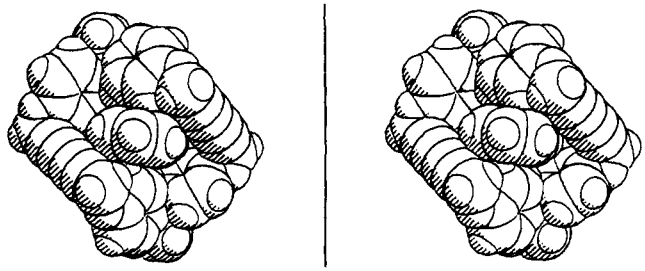

Figure 1. Stereoscopic view of a computer-generated space-filling drawing, based on the X-ray coordinates of molecule **3**, with an included benzene molecule. van der Waals radii of 1.2 Å for H, 1.85 Å for C, and 1.4 Å for O were used. The benzene is clamped at the edge of **3**. Four other benzenes in lattice positions are not shown; two intrude into the cavity of **3**, while the other two are outside the cage. The X-ray data were collected at −100 °C to avoid crystal decomposition, probably benzene loss. The crystal of **3** obtained was triclinic, $P\bar{1}$, $Z = 2$, $a = 15.1221$ (29) Å, $b = 15.5931$ (30) Å, $c = 15.7000$ (41) Å, $V = 3463$ (1) Å^3. A total of 5598 reflections were refined to a final R_w 0.141. Each unit cell contains one left-handed twist molecular complex as shown and one more right-handed mirror image of it.

in 66% yield from tri-*p*-anisylcarbinol.

The dimeric coupling reaction of **2** failed completely under standard and high-dilution coupling conditions ($Cu(OAc)_2$ in pyridine[1c] and Cu(I)–TMEDA–O_2[6]). However, we have devised a new copper coupling procedure that is extremely mild and efficient and that we have used for related couplings. Treatment of **2** (515 mg, 1.23 mmol) in O_2-free pyridine (1230 mL) with anhydrous CuCl (12.1 g, 123 mmol) and anhydrous $CuCl_2$ (2.0 g, 15 mmol) for 48 h at 0 °C gave the cage dimer **3**, mp 180 °C dec, in 35% yield after isolation by preparative plate chromatography (2 mm silica, R_f 0.85, CH_2Cl_2 eluent) and crystallization from benzene. The ^1H NMR in CD_2Cl_2 showed an AA′BB′ pattern for the aromatic hydrogens (7.10, 6.88 ppm, $J = 8.5$ Hz), while the propargyl methylenes and the bridgehead methyls were singlets at 4.78 and 2.05 ppm, respectively.

The crystals of **3** from benzene were suitable for an X-ray structure determination. The picture derived from the crystal structure (Figure 1) shows that one benzene molecule is tightly clamped in the cavity and shows no disorder and two others are more loosely held in the cavity, while two others occupy lattice positions around molecule **3**. Furthermore, as Figure 1 shows, the molecule **3** is twisted by rotation of one triphenylethane unit relative to the other. We show the molecule with a left-handed helical twist, but the unit cell actually contains one left- and one right-handed molecule, with interlocking acetylene chains. The "dihedral" twist angles between phenyl rings across the C_3 rotation axis[1d] are 28°, 35°, and 41°. The lack of a crystallographic C_3 axis reflects the presence of the three unsymmetrically included benzenes. *This twisting brings the two triphenylethane units together, clamping the tightly held benzene molecule in place.* In molecular models the untwisted structure, with the triphenylethane units further apart, is more open and more easily admits the benzene molecule.

The further elaboration of this type of cage molecule must involve the attachment of catalytic and water solubilizing groups. It will also be of interest to see whether with bulkier guest molecules inside the cavity the twist angle is smaller, as expected. The highly efficient one-pot synthesis should make it possible to explore all these questions.

Acknowledgment. This work was supported by the NIH and NSF.

Supplementary Material Available: Crystallographic data, ORTEP, atomic coordinates, bond lengths, bond angles, anisotropic temperature factors, hydrogen coordinates and temperature factors, and reflections, of the cage molecule (47 pp). Ordering information is given on any current masthead page.

(6) (a) Hay, A. S. *J. Org. Chem.* **1962**, *27*, 3320. (b) Hay, A. S. *J. Org. Chem.* **1960**, *25*, 1275.

A-(Modified B_6)-B-[ω-amino(ethylamino)]-β-cyclodextrin as an Artificial B_6 Enzyme for Chiral Aminotransfer Reaction

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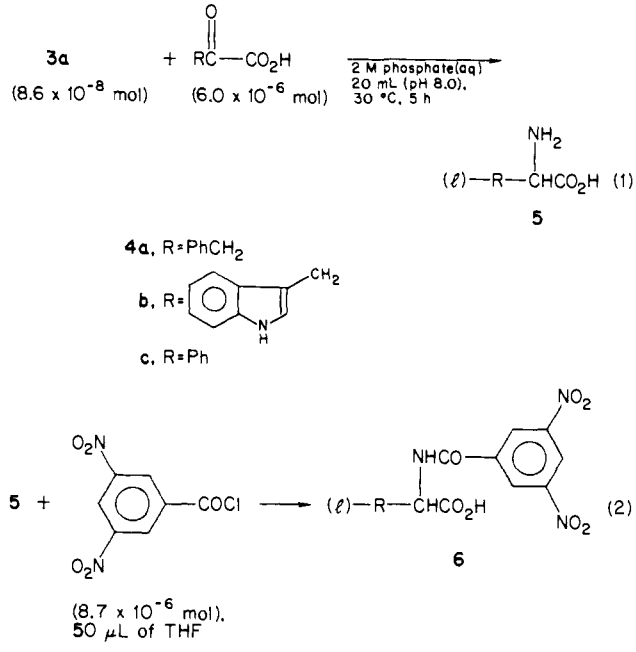
In Kyoto we have studied the regiospecific introduction of functional groups into cyclodextrin for the construction of enzyme mimics;[1] at Columbia pyridoxamine has been attached to cyclodextrin to promote substrate binding, and flexible chains carrying amino groups have been attached to pyridoxamine to promote proton transfers, including stereospecific amino acid synthesis.[2] We now wish to report the coalescence of these research lines: the synthesis of B_6-dependent aminotransferase model **3** (see Chart I): (1) converting certain keto acids into amino acids under mild conditions in water, (2) consisting of two cooperating units, a modified B_6 coenzyme grouping and an ω-amino apoenzyme grouping, (3) exhibiting almost exclusive L-chiral induction from keto-prochiral groupings (see eq 1).



Thus, A,B-capped cyclodextrin **1** was converted to the B_6 model **3** via diiodide **2**[3] by using pyridoxamine thiol[2a,b] under the con-

(1) (a) Tabushi, I.; Shimokawa, K.; Shimizu, N.; Shirakata, H.; Fujita, K. *J. Am. Chem. Soc.* **1978**, *98*, 7855. (b) Tabushi, I.; Kuroda, Y.; Yokota, K.; Yuan, L. C. *Ibid.* **1981**, *103*, 711. (c) Tabushi, I.; Yuan, L. C.; Shimokawa, K.; Mizutani, T.; Kuroda, Y. *Tetrahedron Lett.* **1981**, *22*, 2273. (d) Tabushi, I.; Yuan, L. C. *J. Am. Chem. Soc.* **1981**, *103*, 3574. (e) Tabushi, I.; Kuroda, Y.; Yokota, K. *Tetrahedron Lett.* **1982**, *23*, 4601. (f) Tabushi, I.; Yamamura, K.; Nabeshima, T. *J. Am. Chem. Soc.* **1984**, *106*, 5267. (g) Tabushi, I.; Nabeshima, T.; Fujita, K.; Matsunaga, A.; Imoto, T. *J. Org. Chem.* **1985**, *50*, 2638. For review, see: Tabushi, I., *Acc. Chem. Res.* **1982**, *15*, 66. Tabushi, I.; Kuroda, Y. *Adv. Catal.* **1983**, *32*, 417.

(2) (a) Breslow, R.; Hammond, M.; Lauer, M. *J. Am. Chem. Soc.* **1980**, *102*, 421. (b) Breslow, R.; Czarnik, A. W. *Ibid.* **1983**, *105*, 1390, (c) Zimmerman, S. C.; Czarnik, A. W.; Breslow, R. *Ibid.* **1983**, *105*, 1694. (d) Winkler, J.; Coutouli-Argyropoulou, E.; Leppker, R.; Breslow, R. *Ibid.* **1983**, *105*, 7198. (e) Zimmerman, S. C.; Breslow, R., *Ibid.* **1984**, *106*, 1490.

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Chart I. Preparation of Regioisomeric Artificial B_6 Enzymes from A,B-Capped Cyclodextrin

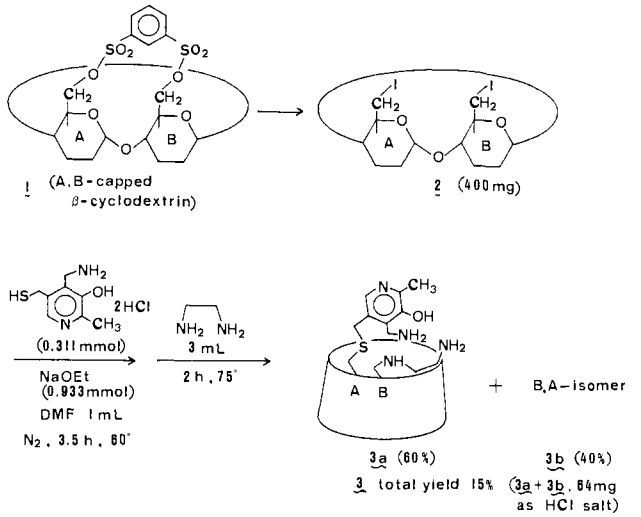
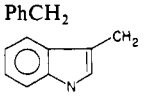


Table I. Characteristic Spectra of **3a**

electronic, nm (ε)	(aq, pH 8.0) 250 (ε 4400), 324 (6600)
400-MHz ^{1}H NMR; ppm from TSP	(D_2O, pH 4.0) SC_6H δ 2.55 dd (J = 12.6, 7.6 Hz), 2.82 dd (J = 12.6, 1.7 Hz). **3b**: 2.64 dd (J = 11.2 Hz, 7.7), and 3.01 dd (J = 11.2 Hz, 1.0).
100-MHz ^{13}C NMR; ppm from TSP	(D_2O, pH 4.0) 157.7, 144.4, 137.5, 132.5, 103.6, 102.8, 84.5, 83.2, 82.9, 74.9, 74.6, 74.3, 74.1, 73.9, 73.7, 73.5, 69.3, 62.5, 62.3, 50.2, 46.7, 37.3, 36.9, 33.7, 33.0, 16.9

Table II. Chiral Induction in Amino Acids Formed via the Artificial B_6 Catalysis[a]

R-$COCO_2H$	L/D
R = $PhCH_2$	98/2
	95/5[b]
Ph	98/2[b]

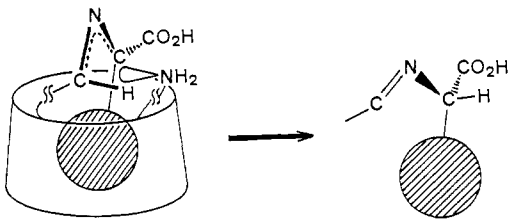
[a] At 30 °C, 2 M K_2HPO_4-KH_2PO_4 buffer, pH 8.0. [b] Recorded ratio is lowest limit.

ditions listed in Chart I. The crude mixture free from ethylenediamine was applied on a CM-25 Sephadex column. From 0.12-0.15 M NH_4HCO_3 gradient via the usual workup was obtained 64 mg of **3**·HCl (15% yield).

Separation of the two regioisomers **3a** and **3b** was successfully carried out again by CM-25 column chromatography of a prepurified **3a** + **3b** mixture (60/40 ratio) by the use of a long, thin column (5 × 1500 mm) eluted with aqueous NH_4HCO_3 (0-0.1 M gradient). The observed elution diagram obtained by measuring intensities of the absorption at 324 nm (B_6 chromophore) of each 3-mL fraction clearly shows that the two regioisomers are satisfactorily separated. The latter eluent was recrystallized from aqueous EtOH twice, giving pure A,B regioisomer **3a**, while from the earlier fractions, pure B,A regioisomer **3b**, was similarly obtained. Both compounds showed pyridoxamine characteristic CH_2 signals and ethylenediamine CH_2 signals in expected intensities, but the signals of **3a** SCH_2 at C_6 were found at 2.82 and 2.55 ppm while those of **3b** were at 3.01 and 2.64 ppm. Less than 1% of the contaminating signal could be seen (see further Table I).

The aminotransfer reaction smoothly proceeded between **3a** and keto acids **4a-c** under the conditions described in eq 1, giving the corresponding amino acids **5a-c**, respectively. The amino acids formed were further converted to the 3,5-dinitrobenzamides **6a-c** which were acidified (pH 3) and extracted with ether (10 mL × 3). The condensed ether layer (150 μL) was analyzed by HPLC by using a Sumipax OA-1000 chiral column eluted with a $MeOH/H_2O/CH_3CO_2H$ mixture (95/5/1 vol). The two peaks of each racemic amino acid derivative were clearly resolved. Under the conditions, total yields of amino acids were ca. 40%[4] and the enantiomeric excess observed for L-amino acid was very high, as listed in Table II.

The observed high chiral induction for **3a** may be understood on the basis of stereospecific participation[2e] of the ω-NH_2 grouping toward the prochiral azomethine plane fixed nearly perpendicular toward the N-lone pair during the prototropy (see eq 3), due to


(3)

the host-guest multiple recognition.[1,5] The mechanism is further supported by the acceleration of prototropy caused by the assisting NH_2 group on the B ring. The observed prototropy rate ratio followed spectroscopically, k (**3**) to k (free B_6), was ca. 2000-2200 in the L-phenylalanine formation reaction, in a good agreement with the observed chiral induction.[6]

(4) The present yield of **6** is neither corrected for the conversion in acylation (which may not be exactly the same for D- and L-amino acid) nor the extraction efficiency.

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(6) Or, rate ratio k (**3**) to k (B_6 cyclodextrin) was 10-11. Detailed analysis of complex multiphase kinetics will appear in a full-length article.

Formation of CO_2 and a Four-Membered 1,3-Dimetallacycle by Deoxygenation of a Ketone with $[Rh(CO)_2Cl]_2$

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8-substituted quinoline ligands have proven useful in studies of carbon-hydrogen and carbon-carbon bond activation by transition metals.[1] They allow specific ligand bonds to be brought into a metal's coordination sphere whereupon reaction can occur. We now wish to describe an unexpected example of deoxygenation of a ketone by a rhodium carbonyl complex in an 8-substituted quinoline ligand.

When 8-quinolinyl phenyl ketone (**1**) and $[Rh(CO)_2Cl]_2$ (**2**) are mixed in benzene at 25 °C under argon (mole ratio 1:1) the initially yellow solution darkens to a deep red color within 1 h.[2] At this time CO_2 evolution begins, as shown by a new IR band in the solution at 2330 cm^{-1} and by trapping of the evolved gas using $Ca(OH)_2$. The CO_2 evolution continues for approximately 24 h. Absorption of the CO_2 on Ascarite indicates slightly less than 1 mol of CO_2 is formed per mole of ketone. Deep red crystals of a new compound **3**, slowly formed and after 3 days these were collected (67% yield).[3] They can be handled in air, but slowly

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(2) Upon mixing, a new species with IR bands at 2098, 2080, 2026, 2011, and 1652 cm^{-1} forms. The decrease in the ketone band from 1668 cm^{-1} in **1** to 1652 cm^{-1} is consistent with bidentate N,O coordination of **1** to a rhodium species.

(3) **3**: mp 172-174 °C dec; IR (CH_2Cl_2) 2079 (s), 2057 (m), 2011 (s) cm^{-1}; NMR (250 MHz, ^{1}H, CD_2Cl_2) δ 8.28 (dd, 1 H), 7.86 (dd, 1 H), 7.50 (dd, 1 H), 7.40 (dd, 1 H), 7.4-7.3 (m 6 H), 7.01 (dd, 1 H).

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