Comparative Crystal Structure Studies on Distortion of *iso*-Butyl(aqua)cobaloxime Induced by α-Cyclodextrin and *β*-Cyclodextrin Hosts

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The crystal and molecular structures of *iso*-butyl(aqua)cobaloxime (**I**) and its hydrated inclusion complexes with α-cyclodextrin (**II**) and *β*-cyclodextrin (**III**) were determined by X-ray diffraction analyses. Crystal data for **I**: $P2_1/c$, $a = 30.450(1)$ Å; $b = 9.659(2)$ Å; $c = 19.200(2)$ Å; $\beta = 107.23(3)°$; $Z = 12$. Crystals of **II**·H_2O and **III**·$9H_2O$ both crystallize in space group $P2_12_12_1$ with $Z = 4$; $a = 13.847(1)$ Å, $b = 19.418(1)$ Å, $c = 24.593(1)$ Å for **II**·$8H_2O$, and $a = 28.188(6)$ Å, $b = 15.190(3)$ Å, $c = 19.017(4)$ Å for **III**·$9H_2O$. In the inclusion complexes, the $Co(DH)_2$ unit is located near the wide opening of the cyclodextrin with its *iso*-butyl group inserted into the cyclodextrin cavity. The structure and conformation changes of the *iso*-butyl(aqua)cobaloxime are probably related to the noncovalent interaction between the *iso*-butyl group and cyclodextrin cavity, and steric interaction between cobaloxime and cyclodextrin rims. Our results also show that distortions of *iso*-butyl(aqua)cobaloxime/cyclodextrin induced by α-CD and *β*-CD occur in different extent, which assumedly is due to the different cavity diameters of the cyclodextrins.

Introduction

Alkylcobaloximes, $RCo(DH)_2L$, where DH = dimethylglyoxime, R = alkyl, L = neutral monodentate axial ligand, are an important coenzyme B_{12} model.[1] They feature a *σ* Co−R bond similar to that in the natural cofactor coenzyme B_{12}, i.e., 5′-deoxyadenosylcobalamin (AdoCbl), which takes part in many enzyme induced 1,2-intermolecular substrate rearrangements. In the most widely accepted catalytic mechanism, homolytic cleavage of the coenzyme's cobalt−carbon bond is the first key step.[2−5] Hay and Finke's studies suggest that AdoCbl-dependent enzymes can increase the rate of thermal homolysis of the AdoCbl by a factor of at least 10^{10} at 25 °C.[6,7] Most of the hypotheses for this mechanism invoke steric distortion of the coenzyme by enzyme as the primary force in promoting homolysis.[3,5,8−14] It appears that the enzyme protein directly modulates the stability and reactivity of cobalamin derivatives though the lower ligand donated by the protein, which has been found to be a histidine from the recent X-ray crystallographic structure studies on two B_{12}-dependent enzymes.[15] Although the exact nature of the structural distortions remain obscure, the flexibility of the corrin ring, the orientation of the side chains, and the angular distortion of Co−C−C group have been suggested as key points in the picture.[1−7,16,17] Among plenty of coenzyme B_{12} model compounds, the alkylcobaloximes present the similarity in the flexibility of the equational $Co(DH)_2$ to that of corrin ring in 5′-deoxyadenosylcobalamin.[1−3,18−20] Studies on X-ray structures of alkylcobaloximes have revealed that the Co−C bond lengths are responsive to both the steric bulk of R and L, as well as the conformational distortion from planarity of the $Co(DH)_2$ unit through steric interactions.[1−3,20]

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Table 1. Crystallographic Data for *i*-BuCo(DH)$_2$H$_2$O (**I**), *i*-BuCo(DH)$_2$H$_2$O/α-CD·8H$_2$O in **II**·8H$_2$O, and *i*-BuCo(DH)$_2$H$_2$O/*β*-CD·9H$_2$O in **III**·9H$_2$O

	I	**II**·8H$_2$O	**III**·9H$_2$O
empirical formula	$C_{12}H_{25}CoN_4O_5$	$C_{48}H_{85}CoN_4O_{35}\cdot 8H_2O$	$C_{54}H_{95}CoN_4O_{40}\cdot 9H_2O$
mol wt	364.3	1476.6	1661.41
a/Å	30.450(1)	13.847(1)	28.188(6)
b/Å	9.659(2)	19.418(1)	15.190(3)
c/Å	19.200(2)	24.593(1)	19.017(4)
β/deg	107.23(3)	90	90
D_c/g cm^{-3}	1.346	1.483	1.355
Z	12	4	4
space group	$P2_1/c$	$P2_12_12_1$	$P2_12_12_1$
cryst syst	monoclinic	orthorhombic	orthorhombic
V/Å^3	5394(3)	6613(3)	8143(3)
limiting indices	$-39 \le h \le 37$, $-12 \le k \le 0$, $0 \le l \le 24$	$-17 \le h \le 17$, $0 \le k \le 24$, $-31 \le l \le 31$	$-34 \le h \le 34$, $0 \le k \le 18$, $0 \le l \le 23$
μ/mm^{-1}	0.980	0.369	0.313
F(000)	2304	3133.43	3536
no. of reflcns collcd	12 769	24 817	13 012
no. of indep reflcns	12 385	13 249	13 012
no. of obsd reflcns	4408 ($I > 2\sigma(I)$)	12 163 ($F > 6.0\sigma(F)$)	11 082 ($I > 2\sigma(I)$)
R_{int}	0.0341	0.0466	0.0000
R_F, wR	0.0787, 0.2127	0.0527, 0.0673	0.0781, 0.1903

α-, *β*-, and *γ*-cyclodextrins (CDs) are truncated cone-shaped cyclic oligosaccharides composed of six, seven, or eight α-1,4 linked D-glucoses, in which the interior surface of the cavity is hydrophobic and the external surface is hydrophilic. They are one class of the most fascinating naturally occurring molecular receptors to a variety of inorganic and organic molecules.[21] Since the noncovalent host−guest interactions have been widely accepted in substrate−enzyme interaction models, CDs and their derivatives have been developed as artificial enzymes to catalyze many reactions.[21−23] We have reported that alkyl(aqua)-cobaloximes can form inclusion complexes with α-cyclodextrin and *β*-cyclodextrin both in aqueous solution and in the solid state.[24] However, so far only the crystal structure of one α-CD inclusion complex with alkylcobaloxime (R = *n*-C_3H_7) has been determined. It has been found that structure and conformational changes of the alkylcobaloxime induced by α-CD are similar to that between AdoCbl and protein in the B$_{12}$-dependent enzyme systems.[24a] In a subsequent investigation of alkylcobaloxime distortion resulting from noncovalent interactions between cobaloxime and cyclodextrin, two new complexes, namely *i*-$C_4H_9Co(DH)_2H_2O$/α-CD and *i*-$C_4H_9Co(DH)_2H_2O$/*β*-CD, have been prepared and their crystal structures have been determined. These results are addressed in the present paper.

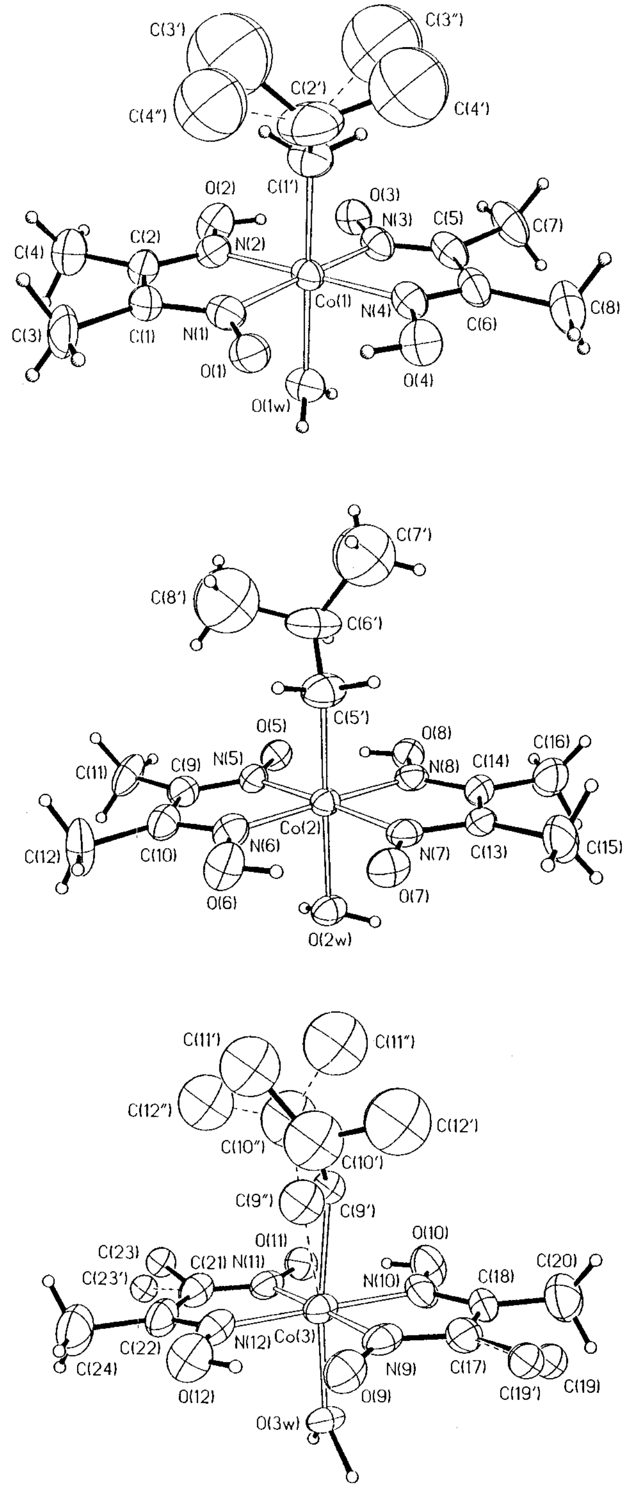

Figure 1. Structure and numbering scheme of *i*-BuCo(DH)$_2$H$_2$O.

Experimental Section

α-CD was obtained from Sigma. *β*-CD was supplied by Nanjing Food Ferment Institute and was recrystallized twice from distilled water. Both compounds were dried in vacuo at 80 °C.

Elemental analysis (EA) was performed on a Perkin-Elmer 240 elemental analysis instrument. ^{1}H NMR spectra were obtained from a Bruker AM-500 spectrometer.

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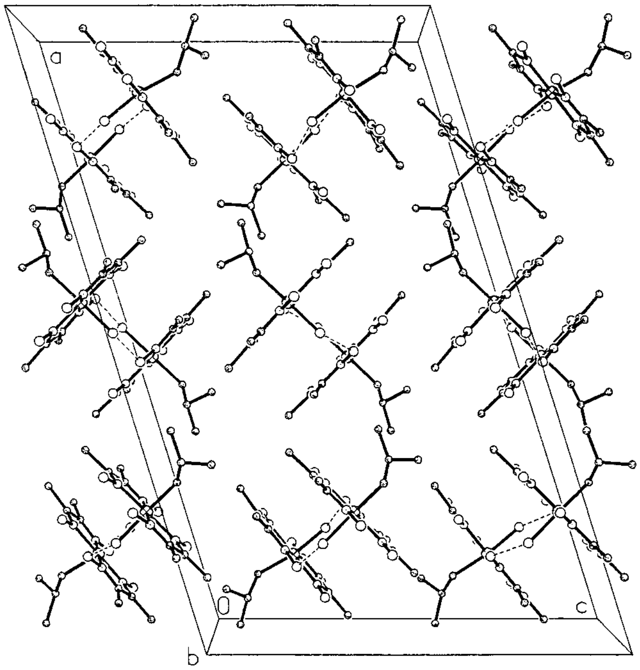

Figure 2. Stereodrawing of the packing of *i*-BuCo(DH)$_2$H$_2$O.

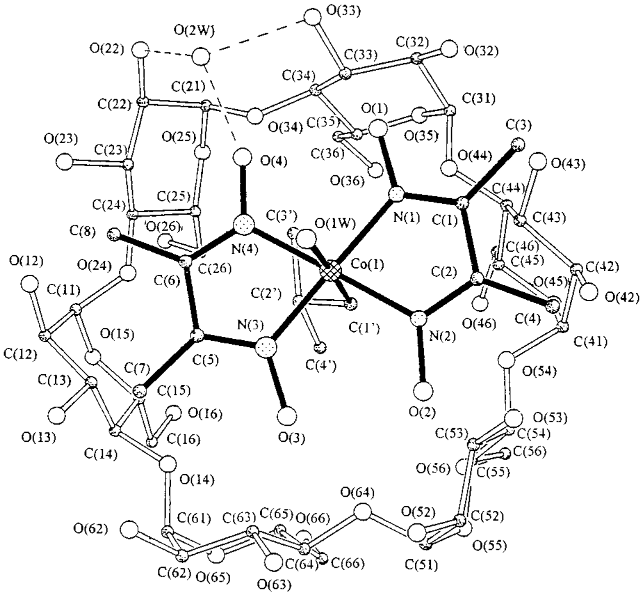

Figure 3. Structure and numbering scheme of *i*-BuCo(DH)$_2$H$_2$O/α-CD (**II**) in **II**·8H$_2$O.

***i*-BuCo(DH)$_2$H$_2$O (I).** The compound was prepared by standard procedures,[25] yield: 60%. Crystals were obtained by slow crystallization from a methanol−water solution (1:1 v/v) at 25 °C. EA, found: C, 39.36; H, 6.91; N, 13.67. Calcd for $C_{13}H_{29}N_4O_6Co$: C, 39.40; H, 7.38; N, 14.14. ^{1}H NMR (D$_2$O, 500 MHz), for *i*-Bu, 0.69 (6H, t, CH$_3$), 0.73 (2H, m, CH$_2$), 1.72 (2H, m, CH$_2$); for Co(DH)$_2$, 2.24 (12H, s, CH$_3$) ppm.

***i*-BuCo(DH)$_2$H$_2$O/α-CD (II).** *i*-BuCo(DH)$_2$H$_2$O and α-CD in 1:1 molar ratio were dissolved in water by constant stirring for 30 min at 50 °C. The resulting solution was filtered, and the filtrate was stored at 25 °C in the dark. One week later, red-brown crystals were obtained (yield 50%). The crystals were easy to crack upon dehydration. EA, found: C, 42.42; H, 6.83; N, 4.22. Calcd for $C_{48}H_{87}CoN_4O_{36}$: C, 42.55; H, 6.45; N, 4.15. ^{1}H NMR (D$_2$O, 500 MHz), for *i*-Bu, 0.75 (6H, t, CH$_3$), 0.81 (2H, m, CH$_2$), 1.78 (1H, dt, CH$_2$); for Co(DH)$_2$, 2.26 (12H, d, CH$_3$); for α-CD, 3.57 (6H, t, H-4), 3.64 (6H, dd, H-2), 3.80 (6H, m, H-5), 3.86 (12H, d, H-6), 3.95 (6H, t, H-3), 5.04 (6H, d, H-1) ppm.

***i*-BuCo(DH)$_2$H$_2$O/*β*-CD (III).** *i*-BuCo(DH)$_2$H$_2$O and *β*-CD in 1:1 molar ratio were dissolved in water at 50 °C, and the solution was filtered. The crystals were obtained by slow evaporation at 25 °C in the dark, yield 50%. The crystals were easy to crack upon dehydration. EA, found: C, 37.99; H, 7.10; N, 3.27. Calcd for $C_{54}H_{121}CoN_4O_{53}$: C, 37.41; H, 7.10; N, 3.27. ^{1}H NMR (D$_2$O, 500 MHz), for *i*-Bu, 0.73 (6H, t, CH$_3$), 0.80 (2H, m, CH$_2$), 1.82 (2H, m, CH$_2$); for Co(DH)$_2$, 2.34 (12H, d, CH$_3$); for *β*-CD, 3.56 (7H, t, H-4), 3.64 (7H, dd, H-2), 3.74 (7H, m, H-5), 3.87−3.88 (14H, m, H-3, H-6), 5.05 (7H, d, H-1) ppm.

Crystallography. Raw intensities for *i*-BuCo(DH)$_2$H$_2$O (**I**) were collected in variable ω scan mode on a Rigaku AFC7R four-circle diffractometer using Mo Kα ($\lambda = 0.710\ 73$ Å) radiation. An empirical absorption correction based on ψ scan data was applied. Raw intensities for the corresponding α-CD and *β*-CD inclusion complexes **II**·8H$_2$O and **III**·9H$_2$O were collected on a Rigaku RAXIS-IIC imaging-plate system with a rotating-anode X-ray source (50 kV, 90 mA) and corrected for absorption using DIFABS program.[26] The Patterson method yielded the positions of the metal atoms and all non-hydrogen atoms were derived from subsequent Fourier-difference syntheses. The hydrogen atoms attached to the carbons of the ligands were placed in calculated positions (C−H 0.96 Å), assigned fixed isotropic thermal parameters, and allowed to ride on their respective parent atoms. Analytical expressions of atomic scattering factors were employed and anomalous dispersion corrections were incorporated. Refinement (on F^2) of the coordinates and anisotropic thermal parameters of the non-hydrogen atoms was carried by the full-matrix least-squares method. All calculations were performed on a 486 personal computer with the SHELXTL-PC program package.[27] Crystallographic data for **I**, **II**, and **III** are listed in Table 1.

Results

Structure Description of *i*-BuCo(DH)$_2$H$_2$O (I). It is noteworthy that there are three crystallographically independent molecules in the asymmetric unit of **I**: in molecule 1, the *i*-Bu group exhibits orientational disorder; molecule 2 is ordered; in molecule 3, the whole *i*-Bu group takes alternate sites, which may account for the disorder of the methyl groups C(19) and C(23). The crystal structure comprises a packing of zigzag chains of molecules linked by donor hydrogen bonds from each axial aqua ligand to the O-oxime groups of two neighboring molecules. The molecule chains run parallel to the *b* axis and those at $x = {}^1/_4$ and ${}^3/_4$ are composed of an alternate arrangement of molecules 1 and 3, whereas those at $x = {}^1/_2$ are constructed entirely from molecule 2. The rather spacious environment of the *i*-Bu groups is consistent with their abnormally large thermal displacement parameters and disordered arrangement (Figures 1 and 2).

The H$_2$O−Co−*i*-Bu fragment is characterized by the O−Co−C$_\alpha$ angle, Co−C$_\alpha$−C$_\beta$ angle, Co−C$_\alpha$ and Co−O bond lengths.[1b] Our results indicate that the O−Co−C$_\alpha$ angles are 177.0(1)° in molecule 1, 177.4(1)° in molecule 2, and 167.3(1)° and 166.8(1)° in molecule 3, respectively, while the Co−C$_\alpha$−C$_\beta$ angles are 121.4(2)°, 122.3(2)°, 121.6(2)°, 119.8(3)°, and 129.1(3)°, respectively. The Co−C$_\alpha$ bond lengths are 1.986(3) Å in molecule 1, 2.011(3) Å in molecule 2, and 2.038(4) and 1.999(4) Å in molecule 3, respectively. The Co−O bond lengths are 2.026(2), 2.052(2), and 2.058(2) Å, respectively. The orientation of the alkyl group with respect to the equatorial plane are described by torsion angles of C$_\beta$−C$_\alpha$−Co−N(eq) and C$_\gamma$−C$_\beta$−C$_\alpha$−Co (data listed in supporting materials). Comparisons

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Table 2. Selected Bond Lengths (Å) and Angles (deg) of *i*-BuCo(DH)$_2$H$_2$O (**I**)

Co(1)−N(1)	1.882(2)	Co(2)−N(5)	1.862(2)	Co(3)−N(9)	1.893(3)
Co(1)−N(2)	1.888(3)	Co(2)−N(6)	1.894(2)	Co(3)−N(10)	1.889(2)
Co(1)−N(3)	1.890(2)	Co(2)−N(7)	1.896(2)	Co(3)−N(11)	1.894(2)
Co(1)−N(4)	1.901(2)	Co(2)−N(8)	1.864(2)	Co(3)−N(12)	1.856(3)
Co(1)−O(1W)	2.026(2)	Co(2)−O(2W)	2.052(2)	Co(3)−O(3W)	2.058(2)
Co(1)−C(1′)	1.986(3)	Co(2)−C(5′)	2.011(3)	Co(3)−C(9′)	2.038(4)
				Co(3)−C(9″)	1.999(4)
C(1′)−C(2′)	1.527(4)	C(5′)−C(6′)	1.523(4)	C(9′)−C(10′)	1.527(4)
C(1′)−C(2″)	1.528(4)			C(9″)−C(10″)	1.516(5)
N(1)−Co(1)−C(1′)	93.25(9)	N(5)−Co(2)−C(5′)	90.72(11)	N(9)−Co(3)−C(9′)	80.50(13)
N(2)−Co(1)−C(1′)	89.16(10)	N(6)−Co(2)−C(5′)	93.79(10)	N(10)−Co(3)−C(9′)	96.53(11)
N(3)−Co(1)−C(1′)	91.12(10)	N(7)−Co(2)−C(5′)	87.78(10)	N(11)−Co(3)−C(9′)	85.10(11)
N(4)−Co(1)−C(1′)	88.46(9)	N(8)−Co(2)−C(5′)	90.17(11)	N(12)−Co(3)−C(9′)	100.14(13)
O(1W)−Co(1)−C(1′)	176.97(8)	O(2W)−Co(2)−C(5′)	177.41(9)	O(3W)−Co(3)−C(9′)	167.33(11)
				N(9)−Co(3)−C(9″)	100.5(2)
				N(10)−Co(3)−C(9″)	83.82(13)
				N(11)−Co(3)−C(9″)	97.87(13)
				N(12)−Co(3)−C(9″)	80.2(2)
				O(3W)−Co(3)−C(9″)	166.80(14)
				C(9′)−Co(3)−C(9″)	25.8(2)
Co(1)−C(1′)−C(2′)	121.4(2)	Co(2)−C(5′)−C(6′)	121.6(2)	Co(3)−C(9′)−C(10′)	119.8(3)
Co(1)−C(1′)−C(2″)	122.3(2)			Co(3)−C(9″)−C(10″)	129.1(3)

Table 3. Extent of Co(DH)$_2$ Distortion in *i*-BuCo(DH)$_2$H$_2$O (**I**)

	1 (1′)	2	3	3′
d (Å)[a]	−0.02	−0.03	−0.02	−0.02
α (deg)[b]	1	3	2	1

[a] Displacement (*d*) of Co atom from the 4-N equatorial plane. [b] Dihedral angle (α) between the DH planes.

Table 4. Selected Bond Lengths (Å) and Angles (deg) of *i*-BuCo(DH)$_2$ H$_2$O/α-CD (**II**) in **II**·8H$_2$O

Co(1)−N(1)	1.889(3)	Co(1)−N(2)	1.907(3)
Co(1)−N(3)	1.865(3)	Co(1)−N(4)	1.897(3)
Co(1)−C(1′)	2.016(4)	Co(1)−O(1W)	2.159(3)
C(1′)−C(2′)	1.499(6)	C(2′)−C(3′)	1.517(7)
C(2′)−C(4′)	1.521(6)		
N(1)−Co(1)−C(1′)	94.0(2)	N(2)−Co(1)−C(1′)	88.4(2)
N(3)−Co(1)−C(1′)	87.3(2)	N(4)−Co(1)−C(1′)	93.4(1)
N(1)−Co(1)−O(1W)	88.9(1)	N(2)−Co(1)−O(1W)	89.8(1)
N(3)−Co(1)−O(1W)	89.7(1)	N(4)−Co(1)−O(1W)	88.4(1)
C(1′)−Co(1)−O(1W)	176.2(1)	Co(1)−C(1′)−C(2′)	123.6(3)
C(1′)−C(2′)−C(3′)	112.6(5)	C(1′)−C(2′)−C(4′)	109.8(3)
C(3′)−C(2′)−C(4′)	108.1(3)		

reveal that rotations around the Co−C$_\alpha$ and C$_\alpha$−C$_\beta$ bonds appear in the compound. Apparently, in the three independent molecules, the C$_\alpha$−C$_\beta$ all lie above between two DH units. Further, the extent of Co(DH)$_2$ distortion is measured by the dihedral angle(α) between the DH planes and the displacement (*d*) of Co from the 4-N equatorial plane.[1b] Data show that almost planar shape for the equatorial Co(DH)$_2$ and Co atom is almost in the 4-N plane for all three molecules (Table 3).

Structure Description of *i*-BuCo(DH)$_2$H$_2$O/α-CD (II) in II·8H$_2$O. The lattice water molecules link the *i*-BuCo(DH)$_2$H$_2$O/α-CD host/guest complexes into a three-dimensional network, and the *i*-Bu group is inserted into the cyclodextrin cavity from its wider opening. With respect to the plane involving O atoms associated with the twelve secondary OH groups (plane 1), the C(2′), C(3′), and C(4′) at *i*-Bu group are above the plane 1 for 0.3, 0.5, and 1.7 Å, respectively, whereas C(1′) is below plane 1 for 0.6 Å. The distances of O(1W), Co(1), C(1′), C(2′), C(3′), and C(4′) to the pseudo-*C*$_6$ axis of α-CD are 1.2, 1.2, 1.3, 0.2, 1.3, and 0.9 Å, respectively (Figure 3 and Table 4).

In addition, the 4-N plane (plane 2) of Co(DH)$_2$ unit is almost parallel to plane 1 (dihedral angle, 1.5°). While the DH plane involving N1, N2, O1, O2, C1, C2, C3, and C4 (plane 3) makes a dihedral angle 8.1° with plane 1, the value for the another DH plane composed of N3, N4, O3, O4, C5,C6, C7, and C8 (plane 4) is 2.4°. The two DH plane make an angle of 9.3°(α).

As for the guest molecule, its O−Co−*i*-Bu fragment is characterized by Co−O, Co−C$_\alpha$, and C$_\alpha$−C$_\beta$ bond lengths of 2.159(3), 2.016(4), and 1.499(6) Å, respectively, and O−Co−C$_\alpha$ and Co−C$_\alpha$−C$_\beta$ angles of 176.2(1) and 123.6(3)°, respectively. Torsion angles of C$_\beta$−C$_\alpha$−Co(1)−N(eq) (see Supporting Information) reveal that C$_\alpha$−C$_\beta$ bond lies above one DH ligand (plane 4).

Structure Description of *i*-BuCo(DH)$_2$H$_2$O/β-CD (III) in III·9H$_2$O. The host/guest complexes are linked by lattice water molecule into a three-dimensional network. The *i*-Bu group at cobaloxime is also included into the β-CD cavity from the secondary hydroxyl side, where C(1′), C(2′), C(3′), and C(4′) are above the mean plane of the O atoms associated with the fourteen secondary OH groups (plane 1′) by 0.04, 1.09, 1.82, and 1.83 Å, respectively. The distance of O(1W), Co(1), C(1′), C(2′), C(3′), and C(4′) to the pseudo-*C*$_7$ axis of β-CD are 0.86, 1.17, 1.59, 0.57, 1.31, and 0.96 Å, respectively. The dihedral angle between 4-N plane (plane 2′) and plane 1′ is 11°, indicating that plane 2′ is oblique to plane 1′. In addition, the dihedral angles between plane 1′ and two DH planes are 15° and 11°, respectively. The bending angle (α) of two DH planes are only 4° (Figure 4 and Table 5).

The parameters for characterization of the O−Co−*i*-Bu fragment present that Co−O, Co−C$_\alpha$, and C$_\alpha$−C$_\beta$ distances are 2.104(2), 2.017(4), and 1.460(5) Å, respectively, and C$_\alpha$−Co−O and Co−C$_\alpha$−C$_\beta$ angles are 175.4(1) and 122.9(3)°, respectively. Additionally, according to the torsion angles of C$_\beta$−C$_\alpha$−Co(1)−N(eq) (see Supporting Information), it has been suggested that the axial C$_\beta$−C$_\alpha$ bond lies above near one of the equatorial Co−N bond.

Discussion

The present study reveals that the structural model for *i*-BuCo(DH)$_2$H$_2$O/α-CD is similar to that for our previous reported *n*-PrCo(DH)$_2$H$_2$O/α-CD. The common features for the two inclusion complexes are as follows: (a) the alkyl group of the guest molecule is inserted into the α-CD cavity from its wider opening; (b) the 4-N plane of the cobaloxime is parallel to the plane consisting of twelve secondary OH groups of α-CD; (c)

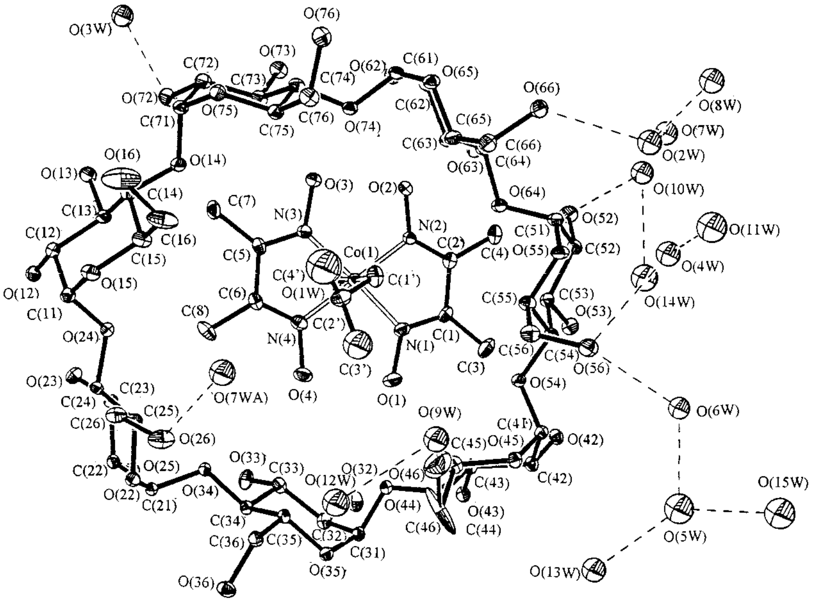

Figure 4. Structure and numbering scheme of *i*-BuCo(DH)$_2$H$_2$O/*β*-CD (**III**) in **III**·9H$_2$O.

Table 5. Selected Bond Lengths (Å) and Angles (deg) of *i*-BuCo(DH)$_2$ H$_2$O/*β*-CD (**III**) in **III**·9H$_2$O

Co(1)–N(1)	1.848(3)	Co(1)–N(2)	1.894(2)
Co(1)–N(3)	1.869(3)	Co(1)–N(4)	1.882(3)
Co(1)–C(1′)	2.017(4)	Co(1)–O(1W)	2.104(2)
C(1′)–C(2′)	1.467(6)	C(2′)–C(4′)	1.235(13)
C(2′)–C(3′)	1.344(11)		
N(1)–Co(1)–C(1′)	92.3(2)	N(3)–Co(1)–C(1′)	87.76(15)
N(4)–Co(1)–C(1′)	93.0(2)	N(2)–Co(1)–C(1′)	88.89(15)
N(1)–Co(1)–O(1W)	89.03(11)	N(3)–Co(1)–O(1W)	91.06(10)
N(4)–Co(1)–O(1W)	91.11(11)	N(2)–Co(1)–O(1W)	86.96(10)
C(1′)–Co(1)–O(1W)	175.44(14)	C(2′)–C(1′)–Co(1)	122.9(3)
C(4′)–C(2′)–C(3′)	109.3(8)	C(4′)–C(2′)–C(1′)	120.3(7)
C(3′)–C(2′)–C(1′)	116.7(6)		

the Co(DH)$_2$ unit bends away from α-CD, and distortions become appreciable (the bending angle (α) are from 1° to 10° for *n*-PrCo(DH)$_2$H$_2$O/α-CD and from 1–3° to 9° for *i*-BuCo(DH)$_2$H$_2$O/α-CD); (d) the Co–O bond length is responsive to the Co(DH)$_2$ distortions and becomes longer than that in the uncomplexed guest molecule; (e) since the bending of the two DH units causes the Co atoms to lie out of 4-N plane toward the R group, the Co–C bond length is expected to be shorter. However, the observed Co–C distances in complexes are almost the same as in the uncomplexed guest molecule, which probably implies the relaxation of the Co–C bond. These results present another example to support our suggestion that the distortion of the guest molecule is induced by steric interaction between Co(DH)$_2$ and the α-CD rim.[24a] Certainly, some differences for two RCo(DH)$_2$H$_2$O/α-CD are also seen. The *n*-propyl group of *n*-PrCo(DH)$_2$H$_2$O is inserted into α-CD cavity more deeply, which probably suggests that the *n*-propyl group fits into an α-CD cavity better than the *i*-butyl group. The result is in agreement with the quantitative NMR determination that the formation constant of *n*-PrCo(DH)$_2$H$_2$O/α-CD ($K_f = 4.9 \times 10^2$) is larger than that of *i*-BuCo(DH)$_2$H$_2$O/α-CD ($K_f = 3.7 \times 10^2$).[24a]

Furthermore, comparing the inclusion model of *i*-BuCo(DH)$_2$H$_2$O/*β*-CD with that of *i*-BuCo(DH)$_2$H$_2$O/α-CD shows (Figure 5) that the *iso*-butyl group at cobaloxime is inserted into cavity from wide opening for both complexes. However, it is found that in the *β*-CD complex (a) the *i*-Bu group is deeper into the host cavity; (b) the 4-N plane is oblique to the plane at *β*-CD consisting of fourteen secondary OH groups; (c) one DH plane bends away from *β*-CD, while the other bends toward the rim of *β*-CD (see Figure 5); (d) the distortion of Co(DH)$_2$ in *β*-CD inclusion complex (α = 4°) is less than that in α-CD inclusion complex (α = 9°); (e) Co–O bond length for the guest molecule is somewhat longer in the α-CD inclusion complex, while Co–C bond lengths are similar for both α-CD and *β*-CD complexes. In addition, the orientation of the *i*-Bu moiety with respect to Co(DH)$_2$ in α-CD and *β*-CD inclusion complexes is similar, but different to that in *i*-BuCo(DH)$_2$ H$_2$O. It is well accepted that the diameters of CDs' can be characterized by the distances of the O(4) atoms from the pseudo-C_n axis. They were calculated to be 4.2–4.5 Å for α-CD and 4.8–5.2 Å for *β*-CD,[21c] respectively. Since the *i*-Bu has a carbon side chain, it is probably better fitted into a *β*-CD cavity than a α-CD cavity. Therefore, a deeper insertion of the R group and greater asymmetric bending of the two DH planes were observed in *β*-CD inclusion complex. Formation constants measured by NMR method, 1.17 × 10^3 for *i*-BuCo(DH)$_2$H$_2$O/*β*-CD and 3.7 × 10^2 for *i*-BuCo(DH)$_2$H$_2$O/α-CD, are consisted with the present crystal structures.

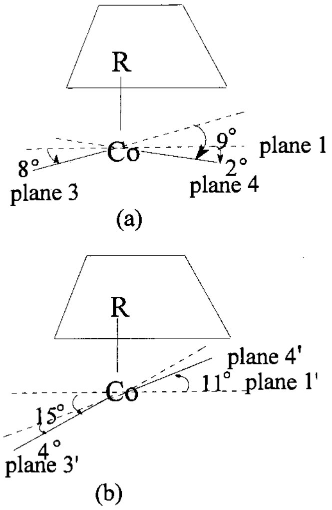

Figure 5. Orientation of *i*-BuCo(DH)$_2$H$_2$O to (a) α-CD and (b) *β*-CD.

Conclusions

Single-crystal X-ray analysis has shown that *iso*-butyl(aqua)cobaloxime undergoes significant changes in structure and conformation upon formation of inclusion complexes with α-CD and *β*-CD. The distortions of alkylcobaloxime effected by α-CD and *β*-CD, and the orientations of *iso*-butyl(aqua)cobaloxime with respect to α-CD and *β*-CD are somewhat different. The results are attributed to hydrophobic interactions between *iso*-butyl and CDs cavities, and steric interactions between $Co(DH)_2$ and CDs rim, as well as the match of geometry between the host and the guest.

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Supporting Information Available: Tables of positional parameters extensive bond distances and bond angles, some torsion angles, least-squares planes, and anisotropic thermal parameters (36 pages) for **I**, **II**·$8H_2O$, and **III**·$9H_2O$.

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