a pseudo-equilibrium[7] that incorporates a primary kinetic isotope effect; i.e., it is determined by the ratio of the rate constants for H removal in the forward direction and D addition in the reverse direction.[8] In contrast, the observed isotope effect will depend largely on the equilibrium isotope effect for the first step in reactions involving initial reversible protonation of carbon[9] or in the later stage of E1cB (reversible) elimination reactions, after complete exchange with the solvent has occurred.[3]

(7) Long, F. A.; Bakule, R. *J. Am. Chem. Soc.* **1963**, *85*, 2313-2323.
(8) Littler, J. S.; Quick, G. R.; Wozniak, D. *J. Chem. Soc., Perkin Trans. 2* **1980**, 657-661, have observed this behavior for the initial rate of cyclohexanone oxidation through the enol in acid solution, which gives inverse solvent isotope effects of 4.9-5.9 and is first order in the oxidant. The initial rate also shows a normal primary isotope effect with deuterated substrate under conditions in which the oxidation step is rate determining because the k_1 step involved H or D, whereas k_{-1} always involves H. The same behavior has been observed for the isomerization of dihydroxyacetone phosphate catalyzed by triose phosphate isomerase, which exhibits a primary isotope effect because of this pseudo-equilibrium under conditions in which proton transfer is not rate determining (Leadlay, P. F.; Albery, W. J.; Knowles, J. R. *Biochemistry* **1976**, *15*, 5617-5620).
(9) The acid-catalyzed hydrolysis of a cyclic vinyl ether has been reported to undergo a leveling of the rate as the buffer concentration increases, with an inverse solvent deuterium isotope effect at high buffer concentration that represents such an equilibrium isotope effect (Cooper, J. D.; Vitullo, V. P.; Whalen, D. L. *J. Am. Chem. Soc.* **1971**, *93*, 6294-6296).

Asymmetric Synthesis of α-Amino Acids Using Chiral Cobalt(III) Complexes

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We have developed a novel asymmetric synthesis of α-amino acids by using chiral cobalt(III) complexes containing 1,5*R*,7*R*,11-Me$_4$-2,3,2-tet[1] as a ligand.

Some studies have been reported on the asymmetric synthesis of α-amino acids[2,3] and asymmetric transformation of α-amino acids[4-6] in their chiral cobalt(III) complexes. In every case, however, amino acids were not isolated from the cobalt(III) complexes until they were subjected to a decomposition process which often accompanied racemization of the amino acids.

We recently discovered a new type of reaction to isolate amino acids with retention of the asymmetric carbon center from the cobalt(III) complexes under mild conditions while also preserving the complexes.

When Λ-β$_2$-[Co(*R* or *S*-Ala)(1,5*R*,7*R*,11-Me$_4$-2,3,2-tet)]$^{2+}$ was warmed in an 0.1 M Na_2CO_3 aqueous solution at 50 °C for 30 min, the starting red solution changed its color to violet. The reaction in a 0.1 M Na_2CO_3-D_2O solution was followed by ^{1}H NMR spectroscopy. The *C*-methyl signal of the coordinated alanine gradually decreased to zero. This color change corresponds also to the shift of absorption maximum in the visible spectrum from 513 to 530 nm. The reaction mixture was loaded on an SP-Sephadex (C-25) cation exchange resin. The colored fraction was adsorbed on the resin. The solution passed through the column was confirmed to contain free alanine by an amino acid analyzer. This free alanine was converted to 2,4-dinitrophenylalanine (DNP-alanine). The DNP-alanine was purified by silica gel thin-layer chromatography. The specific optical rotation of the authentic DNP-(*S*)-alanine was compared with that of the DNP-alanine prepared from pure (*R*)-alaninato or (*S*)-alaninato complex. The comparison indicated that the asymmetry of alanine was retained quantitatively (>99%) during the release.[11]

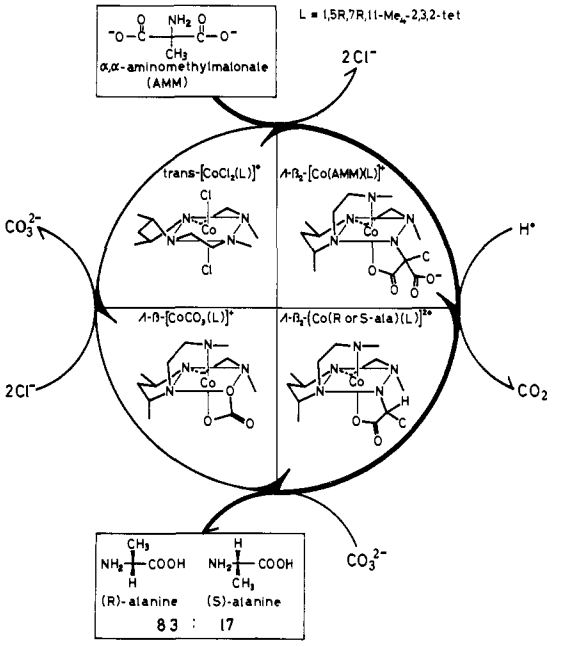

Figure 1.

The ^{1}H NMR, electronic absorption (AB), and CD data for the complex eluted with a 0.05 N $NaClO_4$ solution agreed well with those for the carbonato complex represented as Λ-β-[$CoCO_3$(1,5*R*,7*R*,11-Me$_4$-2,3,2-tet)]ClO_4·H_2O.[7] This carbonato complex was easily converted to the starting trans-dichloro complex of 1,5*R*,7*R*,11-Me$_4$-2,3,2-tet. The new asymmetric synthesis of α-amino acids described above is depicted in Figure 1.

The first step of this cyclic system is the introduction of α-amino-α-methylmalonic acid (AMM) into the starting *trans*-dichloro complex. The *trans*-[$CoCl_2$(1,5*R*,7*R*,11-Me$_4$-2,3,2-tet)]ClO_4 (0.89 g) and ammonium α-amino-α-methylmalonate (0.33 g) were refluxed in 100 mL of methanol. The product was purified through an SP-Sephadex (C-25) cation exchange resin column and isolated as the perchlorate salt. On the basis of analytical and spectral data, the complex was assigned as Λ-β$_2$-[Co(AMM)(1,5*R*,7*R*,11-Me$_4$-2,3,2-tet)]ClO_4·2·5H_2O and obtained stereospecifically.[8]

The second step is the decarboxylation of AMM on the complex. The AB, CD, and ^{1}H NMR spectra of the product decarboxylated from Λ-β$_2$-[Co(AMM)(1,5*R*,7*R*,11-Me$_4$-2,3,2-tet)]$^+$ in 1 N hydrochloric acid at 70 °C were almost the same as those of Λ-β$_2$-[Co(*R*-Ala)(1,5*R*,11-Me$_4$-2,3,2-tet)]$^{2+}$ which was prepared from the reaction between *trans*-[$CoCl_2$(1,5*R*,7*R*,11-Me$_4$-2,3,2-tet)]ClO_4 and (*R*)-alanine.[9] This observation indicates that the above decarboxylation produced predominantly (*R*)-alaninato complex.[10] Actually, the red crystals isolated from the decar-

(1) The fully systematic name is (6*R*,8*R*)-6,8-dimethyl-2,5,9,12-tetraazatridecane.
(2) Asperger, R. G.; Liu, C. F. *Inorg. Chem.* **1967**, *6*, 796-800.
(3) Job, R. C.; Bruice, T. C. *J. Am. Chem. Soc.* **1974**, *96*, 809-819.
(4) Yamaguchi, M.; Yamamatsu, S.; Furusawa, T.; Yano, S.; Saburi, M.; Yoshikawa, S. *Inorg. Chem.* **1980**, *19*, 2010-2016.
(5) Yamaguchi, M.; Yano, S.; Saburi, M.; Yoshikawa, S. *Bull. Chem. Soc. Jpn.* **1980**, *53*, 691-698.
(6) Okawa, H.; Numata, Y.; Mio, A.; Kida, S. *Bull. Chem. Soc. Jpn.* **1980**, *53*, 2248-2251.
(7) Ajioka, M.; Yano, S.; Saburi, M.; Yoshikawa, S. *Inorg. Chem.*, to be published.
(8) Elemental analysis, Anal. Calcd for $C_{15}H_{38}ClCoN_5O_{10.5}$: C, 32.71; H, 6.95; N, 12.71. Found: C, 32.85; H, 6.50; N, 12.25. ^{1}H NMR (D_2O) 1.08 (d, *J* = 7.9 Hz, C-CH_3), 1.42 (d, *J* = 6.0 Hz, C-CH_3), 1.72 (s, C-CH_3 of AMM), 1.92 (s, N-CH_3), 2.18 (s, N-CH_3) ppm; AB (H_2O) $\bar{\nu}_{max}$ 19 300 (log ε = 2.18) 27 000 (log ε = 2.18) cm^{-1}; CD (H_2O) $\bar{\nu}_{max}$ 18 800 (Δε −0.44) 21 000 (Δε +0.70) 27 500 (Δε −0.36) cm^{-1}.
(9) Ajioka, M.; Yano, S.; Toriumi, K.; Ito, T.; Yoshikawa, S., to be submitted for publication. The bromide was converted from the Λ-β$_2$-[Co(*R*-Ala)(1,5*R*,7*R*,11-Me$_4$-2,3,2-tet)]$(ClO_4)_2$·H_2O obtained in the second step of the cycle. The crystals from in the orthorhombic space group $P2_12_12_1$ with *a* = 11.713 (1), *b* 20.301(2), *c* 10.113(2) Å; Z = 4. The structure was solved by heavy-atom methods and refined by full-matrix least-squares procedures with anisotropic temperature factors; $R = \sum||F_o| - |F_c||/\sum|F_o| = 0.054$; $R' = [\sum W(|F_o| - |F_c|)^2/\sum W|F_o|^2] = 0.054$, where $1/W = [\sigma(|F|)]^2 = [\sigma(\text{count})]^2 + [0.015|F_o|]^2$. Tables of the final positional and thermal parameters, bond distances, and bond angles are available as supplementary material.

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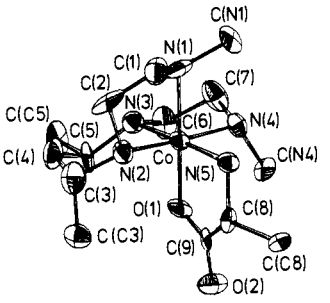

Figure 2.

boxylation solution were Λ-β_2-[Co(*R*-Ala)(1,5*R*,7*R*,11-Me_4-2,3,2-tet)]$(ClO_4)_2 \cdot H_2O$ crystals.

The third step is the release of alanine from the complex and recovery of the carbonato complex. The recoveries were 88% for the DNP-alanine and 64% for the carbonato complex. The specific optical rotation of the DNP-alanine obtained here indicated a mixture of *R* and *S* isomers in the ratio 83:17.[11] This optical yield is fairly high compared with the reported results.[2]

The last step in the asymmetric synthesis is to regenerate the starting *trans*-dichloro complex from the carbonato complex. Treatment of the carbonato complex with concentrated HCl produced the expected *trans*-dichloro complex.[7] The most important reaction in this cyclic system is the release of alanine from $[Co(Ala)(1,5R,7R,11\text{-}Me_4\text{-}2,3,2\text{-tet})]^+$ ion under mild conditions.

To confirm the structure of this complex cation, we previously determined the structure of $(-)_{546}$-Λ-β_2-[Co(*R*-Ala)-(1,5*R*,7*R*,11-Me_4-2,3,2-tet)]$Br_2 \cdot 3H_2O$ by an X-ray crystallographic study.[9] The absolute configuration of the complex cation is Λ in the β_2 form, and the alanine coordinates to cobalt ion with bidentate (Figure 2). Bond distances and angles were quite usual.

Quite recently, the release of alanine was also observed for an alaninato complex of 2*R*,4*R*,9*R*,11*R*-Me_4-3,2,3-tet.[12] The first absorption bands of alaninato complexes containing 5*R*,7*R*-Me_2-2,3,2-tet,[13] 2*R*,4*R*,9*R*,11*R*-Me_4-3,2,3-tet, and 1,5*R*,7*R*,11-Me_4-2,3,2-tet shifted by 200, 600, and 700 cm^{-1} to lower energy, respectively, as compared to that of 2,3,2-tet[14] complex. For both the alaninato complexes of 2,3,2-tet and 5*R*,7*R*-Me_2-2,3,2-tet, the release of alanine has not been observed but racemization of alanine of the complex has been observed. Therefore we consider the labile feature of the alaninato complex containing 1,5*R*,7*R*,11-Me_4-2,3,2-tet or 2*R*,4*R*,9*R*,11*R*-Me_4-3,2,3-tet relates closely to the strength of the ligand field. Consequently, many inert cobalt(III) complexes might be activated to be catalysts for the asymmetric synthesis of α-amino acids by the modification of ligands so that they could produce an appropriate ligand field.

We also found that glycine and valine were released from the corresponding amino acidato complexes of 1,5*R*,7*R*,11-Me_4-2,3,2-tet. Accordingly, the present asymmetric synthesis depicted in Figure 1 could be practically applied to the synthesis of expensive and naturally rare α-amino acids by variation of aminoalkylmalonic acids.

Acknowledgment. We are grateful to Dr. Tasuku Itoh, Dr. Koshiro Toriumi, and Dr. Hideomi Koinuma for their helpful discussion. Expenses for the work were defrayed by a grant-in-aid from the Ministry of Education (No. 475657).

Supplementary Material Available: Final positional and thermal parameters, bond distances, and bond angles (4 pages). Ordering information is given on any current masthead page.

(10) The decarboxylated solution also contained the minor (*S*)-alaninato complex.

(11) The specific optical rotation of the solution was observed at 546 nm, and the concentration of the same solution was calculated from the extinction coefficient at 360 nm (ϵ 1.72 × 10^4). Authentic DNP-(*S*)-alanine: $[\alpha]_{546}$ +221° (1% $NaHCO_3$).

(12) The fully systematic name is (2*R*,4*R*,9*R*,11*R*)-4,9-dimethyl-5,8-diazadecane-2,11-diamine.

(13) The fully systematic name is (4*R*,6*R*)-4,6-dimethyl-3,7-diaza-1,9-nonanediamine.

(14) The fully systematic name is 3,7-diaza-1,9-nonanediamine.

Observation of an Unprecedented Heavy-Atom Effect on the Rate of $^1n,\pi^* \rightarrow {}^3n,\pi^*$ in a β,γ-Unsaturated Ketone[1]

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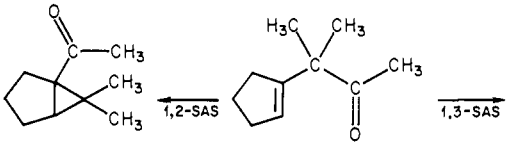
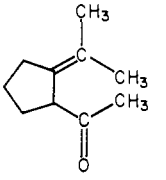
Wagner[2] experimentally demonstrated that heavy-atom solvents have no effect on the intersystem crossing rate of alkanones. This supported El-Sayed's earlier calculations[3] on $\pi^* \rightarrow n$ transitions of X_2CO (X = halogen) which suggested that further enhancement of the already large rates of $S \rightleftharpoons T$ transitions in "pure" n,π^* states (due to effective spin-orbit coupling) by internal heavy atoms should be negligible, although it should be noted that calculations by Carroll et al.[4] predict a substantial internal heavy-atom effect (HAE) on phosphorescence lifetimes of X_2CO due to considerable delocalization of the oxygen n electron. Morrison[5] has shown that an external heavy atom can affect the photochemical behavior (dimerization) of coumarin, an unsaturated carbonyl compound, although the heavy atom does not effect the triplet yield but rather perturbs later stages of the dimerization mechanism.

We present experimental evidence that the n,π^* excited singlet of 3-(1-cyclopentenyl)-3-methyl-2-butanone (I) is sensitive to an external HAE. It has been previously observed[6] that direct



III I



II

irradiation of I gives the 1,3-sigmatropic acyl shift (1,3-SAS) product II and other products, while acetone sensitization affords II as well as the product (III) of a 1,2-sigmatropic acyl shift (1,2-SAS) or oxa-di-π-methane (ODPM) rearrangement. These results were confirmed in the present study. We have further been able to demonstrate that the formation of II occurs from both $S_1(n,\pi^*)$ and $T_2(n,\pi^*)$ states, the former populated on direct light absorption and the latter under conditions of triplet sensitization, while III arises exclusively from the $T_1(\pi,\pi^*)$ state. These assignments are based on differential sensitization and quenching results, and the inverse temperature dependence of the fluorescence yield and the quantum efficiency of the 1,3-SAS ($\Phi_{1,3}$).[7]

Irradiation of I (purified by preparative high-pressure liquid chromatography) under 2.2 atm of xenon resulted in a 21 ± 1% decrease in its fluorescence intensity (see Figure 1), while the efficiency of formation of the 1,3-SAS product ($\Phi_{1,3}$) increased from 0.058 ± 0.006 to 0.072 ± 0.007. The fluorescence intensity decrease[8] was observed in three runs by using two different samples, while more modest and less precise enhancements in $\Phi_{1,3}$

(1) Photochemistry of Ketones in Solution. 63. Paper 62: Schuster, D. I.; Nuñez, I. M.; Chan, C. B. *Tetrahedron Lett.* **1981**, *22*, 1187.

(2) Wagner, P. J. *J. Chem. Phys.* **1966**, *45*, 2335.

(3) El-Sayed, M. A. *J. Chem. Phys.* **1964**, *41*, 2462.

(4) Carroll, D. G.; Vanquickenborne, L. G.; McGlynn, S. P. *J. Chem. Phys.* **1966**, *45*, 2777.

(5) Hottman, R.; Wells, P.; Morrison, H. *J. Org. Chem.* **1971**, *36*, 102.

(6) Engel, P. S.; Schexnayder, M. A. *J. Am. Chem. Soc.* **1975**, *97*, 145.

(7) Schuster, D. I.; Calcaterra, L. T., unpublished results. Calcaterra, L. T. Ph.D. Dissertation, New York University, 1981.

(8) There was no measurable change in the optical density of the solutions upon addition of xenon; the UV absorption and fluorescence spectra also showed no change in either shape or position (see Figure 1).

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