July, 1976] BULLETIN OF THE CHEMICAL SOCIETY OF JAPAN, VOL. 49 (7), 1879—1882 (1976) 1879

# Isomers of *trans*-Dichlorocobalt(III) Complex with (2*S*,10*S*)-2,10-Diamine-4,8-diazaundecane

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(Received March 15, 1976)

A novel complex, *trans*(*R*,*S*)-[$CoCl_2$((2*S*,10*S*)-$Me_2$-2,3,2-tet)]$ClO_4$((2*S*,10*S*)-$Me_2$-2,3,2-tet=(2*S*,10*S*)-4,8-diazaundecane-2,10-diamine) was prepared from the *trans*(*R*,*R*) isomer in basic methanol. The configuration of the *trans*(*R*,*S*) isomer was determined from the PMR and CD evidences. The equilibrium ratio of the *R*,*S* and *R*,*R* isomers in basic methanol was estimated to be 7.6±0.3: 1 ($\Delta G_{298}$=1.20±0.03 kcal/mol), the former being in preference to the latter.

It has been demonstrated that the linear tetramine 3,7-diazanonane-1,9-diamine, $NH_2(CH_2)_2NH(CH_2)_3NH(CH_2)_2NH_2$ (abbreviated as 2,3,2-tet), tends to coordinate to metal ions with the *trans* geometry more easily than the triethylenetetramine.[3-5] The possible three isomers of *trans*-$CoCl_2$(2,3,2-tet)$^+$ arisen from the difference in the configurations of the asymmetric secondary nitrogen atoms *R*,*S*(*meso*), *R*,*R*, and *S*,*S* have been isolated.[5,7,8] Further, the thermodynamic advantage of the *R*,*S* configuration over the racemic forms (*R*,*R* and *S*,*S*) has been suggested, though any detailed evidences have not been reported yet.[9]

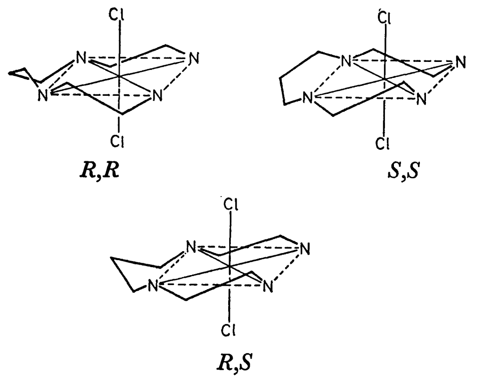

Fig. 1. Possible structures of *trans*-[$CoCl_2$(2,3,2-tet)]$^+$; *R*,*R*, *S*,*S*, and *R*,*S*.

The dominant difference between the *R*,*S* and *R*,*R* (or *S*,*S*) forms consists in the conformation of the central six-membered chelate ring. The chair conformation is adopted in the *R*,*S* form, while the skew-boat conformation in the *R*,*R* and *S*,*S*, as indicated in Fig. 1. The former should be fairly preferred over the latter in a similar manner as in the cyclohexane ring.

Recently, Alexander and coworkers reported some cobalt(III) complexes with (2*S*,10*S*)-4,8-diazaundecane-2,10-diamine (=(2*S*,10*S*)-$Me_2$-2,3,2-tet[10]), a methyl-substituted derivative of 2,3,2-tet. For the *trans*-dichlorocobalt(III) complex they obtained only one isomer, in which both of the methyl groups adopt the equatorial orientation and the absolute configurations of the secondary N atoms are *R*,*R*.

We have isolated the other *trans*-dichlorocobalt(III) complex of (2*S*,10*S*)-$Me_2$-2,3,2-tet and assigned the *R*,*S* configuration to it on the proton magnetic resonance (PMR) and other data, the results of which will be reported in the present paper.

## Experimental

The ligand (2*S*,10*S*)-$Me_2$-2,3,2-tet was prepared in a similar way as reported by Harrington, Linke and Alexander,[9] and isolated by distillation. Bp 120—125 °C (4 mmHg).

*Preparation of* trans-[$CoCl_2$((2S,10S)-$Me_2$-2,3,2-tet)]$ClO_4$ *(A Mixture of Two Isomers).* (2*S*,10*S*)-$Me_2$-2,3,2-tet (2.04 g) and $CoCl_2\cdot6H_2O$ (2.58 g) were dissolved in 1 M HCl (11 ml) and then water (10 ml) was added. The resultant solution was aerated for 6 h. Concentrated hydrochloric acid (10 ml) was added and the dark wine-red solution was evaporated on a water bath to a volume of 10 ml. To the violet solution was added 60% $HClO_4$ (4 ml), and the green crystals which separated were filtered off after cooling in an ice bath for 1 h, washed with ethanol and ether, and air-dried. Yield, 2.36 g. The product was revealed to be a mixture of two isomers from the PMR measurement.

*Preparation of Λ-β(*R,R*)-[$CoCO_3$((2*S,*10*S)-$Me_2$-2,3,2-*tet*)]-$ClO_4\cdot H_2O$.* The isomeric mixture of *trans*-[$CoCl_2$((2*S*,10*S*)-$Me_2$-2,3,2-tet)]$ClO_4$ (0.60 g)was dissolved in 18 ml of water containing 1 ml of 2 M $HClO_4$ with heating and 1.5 g of $NaHCO_3$ were added in small portions. The resultant red solution was concentrated on a water bath to a volume of 10 ml and, then, solid $LiClO_4\cdot3H_2O$ (2 g) was added. After cooling wine-red crystals which separated were collected, washed with ethanol and ether, and air-dried. Yield, 0.52 g. Found: C, 28.40; H, 6.29; N, 13.13%. Calcd for [$CoCO_3(C_9H_{24}N_4)$]$ClO_4\cdot H_2O$: C, 28.28; H, 6.17; N, 13.19%.

*Preparation of* trans(R,R)*-[$CoCl_2$((*2S,10S*)-$Me_2$-2,3,2-tet)]-$ClO_4$.* Λ-β(*R*,*R*)-[$CoCO_3$((2*S*,10*S*)-$Me_2$-2,2,2-tet)]-$ClO_4$ (0.50 g) was added to a mixture of concentrated hydrochloric acid (2 ml) and water (1 ml). After the evolution of carbon dioxide had ceased, 60% $HClO_4$ (2 ml) was added, and the resultant red solution was warmed on a water bath until the separation of green crystals was almost completed. The contents were cooled and the crystals were filtered off, washed with ethanol and ether, and air-dried. Yield, 0.40 g. Found: C, 25.76; H, 5.94; N, 13.32%. Calcd for [$CoCl_2(C_9H_{22}N_4)$]$ClO_4$: C, 25.88; H, 5.80;N, 13.42%.

*Preparation of* trans(R,S)*-[$CoCl_2$((*2S,10S*)-$Me_2$-2,3,2-tet)]-$ClO_4$.* *trans*(*R*,*R*)-[$CoCl_2$((2*S*,10*S*)-$Me_2$-2,3,2-tet)]$ClO_4$ (0.86 g) was dissolved in 2% 2,6-lutidine in methanol, and the solution was heated under reflux for 2 h. The resultant solution was acidified with methanol saturated with hydrogen chloride gas at room temperature, and then, concentrated to about 10 ml on a rotary evaporator. Solid $LiClO_4$ (2.5 g) was added and the crystals which appeared were filtered off, washed with ethanol and ether, and air-dried. Yield, 0.52 g. A mixture of *trans*(*R*,*S*) and *trans*(*R*,*R*) isomers, thus obtained, was carefully recrystallized from methanol, and the initial fraction composed of deep green crystals was collected, washed with ethanol and ether, and air-dried. Found: C, 25.74; H, 5.94; N, 13.48%. Calcd for $[CoCl_2(C_9H_{24}N_4)]ClO_4$: C, 25.88; H, 5.80; N, 13.42%.

*Measurements.* Visible absorption spectra were obtained on a Shimadzu UV-210 spectrophotometer. Circular dichroism spectra were recorded on a JASCO J-20 recording spectropolarimeter. The visible absorption and CD spectra of *trans*-dichloro complexes were obtained in a methanol solution, while the spectra for the carbonato complex was recorded in a aqueous solution. Proton magnetic resonance spectra were obtained on a Hitachi R-20B spectrometer using sodium 2,2-dimethyl-2-silapentane-5-sulfonate as an internal standard reference. The spectra of the *trans*-dichloro complexes were obtained in tetradeutetrated methanol immediately after treating with tetraphenylarsonium chloride and filtering the precipitates. The PMR spectrum of the carbonato complex was recorded in deuterium oxide.

*Measurements of Isomerization and Equilibrium between the* R,R *and* R,S *Isomers of* trans-$CoCl_2((2S,10S)$-$Me_2$-2,3,2-tet$)^+$. A weighed sample (about 15 mg) of *trans* (*R,R*)- or *trans*(*R,S*)-$[CoCl_2((2S,10S)$-$Me_2$-2,3,2-tet$)]ClO_4$ was dissolved in 8 ml of 2% lutidine in methanol in a 10 ml volumetric flask, and the solution was warmed to 50 °C for 40 min. After cooling to room temperature (25 °C), the solution was acidified by gentle bubbling of dry hydrogen chloride gas. The volume was adjusted to 10 ml by adding methanol and the CD curve of the resultant solution was recorded.

## Results and Discussion

Harrington, *et al.* prepared the *trans*(*R,R*)-$[CoCl_2((2S,10S)$-$Me_2$-2,3,2-tet$)]ClO_4$ from the $\Lambda$-*cis*-$\beta$-$[CoCl_2((2S,10S)$-$Me_2$-2,3,2-tet$)]Cl$, which was isolated from the usual air oxidation products by means of cation exchange chromatography technique, and isomerized to the *trans*(*R,R*) in methanol solution.[9] We obtained the *trans*-dichloro complex by adding perchloric acid (60%) directly to a reaction mixture of the air oxidation procedure. The product, thus obtained, was revealed to be an isomeric mixture of two species from the PMR evidence (Fig. 2-a). The overlapped two doublets of unequal intensities were observed in the region of C-methyl resonance (1.3—1.5 ppm).

The isomeric mixture of *trans*-dichloro complex was converted to the carbonato complex, the PMR spectrum of which showed two overlapping methyl doublets (Fig. 3). This indicates that the carbonato complex has no $C_2$ symmetry axis and is assigned to the $\beta$ topology. The CD curve (Fig. 4) exhibits a dominant positive band in the first absorption band region $(^1A_{1g} \rightarrow {}^1T_{1g}\ (O_h))$, demonstrating the $\Lambda$ configuration of the complex.

The *trans*-dichloro complex prepared from the above-mentioned carbonato complex under strongly acidic condition proved to be identical with the *trans*(*R,R*) isomer reported previously.[9] The PMR spectrum shows a single methyl doublet (Fig. 2-b), and coincides with that reported by Alexander *et al.* The CD spectrum is also the same as the curve previously assigned to the *R,R* isomer[9] (Fig. 5). These results indicates that the carbonato complex also adopts the *R,R* configuration with respect to the secondary N atoms, since the conversion from carbonato to *trans*(*R,R*) dichloro complexes should proceed with retention of secondary N configurations under the acidic condition employed.

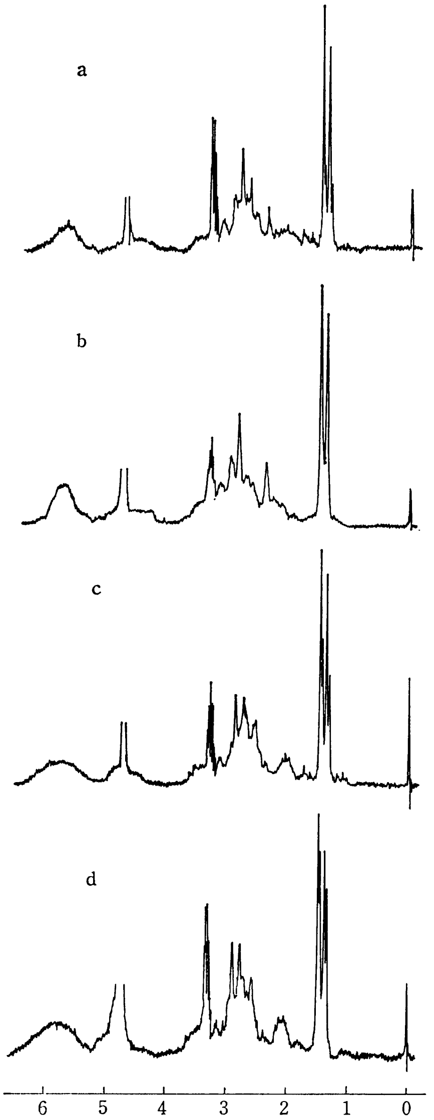

Fig. 2. PMR spectra of *trans*-$[CoCl_2((2S,10S)$-$Me_2$-2,3,2-tet$)]^+$; (a), a mixture of *R,R* and *R,S* initially obtained: (b), the pure *R,R* isomer; (c), a mixture of *R,R* and *R,S* (*R,R*<*R,S*)) recovered after the equilibration in basic methanol; and (d), the pure *R,S* isomer (in $CD_3OD$).

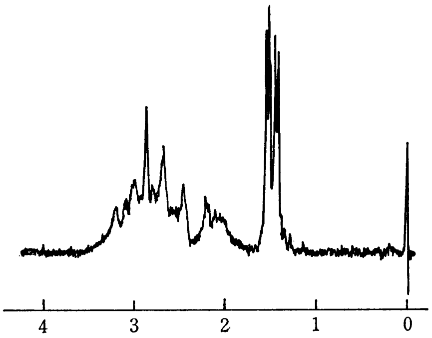

Fig. 3. PMR spectrum of $\Lambda$-$\beta$-$[CoCO_3((2S,10S)$-$Me_2$-2,3,2-tet$)]^+$ (in $D_2O$).

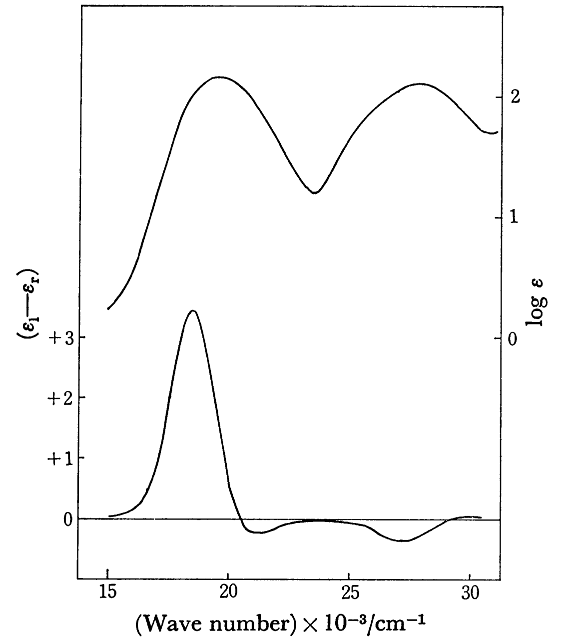

Fig. 4. Visible absorption and CD spectra of $\Lambda$-$\beta$-[Co$CO_3$((2*S*,10*S*)-$Me_2$-2,3,2-tet)]$ClO_4$.

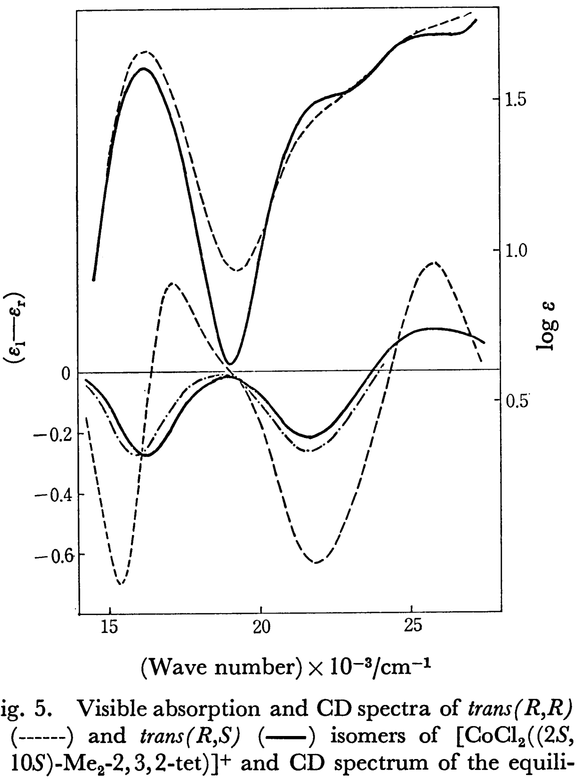

Fig. 5. Visible absorption and CD spectra of *trans(R,R)* (------) and *trans(R,S)* (——) isomers of [$CoCl_2$((2*S*,10*S*)-$Me_2$-2,3,2-tet)]$^+$ and CD spectrum of the equilibrated mixture (–•–•–).

It was described that the *trans*(*R*,*R*)-dichloro complex exhibited no evident structural changes in slightly basic methanol solution.[9] We found, however, that the *trans*-dichloro complex obtained directly from an air-oxidation product composed of at least two isomers. So we attempted to isomerize the *trans*(*R*,*R*) form under strongly basic condition such as in 2% 2,6-lutidine in methanol under reflux. The CD curve obtained after the reflux for 2 h was found to be significantly different from the original curve. The *trans*-dichloro complex recovered from the above solution exhibited two methyl doublets with unequal intensities in the PMR spectrum (Fig. 2-c). The *trans*-dichloro isomer different from the *trans*(*R*,*R*) could be purified by carefully repeated recrystallization from methanol as prismatic crystals. The PMR and CD spectra of the present isomer are shown in Figs. 2-d and 5, respectively. The intensities of the two methyl doublets in this PMR can be regarded to be practically equivalent.

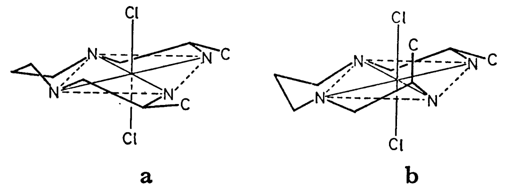

Fig. 6. Possible structures of *trans*-[$CoCl_2$((2*S*, 10*S*)-$Me_2$-2,3,2-tet)]$^+$: (a) *trans(R,R)*, and (b) *trans(R,S)*.

It is reasonable to consider that the possible structures for the *trans*-$CoCl_2$((2*S*,10*S*)-$Me_2$-2,3,2-tet)$^+$ ion are those depicted in Fig. 6. The structure shown in Fig. 6-a corresponds to the *trans*(*R*,*R*) configuration, which has the central six-membered chelate ring in the skew-boat conformation and the five-membered rings in the same $\delta$ conformation, and further two equivalent methyl groups oriented equatorially. The PMR and CD spectra given in Figs. 2 and 5 for *trans*(*R*,*R*) isomer are in accord with these structural features as described by Harrington, Linke, and Alexander.[9]

The other structure for the *trans*-dichloro complex (Fig. 6-b), which will be designated as *trans*(*R*,*S*) because the secondary nitrogen centers adopt the opposite configuration to each other, has the six-membered ring in the chair conformation and the five-membered rings in the conformation of opposite chirality. One of the methyl groups must have an axial position, while the other in an equatorial position. The PMR spectrum for *trans*(*R*,*S*) isomer should give rise to two methyl doublets of the equal intensities, since the axial methyl group will exhibit, in principle, a different chemical shift from that of the equatorial methyl group. The PMR spectrum of the novel *trans* isomer (Fig. 2-d) is in accord with the requirements from *trans*(*R*,*S*) geometry.

For the *trans*(*R*,*S*) isomer the conformational effects will not contribute to the optical activity for the first approximation because the five-membered rings has the opposite conformation. The vicinal effects from the two methyl groups should primarily be appeared in the CD curve. It is expected from the results on the CD of *trans*-[$CoCl_2(N)_4$]$^+$ type complexes with diamines[11] or tetramines[12] that the equatorial methyl group shows a relatively small vicinal effect. The vicinal effect from an axial methyl group which has not been estimated yet would not be much intense compared with that from the equatorial methyl group.

The CD curve of new *trans*-[$CoCl_2$((2*S*,10*S*)-$Me_2$-2,3,2-tet)]$ClO_4$ shown in Fig. 5 is fairly different from and apparently less intense than that of the *trans*(*R*,*R*) isomer. It will be reasonable that the *trans*(*R*,*S*) isomer of $CoCl_2$((2*S*,10*S*)-$Me_2$-2,3,2-tet)$^+$ gives such a CD spectrum as indicated above. Consequently, we assign the novel *trans*-dichloro complex to the *R,S* configuration on the ground of characteristics of the PMR and CD data.

The reaction condition employed for obtaining the *trans*(*R,S*) isomer from the *trans*(*R,R*) isomer should promote the reverse change (*R,S*→*R,R*), and establish ultimately an equilibrium between the isomers. The CD curves of both of the *trans*-dichloro complexes obtained after heating under reflux for 1 h in a 2% 2,6-lutidine methanol solution found to agree with each other within the experimental error. The CD curve of the equilibrium mixture at room temperature shown in Fig. 5 crosses at the intersections of the CD curves for the *R,R* and the *R,S* isomer except in the higher energy region where the influences due to 2,6-lutidine are considered to occur. Assuming that only the two isomers, *R,R* and *R,S*, are equilibrated under the above condition, the ratio of these isomers was estimated to be $7.6 \pm 0.3:1$ ($\Delta G = -1.20 \pm 0.03$ kcal/mol) in favor of the *R,S* isomer.

It is very interesting that the *trans*(*R,S*) isomer having the six-membered ring in the chair conformation and one of the methyl groups in an axial location is fairly stable than the *trans*(*R,R*) having the six-membered ring in the skew-boat conformation and both of the methyl groups in the equatorial situation. The energetic advantage of the chair conformation over the skew-boat conformation with respect to the six-membered ring exceeds significantly the disadvantage brought about by an axial methyl group.

Therefore, the most stable configuration for (2*S*,10*S*)-$Me_2$-2,3,2-tet complexes should be the *Λ*-*cis*-*β* geometry, in which the six-membered chelate ring adopts the chair conformation and both of the methyl groups can occupy equatorial positions. This is in accord with the observation that the dominant isomer obtained from the air-oxidation products by means of ion-exchange chromatography is the *Λ*-*cis*-*β* dichloro complex.[9]

Recently, an X-ray crystallographic study have demonstrated that the six-membered ring adopts the chair conformation in the *Λ*-*β*-[Coox(5*R*,7*R*)-$Me_2$-2,3,2-tet)]$^+$ ion, even though one of the methyl groups occupies an axial orientation at the six-membered ring.[13] On these findings we conclude that metal complexes coordinating methyl-substituted 2,3,2-tet derivatives will often give rise to isomers having an axial methyl group due to the higher preference of the chair conformation for the six-membered ring.

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10) Alexander *et al.* abbreviated the ligand 4,8-diazaundecane-2,10-diamine simply as diMe-2,3,2-tet. We consider, however, that it is necessary to designate the positions of the methyl groups on the ligand skeleton for the sake of avoiding the confusions, since the other ligands such as (4*R*,6*R*)-4,6-dimethyl-3,7-diazanonane-1,9-diamine can be also abbreviated as diMe-2,3,2-tet. For convenience the rules we employed for the triethylenetetramine series are introduced in this report to the methyl-substituted 2,3,2-tet ligands regarding the 2,3,2-tet chain as 1,4,8,11-tetraazaundecane as in the case of 5-methyl derivatives: P. W. R. Corfield, J. C. Dabrowiak, and E. S. Gore, *Inorg. Chem.*, **12**, 1734 (1973). The following abbreviations will be used: (5*R*)-Me-2,3,2-tet (=(5*R*)-5-methyl-1,4,8,11-tetraazaundecane or (4*R*)-4-methyl-3,7-diazanonane-1,9-diamine), (5*R*,7*R*)-$Me_2$-2,3,2-tet (=(4*R*,6*R*)-1,9-diamino-4,6-dimethyl-3,7-diazanonane).

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