. The resulting violet solution was poured into a column (50 mm × 450 mm) containing anion-exchange resin (Dowex 1-X8, 200—400 mesh, CH_3COO^- form). The adsorbed band was separated into three bands (violet, violet, and red in the order of elution) by elution with *ca.* 0.05 mol dm^{-3} CH_3COOK solution. From their absorption and CD spectra, it was found that the first and second violet bands consist of Λ- and Δ-*mer*-[Co(tmdda)(L-asp)]$^-$, respectively, and the third band consists of Δ-*fac*-[Co(tmdda)(L-asp)]$^-$. The yield of each of the three isomers being very small, the chromatographic separation was repeated several times in order to store up the same eluates.

Each of the stored eluates was concentrated to a small volume with a rotary evaporator and the precipitated CH_3COOK was removed by filtration. The filtrate was then poured into a column (30 mm × 530 mm) packed with Sephadex G-10 resin and the adsorbed band was eluted with water in order to remove the residual CH_3COOK in the filtrate. The eluate was passed through a column (30 mm × 100 mm) containing cation-exchange resin (Dowex 50W-X8, 200—400 mesh, H^+ form). The passed solution was concentrated and kept in a refrigerator for two or three days after the addition of ethanol and ether. The resulting crystals were collected, washed with ethanol and then ether and dried in the air. The crystals were recrystallized from an ethanol–water (5:1) mixture by addition of acetone. Potassium salt of the Λ-*uns-cis-mer* isomer for the PMR measurement was isolated before being passed through a column containing cation-exchange resin.

The fourth isomer, Λ-*uns-cis-fac*-[Co(tmdda)(L-aspH)], not formed by the above procedure, was obtained in the following way. A reaction solution was prepared from a solution containing 2.6 g (7.93×10^{-3} mol) of H[Co(tmdda)Cl_2]$\cdot 0.5H_2O$ in 100 cm^3 of water and a solution containing 1.4 g (1.05×10^{-2} mol) of L-aspartic acid in 150 cm^3 of water. The solution was mechanically stirred at *ca.* 65 °C for 60 min, no activated charcoal being used. After a small amount of insoluble material had been filtered off, the filtrate was concentrated to *ca.* 50 cm^3 with an evaporator. The solution was chromatographed on an anion-exchange column (Dowex 1-X8, 200—400 mesh, CH_3COO^- form). A large amount

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TABLE 1. ELEMENTAL ANALYSES FOR *uns-cis*-[Co(tmdda)(L-am)] COMPLEXES

Complex	Found (%)			Calcd (%)		
	C	H	N	C	H	N
Λ-mer-[Co(tmdda)(L-aspH)]·2.5H_2O	30.95	5.48	9.88	31.15	5.47	9.90
Δ-mer-[Co(tmdda)(L-aspH)]·H_2O·0.5C_2H_5OH	34.26	5.42	10.12	34.29	5.52	10.00
Δ-fac-[Co(tmdda)(L-aspH)·3H_2O	30.90	5.58	9.84	30.49	5.58	9.70
Λ-mer-[Co(tmdda)(L-gluH)]·H_2O	34.89	5.46	9.99	35.05	5.39	10.22
Δ-mer-[Co(tmdda)(L-gluH)]·2H_2O	33.59	5.63	9.59	33.58	5.64	9.79
Λ-fac-[Co(tmdda)(L-gluH)]·1.5H_2O	34.06	5.47	9.99	34.30	5.52	10.00
Δ-fac-[Co(tmdda)(L-gluH)]·1.5H_2O·0.5C_2H_5OH	34.91	5.93	9.18	35.22	5.92	9.48
Λ-mer-[Co(tmdda)(L-ala)]	32.30	6.02	11.38	32.35	5.97	11.32
Δ-mer-[Co(tmdda)(L-ala)]·2H_2O	35.95	5.53	12.30	35.83	5.42	12.54
Λ-mer-[Co(tmdda)(L-val)]	39.53	6.15	11.45	39.67	6.12	11.57
Δ-mer-[Co(tmdda)(L-val)]·2H_2O	36.31	6.74	10.22	36.10	6.56	10.52
Λ-mer-[Co(tmdda)(L-pro)]·0.5H_2O·0.5C_2H_5OH	40.10	5.92	10.78	39.69	6.16	10.69
Δ-mer-[Co(tmdda)(L-pro)]·2.5H_2O	35.06	5.91	10.35	35.47	6.21	10.34

of complex unreacted, presumably [Co(tmdda)$(OH_2)_2$]$^+$, was swept out with water. The adsorbed band was separated into four bands, violet, violet, red, and red, by elution with *ca.* 0.05 mol dm^{-3} CH_3COOK solution. It was confirmed from the absorption and CD spectra that the red band eluted last contains *Λ-uns-cis-fac*-[Co(tmdda)(L-asp)]$^-$. The last eluate was desalted and passed through a cation-exchange column (Dowex 50W-X8, 200—400 mesh, H$^+$ form). After the eluate had been concentrated, the solution was applied to the Sephadex G-10 column once again. This eluate was used for the absorption and CD measurements. The concentration of the eluate was determined with a Hitachi 208 atomic absorption spectrophotometer.

Preparation and Separation of Isomers of uns-cis-*(Trimethylenediamine-*N,N′*-diacetato)(*L*-hydrogen glutamato)cobalt(III), [Co(tmdda)(*L*-gluH)].* The complex was prepared and separated into four isomers in the same procedure as that for [Co(tmdda)(L-aspH)] using L-glutamic acid instead of L-aspartic acid. The reaction solution was concentrated and chromatographed on an anion-exchange column. The adsorbed band was separated into four bands (violet, violet, red, and red in the order of elution). From their absorption and CD spectra, the first and second violet bands turned out to be *Λ*- and *Δ-mer* isomers, respectively, and the third and fourth red bands *Δ*- and *Λ-fac* isomers, respectively. The four isomers have been isolated in the same procedure as that for L-aspartato complex. Since the yield of each isomer was very small, the isomers were treated in the same way as in the case of [Co(tmdda)(L-aspH)].

Preparation and Separation of Isomers of uns-cis-*(Trimethylenediamine-*N,N′*-diacetato)(*L*-prolinato)cobalt(III), [Co(tmdda)(*L*-pro)].* The complex was prepared in the same way as that for [Co(tmdda)(L-aspH)] using 0.05 g (1.52 × 10^{-3} mol) of H[Co(tmdda)Cl_2]·0.5H_2O[1] and 0.22 g (1.89 × 10^{-3} mol) of L-proline. The separation of the diastereomers was carried out by use of a column (QAE-Sephadex A-25, Cl$^-$ form). The adsorbed band was progressively separated into three bands by elution with water. It was shown, from the absorption and CD spectra, that the first and second violet bands contain *Λ-mer* and *Δ-mer* isomers, respectively. A trace amount of the third red band was confirmed to be *fac* isomers. The two *mer* isomers have been isolated as follows.

Λ-uns-cis-mer-*[Co(tmdda)(*L*-pro)]*: The first eluate was concentrated to a small volume with a rotary evaporator and the violet complex was deposited by adding ethanol to the concentrated solution. The complex was recrystallized from an ethanol–water (3:1) mixture by adding acetone. Yield: 0.06 g.

Δ-uns-cis-mer-*[Co(tmdda)(*L*-pro)]·2.5H_2O*: The second eluate was concentrated and the violet crystals were deposited by adding ethanol and acetone to the solution. The crystals were recrystallized from an ethanol-water mixture and dried in a desiccator. Yield: 0.33 g.

Preparation and Separation of Isomers of uns-cis-*(Trimethylenediamine-*N,N′*-diacetato)(*L*-valinato)cobalt(III), [Co(tmdda)(*L*-val)].* The complex was prepared in the same way as that for [Co(tmdda)(L-aspH)] using 2.6 g (7.93 × 10^{-3} mol) of H[Co(tmdda)Cl_2]·0.5H_2O[1] and 1.2 g (1.00 × 10^{-2} mol) of L-valine. The reacted solution was evaporated to *ca.* 20 cm^3 with a rotary evaporator. The resulting violet solution was chromatographed on a column (30 mm × 850 mm, QAE-Sephadex A-25, Cl$^-$ form). The adsorbed band was separated into two bands. It was confirmed from absorption and CD spectra that the first violet band contains *Δ-mer* and *Λ-mer* isomers, and the second red band *Λ-fac* and *Δ-fac* isomers. The two *mer* isomers were isolated as follows. The first violet eluate was concentrated and the solution was kept at room temperature overnight after the addition of ethanol and ether to the concentrated solution. The purple precipitate (F 1) was separated by filtration and washed with acetone and then ether and dried in the air. Further fractions (F2—7) were obtained from the mother liquor by further addition of ethanol and ether and subsequent cooling. It was found from absorption and CD spectra that F 1, F 5, and F 6 contain both *Δ-mer* and *Λ-mer* isomers, F 2 *Λ-mer* isomer, and F 3, F 4, and F 7 *Δ-mer* isomer. Yield: 0.25 g for *Λ-mer* isomer, 1.11 g for *Δ-mer* isomer. The *Λ-mer* isomer is less soluble in water or ethanol than the *Δ-mer* isomer. The *Δ-uns-cis-mer* isomer was recrystallized from an ethanol–water (10:1) mixture and *Λ-uns-cis-mer* isomer from an ethanol–water (5:2) mixture by adding a small amount of acetone. The CD intensities of the isomers were unchanged by repeated recrystallization.

Preparation and Separation of Isomers of uns-cis-*(Trimethylenediamine-*N,N′*-diacetato)(*L*-alaninato)cobalt(III), [Co(tmdda)(*L*-ala)].* The complex was prepared by the same procedure as that for the L-valinato complex using 0.89 g (1.00 × 10^{-2} mol) of L-alanine in 100 cm^3 of water. Two *mer* isomers were isolated as follows. Separation of the *mer* isomers from a trace amount of *fac* isomers was carried out using a QAE-Sephadex column. The first eluate containing *Λ-mer* and *Δ-mer* isomers was concentrated and the solution was kept at room temperature overnight, after the addition of ethanol and ether. The purple precipitate (F 1) was separated by filtration and washed with ethanol and then ether. F 2 and F 3 were obtained from the mother liquor by further addition of ethanol and ether and subsequent cooling. It was found from absorption and CD spectra that F 1 contains *Λ-mer* isomer, F 2 *Δ-mer* isomer, and F 3 both *Δ-mer* and *Λ-mer* isomers. Yield: 0.60 g for *Δ-mer* isomer, 0.60 g for *Λ-mer* isomer. Recrystallization was carried out twice for the *Δ-mer* isomer and three times for the *Λ-mer* isomer, giving no change in CD intensity from a mixture of ethanol and water by adding a small amount of acetone.

Measurements. Electronic absorption spectra were recorded with a JASCO UVIDEC-1 spectrophotometer and CD spectra with a JASCO J-20 spectropolarimeter. PMR spectra were recorded on a JEOL JNM-MH-100 NMR spectrometer at probe temperature in D_2O as solvent. Sodium 2,2-dimethyl-2-silapentane-5-sulfonate (DSS) was used as an internal reference. For determination of the concentration of *Λ-uns-cis-fac*-[Co(tmdda)(L-aspH)] aqueous solution, a Hitachi 208 atomic absorption spectrophotometer was used. The formation ratios for the L-aspartato and L-glutamato complexes were evaluated on the basis of the absorption measurements of the bands separated chromatographically.

Results and Discussion

Structural Assignments for Isomers of [Co(tmdda)(L-am)]. Three geometrical isomers, *uns-cis-mer*, *uns-cis-fac*, and *s-cis*, are possible for the [Co(tmdda)(L-am)] type complex as shown in Fig. 1. Only the *uns-cis* isomers were obtained for the $[Co(tmdda)(N\text{–}N)]^+$ and $[Co(tmdda)(O\text{–}O)]^-$ type complexes except for the ethylenediamine complex in which the *s-cis* isomer was obtained as a minor product.[1-3] It is presumed that the *uns-cis* isomers would be dominantly formed in the present series unless there is any special interaction between the L-amino carboxylate ion and tmdda.

The CD and absorption spectra of the complexes obtained are shown in Figs. 2—6. Of the *uns-cis-mer*, *uns-cis-fac*, and *s-cis* isomers of [Co(tmdda)(L-am)] complex, the *s-cis* isomer should take only *mer* configuration with respect to the coordination atoms because of the regulated coordination of tmdda (Fig. 1). The *mer* and *fac* isomers can be easily assigned from their d-d electronic absorption spectra; the holohedrized symmetry[20] of the *fac* isomer is cubic, whereas that of the *mer* isomer is rhombic. The former can be expected to show a sharp first absorption band and the latter a broad one[19] (Figs. 2—6). The two *mer* isomers, the *s-cis* and the *uns-cis*, can not be distinguish-

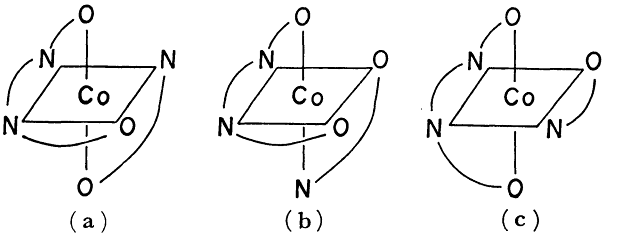

Fig. 1. Three geometrical isomers of [Co(O-N-N-O)-(L-am)] type complexes, (a) *uns-cis-mer*, (b) *uns-cis-fac*, and (c) *s-cis*.

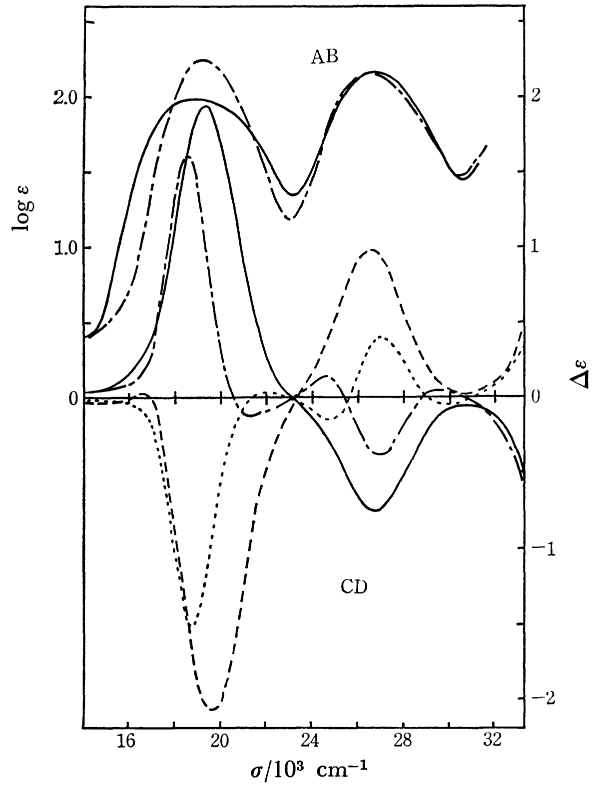

Fig. 2. Absorption and CD spectra for the isomers of *uns-cis*-[Co(tmdda)(L-aspH)], *Λ-mer* (——), *Δ-mer* (----), *Λ-fac* (———), and *Δ-fac* (······).

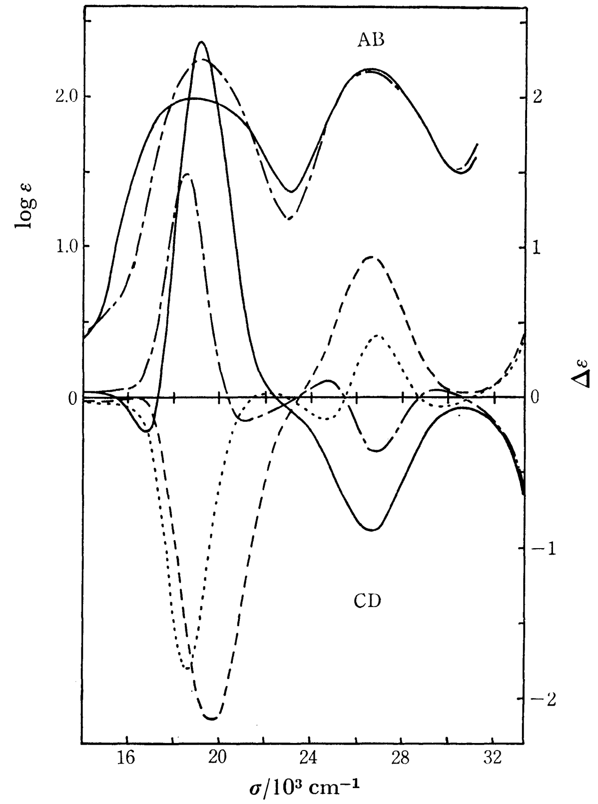

Fig. 3. Absorption and CD spectra for the isomers of *uns-cis*-[Co(tmdda)(L-gluH)], *Λ-mer* (——), *Δ-mer* (----), *Λ-fac* (———), and *Δ-fac* (······).

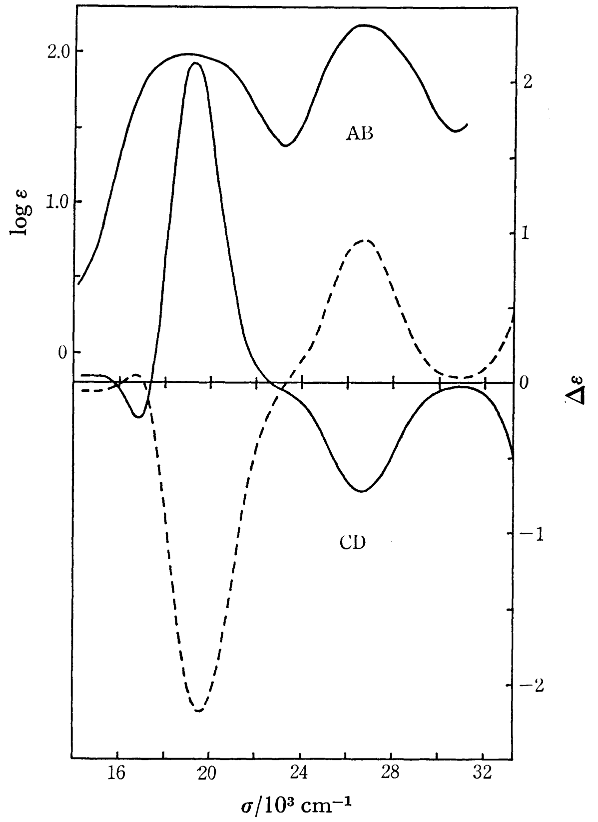

Fig. 4. Absorption and CD spectra for the isomers of *uns-cis*-[Co(tmdda)(L-ala)], *Λ-mer* (——) and *Δ-mer* (----).

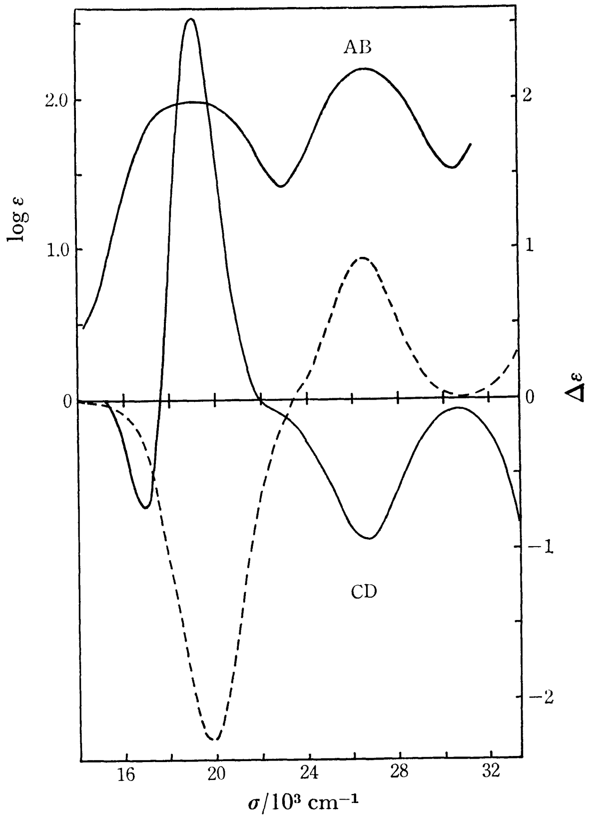

Fig. 5. Absorption and CD spectra for the isomers of *uns-cis*-[Co(tmdda)(L-val)], *Λ-mer* (——) and *Δ-mer* (----).

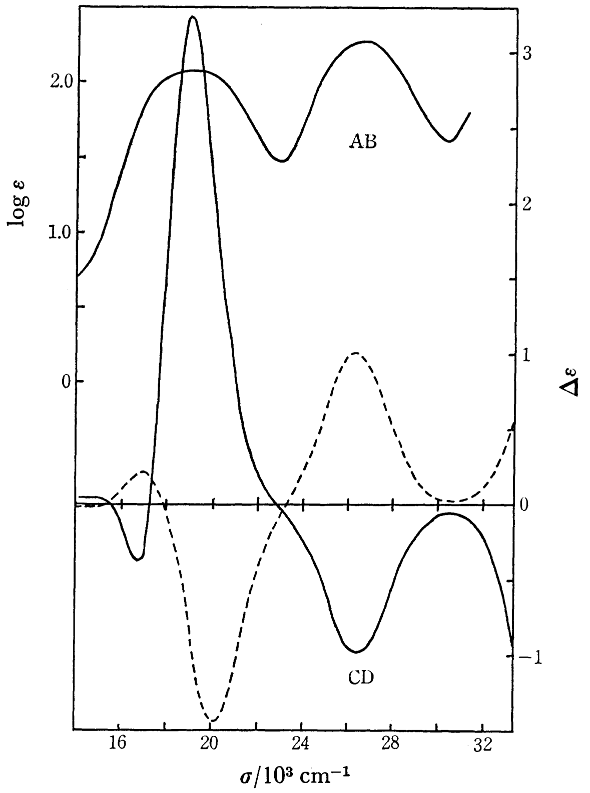

Fig. 6. Absorption and CD spectra for the isomers of *uns-cis*-[Co(tmdda) (L-pro)], *Λ-mer* (——) and *Δ-mer* (----).

ed from the patterns of their first absorption bands. Therefore, each was investigated on the basis of their PMR spectra.

The geminal proton coupling constants (J_{AB}) for (amino carboxylato)cobalt(III) complexes are classified into two groups, those in the vicinity of 16 Hz for in-plane (G) rings and those of 18 Hz for out-of-plane (R) rings.[27] This was also investigated for the *s-cis* and *uns-cis* isomers of edda Co(III) complexes.[9,11,16] Coleman *et al.*[9] and Kuroda[11] reported that *s-cis*-[Co(edda)A$_2$] complex shows only one AB pattern (J_{AB}=*ca.* 18 Hz) due to the R rings, and *s-cis*-[Co(edda)AB] complex two AB patterns (J_{AB}=*ca.* 18 Hz) due to two different unidentate ligands, A and B, in contrast to which the *uns-cis* isomers of [Co(edda)A$_2$] show a single intense peak due to the G ring protons superimposed on one AB pattern of the R ring protons. The singlet was considered to be an extreme case of an AB pattern in which the environments of the two protons are very similar.[9] A similar spectral behavior was also observed for the *uns-cis* isomer of [Co(tmdda)(NH$_3$)$_2$]Cl.[3] PMR data we obtained for tmdda Co(III) complexes are given in Table 4. All the *mer* isomers show two four-line AB patterns with J_{AB}, 16.0—16.5 Hz and 18.0—18.5 Hz for the glycinate protons. As an example, the spectrum of *mer*-K[Co(tmdda)(L-asp)] is shown (Fig. 7a). The resonance line with J_{AB}=*ca.* 18 Hz is assigned to the R ring protons and that with J_{AB}=*ca.* 16 Hz to the G ring protons. Thus it is concluded that the *mer* isomers obtained are all *uns-cis* one (Table 4). For the *fac*

TABLE 2. ABSORPTION DATA OF *uns-cis*-[Co(tmdda)(L-am)] COMPLEXES

Complex	First band		Second band	
Λ-*mer*-[Co(tmdda)(L-aspH)]·$2.5H_2O$	18.69	(1.99)	26.67	(2.19)
Δ-*mer*-[Co(tmdda)(L-aspH)]·H_2O·$0.5C_2H_5OH$	18.69	(2.00)	26.53	(2.19)
Λ-*fac*-[Co(tmdda)(L-aspH)]	19.08	(2.31)	26.46	(2.23)
Δ-*fac*-[Co(tmdda)(L-aspH)]·$3H_2O$	19.19	(2.25)	26.53	(2.15)
Λ-*mer*-[Co(tmdda)(L-gluH)]·H_2O	18.80	(1.99)	26.60	(2.20)
Δ-*mer*-[Co(tmdda)(L-gluH)]·$2H_2O$	18.83	(2.01)	26.60	(2.20)
Λ-*fac*-[Co(tmdda)(L-gluH)]·$1.5H_2O$	19.16	(2.25)	26.39	(2.17)
Δ-*fac*-[Co(tmdda)(L-gluH)]·$1.5H_2O$·$0.5C_2H_5OH$	19.16	(2.25)	26.39	(2.17)
Λ-*mer*-[Co(tmdda)(L-ala)]	18.94	(1.98)	26.67	(2.18)
Δ-*mer*-[Co(tmdda)(L-ala)]·$2H_2O$	18.80	(2.00)	26.60	(2.17)
Λ-*mer*-[Co(tmdda)(L-val)]	18.90	(1.99)	26.60	(2.20)
Δ-*mer*-[Co(tmdda)(L-val)]·$2H_2O$	18.73	(2.01)	26.60	(2.19)
Λ-*mer*-[Co(tmdda)(L-pro)·$0.5H_2O$·$0.5C_2H_5OH$	19.08	(2.08)	26.39	(2.29)
Δ-*mer*-[Co(tmdda)(L-pro)]·$2.5H_2O$	18.66	(2.03)	26.32	(2.20)

Wave numbers and log ε values (in parentheses) are given in 10^3 cm^{-1} and mol^{-1} dm^3 cm^{-1}, respectively.

TABLE 3. OBSERVED CD DATA OF *uns-cis*-[Co(tmdda)(L-am)] COMPLEXES

Complex	First band region		Second band region	
Λ-*mer*-[Co(tmdda)(L-aspH)]·$2.5H_2O$	19.34	(+1.95)	26.81	(−0.76)
Δ-*mer*-[Co(tmdda)(L-aspH)]·H_2O·$0.5C_2H_5OH$	16.67 19.69	(+0.05) (−2.08)	26.60	(+0.99)
Λ-*fac*-[Co(tmdda)(L-aspH)]	18.52 21.28	(+1.61) (−0.13)	24.63 26.88 29.41	(+0.14) (−0.39) (+0.04)
Δ-*fac*-[Co(tmdda)(L-aspH)]·$3H_2O$	18.73 21.93	(−1.52) (+0.03)	24.81 27.10 29.76	(−0.15) (+0.40) (−0.05)
Λ-*mer*-[Co(tmdda)(L-gluH)]·H_2O	16.86 19.19	(−0.23) (+2.37)	26.74	(−0.88)
Δ-*mer*-[Co(tmdda)(L-gluH)]·$2H_2O$	19.69	(−2.13)	26.60	(+0.95)
Λ-*fac*-[Co(tmdda)(L-gluH)]·$1.5H_2O$	18.52 21.05	(+1.50) (−0.15)	24.69 26.88 29.50	(+0.12) (−0.36) (+0.06)
Δ-*fac*-[Co(tmdda)(L-gluH)]·$1.5H_2O$·$0.5C_2H_5OH$	18.62 22.12	(−1.80) (+0.03)	24.69 26.88 29.76	(−0.15) (+0.41) (−0.05)
Λ-*mer*-[Co(tmdda)(L-ala)]	16.89 19.23	(−0.24) (+2.14)	26.88	(−0.73)
Δ-*mer*-[Co(tmdda)(L-ala)]·$2H_2O$	16.72 19.61	(+0.05) (−2.18)	26.67	(+0.96)
Λ-*mer*-[Co(tmdda)(L-val)]	16.89 19.08	(−0.73) (+2.54)	26.74	(−0.94)
Δ-*mer*-[Co(tmdda)(L-val)]·$2H_2O$	19.88	(−2.26)	26.60	(+0.93)
Λ-*mer*-]Co(tmdda)(L-pro)]·$0.5H_2O$·$0.5C_2H_5OH$	16.78 19.01	(−0.39) (+3.24)	26.53	(−0.98)
Δ-*mer*-[Co(tmdda)(L-pro)]·$2.5H_2O$	16.92 20.12	(+0.22) (−1.46)	26.39	(+1.01)

Wave numbers and Δε values (in parentheses) are given in 10^3 cm^{-1} and mol^{-1} dm^3 cm^{-1}, respectively.

isomers of [Co(tmdda)(L-am)] assigned from the first absorption band pattern, one AB pattern (J_{AB}=*ca.* 18 Hz) and a single intense peak superimposed on an AB pattern are observed. The spectrum of *fac*-[Co(tmdda)(L-aspH)] is shown as an example in Fig. 8. The singlet intense peak is assigned to the G ring and the AB pattern to the R ring (Table 4). It is concluded that the *fac* isomers are also *uns-cis*. The information from the PMR spectrum is consistent with the consideration based on the molecular model construction that the *fac* isomer takes an *uns-cis* arrangement (Fig. 1). Another support for the assignments of *uns-cis* isomers is based on the selective deuteration of R ring proton.[9,28–31] H_A (the less sterically hindered proton) of the R ring protons is selectively deuterated in the course of heating of the sample solution. The PMR spectra of *mer*-K[Co(tmdda)(L-asp)] are shown in Fig. 7 (7a is the spectrum of a freshly prepared D_2O solution and 7b the spectrum of the sample solution after being heated in boiling water for 30 min). In

Table 4. Chemical shifts of the glycinate ring methylene protons in *uns-cis*-[Co(tmdda)(L-am)] complexes[a)]

Complex	R ring[b),d)]				G ring[c),d)]			
	H_A		H_B		H_A		H_B	
Λ-*mer*-K[Co(tmdda)(L-asp)]	3.84	3.66	3.38	3.20	3.94	3.78	3.68	3.52
Λ-*mer*-[Co(tmdda)(L-aspH)]	3.82	3.65	3.47	3.29	3.98	3.82	3.72	3.55
Δ-*mer*-[Co(tmdda)(L-aspH)]	3.80	3.63	3.46	3.27	3.96	3.79	3.71	3.55
Δ-*fac*-[Co(tmdda)(L-aspH)]	4.00	3.82	3.49	3.31	3.65			
Λ-*mer*-K[Co(tmdda)(L-glu)]	3.80	3.62	3.41	3.22	3.93	3.77	3.69	3.52
Λ-*mer*-[Co(tmdda)(L-gluH)]	3.81	3.63	3.42	3.24	3.93	3.76	3.69	3.53
Δ-*mer*-[Co(tmdda)(L-gluH)]	3.80	3.62	3.44	3.26	3.97	3.81	3.71	3.54
Λ-*fac*-[Co(tmdda)(L-gluH)]	3.93	3.74	3.43	3.25	3.61			
Λ-*mer*-[Co(tmdda)(L-ala)]	3.81	3.63	3.42	3.24	3.93	3.77	3.70	3.54
Λ-*mer*-[Co(tmdda)(L-ala)]	3.82	3.63	3.43	3.25	3.96	3.79	3.71	3.54
Δ-*mer*-[Co(tmdda)(L-val)]	3.78	3.60	3.48	3.30	3.95	3.78	3.70	3.53
Δ-*mer*-[Co(tmdda)(L-val)]	3.80	3.62	3.43	3.25	3.97	3.80	3.71	3.54
Λ-*mer*-[Co(tmdda)(L-pro)]	3.85	3.67	3.50	3.31	3.92	3.75	3.69	3.52
Δ-*mer*-[Co(tmdda)(L-pro)]	3.85	3.67	3.47	3.28	3.96	3.79	3.70	3.53

a) Values in ppm from DSS. b) J_{AB}=18.0—18.5 Hz. c) J_{AB}=16.0—16.5 Hz. d) Where an AB quartet was observed for the glycinate ring protons, the low field proton has been designated H_A in accordance with nomenclature already devised.[9)]

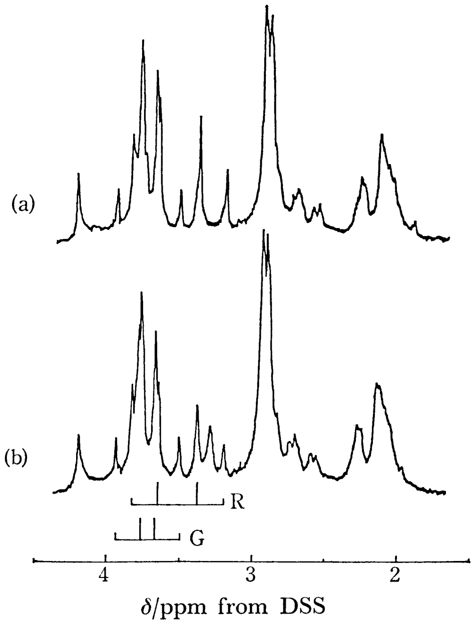

Fig. 7. Proton magnetic resonance spectra of Λ-*uns-cis-mer*-K[Co(tmdda)(L-asp)] in D_2O solution. (a) The spectrum of a freshly prepared D_2O solution. (b) The spectrum of the solution after being heated in boiling water for 30 min.

the spectrum, the AB pattern (J_{AB}=16.0 Hz) due to the G ring protons is observed at 3.94, 3.78, 3.68, and 3.52 ppm, and another AB pattern (J_{AB}=18.0 Hz) due to the R ring protons is observed at 3.84, 3.66, 3.38, and 3.20 ppm. On the other hand, the 7b spectrum shows a new peak at 3.30 ppm, the intensity of the AB pattern due to the R ring protons decreasing drastically. The new peak increases to an integrated value equivalent to one proton, the AB pattern due to the R ring disappearing completely after being heated in boiling water for 2.5 h. The new peak is assigned to the resonance for decoupled H_B. The AB pattern due to the G ring protons (J_{AB}=16.0 Hz) is not deuterated under the same conditions. This indicates that *mer*-K[Co(tmdda)(L-asp)] takes the *uns-cis* configuration. The same behavior is also observed for *mer*-K[Co(tmdda)(L-glu)]. From the results of absorption and PMR measurements, all of the complexes obtained can be assigned to the *uns-cis* configuration.

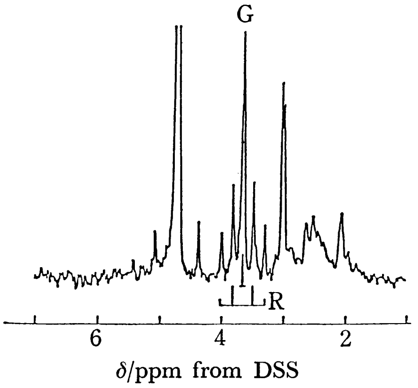

Fig. 8. Proton magnetic resonance spectra of Δ-*uns-cis-fac*-[Co(tmdda)(L-aspH)] in D_2O solution (after heating the sample in boiling water for 30 min).

Stereochemistry of the Isomers. On the basis of the CD spectra in the first absorption band region, the absolute configurations of *uns-cis*-[Co(tmdda)A_2]$^+$ (A_2=$(NH_3)_2$, en, and tn) and *uns-cis*-[Co(edda)A_2]$^+$ were discussed in the same category, though the difference in the backbone diamine ring of the quadridentate ligands gives rise to a slight change in the shape of CD curves.[1)] Thus, the absolute configurations of the isomers are assigned tentatively from the sign of a major CD band in the first absorption band region as shown in Table 3 and Figs. 2—6.

A remarkable CD difference between the *mer* and

Table 5. Calculated configurational CD data of Λ-*uns-cis*-[Co(tmdda)(L-am)] complexes

Complex	First band region		Second band region	
mer-[Co(tmdda)(L-aspH)]	19.53	(+2.00)	26.60	(−0.87)
fac-[Co(tmdda)(L-aspH)]	18.66	(+1.56)	24.75	(+0.15)
	21.65	(−0.07)	27.03	(−0.39)
			29.76	(+0.05)
mer-[Co(tmdda)(L-gluH)]	16.72	(−0.12)	26.74	(−0.91)
	19.31	(+2.21)		
fac-[Co(tmdda)(L-gluH)]	18.52	(+1.65)	24.75	(+0.13)
	21.55	(−0.08)	26.88	(−0.39)
			29.59	(+0.05)
mer-[Co(tmdda)(L-ala)]	16.84	(−0.15)	26.60	(−0.84)
	19.38	(+2.14)		
mer-[Co(tmdda)(L-val)]	16.67	(−0.23)	26.60	(−0.93)
	19.38	(+2.28)		
mer-[Co(tmdda)(L-pro)]	16.67	(−0.30)	26.60	(−1.00)
	19.38	(+2.11)		

Wave numbers and $\Delta\varepsilon$ values (in parentheses) are given in $10^3\ \mathrm{cm}^{-1}$ and $\mathrm{mol}^{-1}\ \mathrm{dm}^3\ \mathrm{cm}^{-1}$, respectively.

Table 6. Formation ratios (percent compositions) of reaction mixture

Complex	Isomer			
	Λ-*mer*	Δ-*mer*	Λ-*fac*	Δ-*fac*
uns-cis-[Co(tmdda)(L-asp)]$^-$	81%	6%	0%	13%
uns-cis-[Co(tmdda)(L-glu)]$^-$	51%	40%	3%	6%

fac isomers appears in the second absorption band region. The *uns-cis-fac*-[Co(tmdda)(L-aspH)] shows three CD bands (+, −, and + from the lower energy side) for the Λ isomer, while the *uns-cis-mer* isomer shows a negative band for the Λ isomer (Fig. 2). The CD difference substantiates the configurational CD curves estimated from the observed CD curves of Λ- and Δ-*uns-cis-fac*-[Co(tmdda)(L-aspH)] and the observed CD curves of Λ- and Δ-*uns-cis-mer*-[Co(tmdda)(L-aspH)] (Table 5). A similar CD behavior in the second absorption band region is also observed for the isomers of *uns-cis*-[Co(tmdda)(L-gluH)] (Table 5). The behavior seems to be a characteristic pattern reflecting the arrangement of ligands. A similar behavior was pointed out for the CD spectra of the C_1-*cis* and C_2-*cis* isomers of $[\mathrm{Co(am)_2ox}]^-$ or $[\mathrm{Co(am)_2en}]^+$.26) However, no CD difference in the second absorption band region is observed for the CD spectra of the *mer* and *fac* isomers of *uns-cis*-[Co(edda)(L-am)]. The CD difference in the present isomers is not due to the difference of the *mer* and *fac* arrangements, but can be attributed to the chelate ring conformations of the backbone diamine of the coordinated tmdda.

It was suggested that the tmdda Co(III) complexes prefer the *uns-cis* configuration to the *s-cis* one and the backbone diamine chelate ring of tmdda has a marked effect on the distribution of geometrical isomers.1) This is also applicable to the present work. Of the *uns-cis-mer* and *uns-cis-fac* configurations, the *uns-cis-mer* isomer was formed dominantly. For the L-alaninato, L-valinato, and L-prolinato complexes, the *uns-cis-mer* isomer was easily formed, while the *uns-cis-fac* isomer was hardly formed. The reason for the *uns-cis-mer* configuration dominancy is unknown at present. In the case of the L-aspartate and L-glutamate ions which have three functional groups, both the *uns-cis-mer* and *uns-cis-fac* isomers were obtained, though the *uns-cis-mer* isomers were also formed dominantly. The formation ratios (percent compositions) of their possible isomers are given in Table 6. A marked stereoselectivity was found for the Λ configuration of *uns-cis-mer*-[Co(tmdda)(L-asp)]$^-$ (Λ-*mer* : Δ-*mer*=81 : 6) and for the Δ configuration of the *uns-cis-fac* isomer (Λ-*fac* : Δ-*fac*=0 : 13). A similar trend was also observed for the isomers of the L-glutamato complex, though it was to a much smaller extent (Table 6). The stereoselectivities might be explained on the basis of the enhanced stabilization of Λ-*uns-cis-mer* and Δ-*uns-cis-fac* isomers caused by the formation of interligand hydrogen-bond in the isomer.17,21–24) In the alkaline condition employed for the preparation of the complexes, the dangling β-carboxylato group of the coordinated L-aspartate ion is deprotonated. As a result, the β-carboxylato group can form a hydrogen-bond with the imino group of tmdda in the case of Λ-*uns-cis-mer* and Δ-*uns-cis-fac* isomers of L-aspartato complexes. The same consideration can be applied to the isomers of L-glutamato complex. The selectivity of L-glutamato complex is lower than that of L-aspartato one (Table 6). It can be presumed that the lower selectivity in comparison to that of L-aspartato complex is due to the longer dangling group of the coordinated L-glutamate ion.21,24)

References

1) K. Igi and B. E. Douglas, *Inorg. Chem.*, **13**, 425 (1974).

2) K. Igi and B. E. Douglas, *Inorg. Chim. Acta*, **10**, 109 (1974).

3) K. D. Gailey, K. Igi, and B. E. Douglas, *Inorg. Chem.*, **14**, 2956 (1975).

4) M. Mori, M. Shibata, E. Kyuno, and F. Maruyama, *Bull. Chem. Soc. Jpn.*, **35**, 75 (1962).

5) J. I. Legg and D. W. Cooke, *Inorg. Chem.*, **4**, 1576 (1965).

6) J. I. Legg, D. W. Cooke, and B. E. Douglas, *Inorg. Chem.*, **6**, 700 (1967).

7) J. I. Legg and B. E. Douglas, *Inorg. Chem.*, **7**, 1452 (1968).

8) C. W. Van Saun and B. E. Douglas, *Inorg. Chem.*, **8**, 115 (1969).

9) P. F. Coleman, J. I. Legg, and J. Steele, *Inorg. Chem.*, **9**, 937 (1970).

10) K. Kuroda and K. Watanabe, *Bull. Chem. Soc. Jpn.*, **44**, 1034 (1971).

11) K. Kuroda, *Bull. Chem. Soc. Jpn.*, **45**, 2176 (1972).

12) W. T. Jordan and B. E. Douglas, *Inorg. Chem.*, **12**, 403 (1973).

13) K. Kuroda, *Chem. Lett.*, **1974**, 17.

14) W. T. Jordan and J. I. Legg, *Inorg. Chem.*, **13**, 955 (1974).

15) L. J. Halloran and J. I. Legg, *Inorg. Chem.*, **13**, 2193 (1974).

16) P. J. Garnett and D. W. Watts, *Inorg. Chim. Acta*, **8**, 293 (1974).

17) K. Kawasaki, J. Yoshii, and M. Shibata, *Bull. Chem. Soc. Jpn.*, **43**, 3819 (1970).

18) C. T. Liu and B. E. Douglas, *Inorg. Chem.*, **3**, 1356 (1964).

19) B. E. Douglas and S. Yamada, *Inorg. Chem.*, **4**, 1561 (1965).

20) C. J. Hawkins, "Absolute Configuration of Metal Complexes," Wiley-Interscience, N. Y. (1971).

21) K. Kawasaki and M. Shibata, *Bull. Chem. Soc. Jpn.*, **45**, 3100 (1972).

22) T. Matsuda, T. Okumoto, and M. Shibata, *Bull. Chem. Soc. Jpn.*, **45**, 802 (1972).

23) T. Matsuda and M. Shibata, *Bull. Chem. Soc. Jpn.*, **46**, 3104 (1973).

24) M. Takeuchi and M. Shibata, *Bull. Chem. Soc. Jpn.*, **47**, 2797 (1974).

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

26) N. Matsuoka, J. Hidaka, and Y. Shimura, *Bull. Chem. Soc. Jpn.*, **48**, 458 (1975).

27) J. L. Sudmeier, A. J. Senzel, and G. L. Blackmer, *Inorg. Chem.*, **10**, 90 (1971).

28) D. H. Williams and D. H. Busch, *J. Am. Chem. Soc.*, **87**, 4644 (1965).

29) J. B. Terrill and C. N. Reilley, *Inorg. Chem.*, **5**, 1988 (1966).

30) J. L. Sudmeier and G. Occupati, *Inorg. Chem.*, **12**, 2524 (1968).

31) G. L. Blackmer and J. L. Sudmeier, *Inorg. Chem.*, **10**, 2019 (1971).