# A New Ruthenium(II) Chiroporphyrin Containing a Multipoint Recognition Site: Enantioselective Receptor of Chiral Aliphatic Alcohols

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The design of chiral porphyrins as asymmetric catalysts[1] and selective receptors of optically active natural products[2a−g] or synthetic ligands[2h] is of increasing interest in the development of enantioselective synthesis, and of molecular and chiral recognition.[3] Our approach to $C_2$-symmetric metalloporphyrin catalysts, based on Pfaltz's analysis,[4] is to attach bulky substituents on chiral centers near the plane of the tetrapyrrolic ring, as close as possible to the metal atom to maximize steric interaction with incoming substrate. We have shown recently[5] that a *chiroporphyrin* catalyst possessing these topological features can be easily constructed from a chiral cyclopropanecarbaldehyde derivative. We report here that the chiroporphyrin unit also possesses multipoint binding properties with potentially important applications in chiral recognition of aliphatic alcohols. We find that tetra*methyl*chiroporphyrin $H_2$-TMCP, **1**, is obtained from (1*R*)-*cis*-caronaldehydic acid *methyl* ester[6,7] and pyrrole as the desired $D_2$-symmetric $\alpha\beta\alpha\beta$ atropisomer exclusively.[8] Its (carbonyl)ruthenium(II) complex was obtained by gentle metal insertion with dodecacarbonyltriruthenium in refluxing toluene. Recrystallization from dichloromethane−ethanol gave X-ray quality crystals of the six-coordinate complex Ru(CO)(EtOH)TMCP,[9a] **2**. The $^1$H and $^{13}$C NMR spectra of **2** are consistent with the expected $C_2$ symmetry axis along the Ru−C−O fragment.[9b,c]

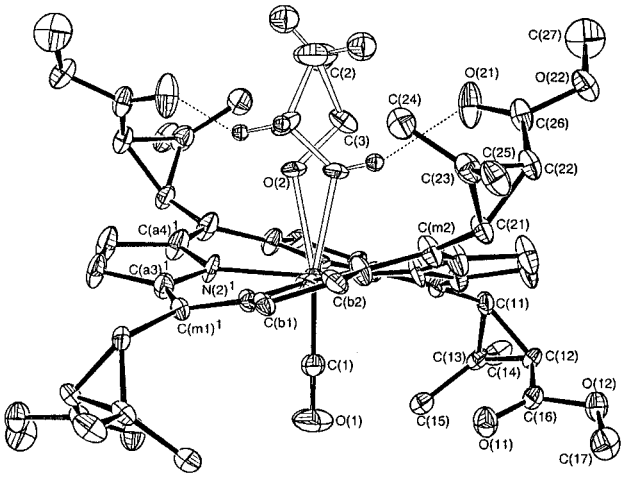
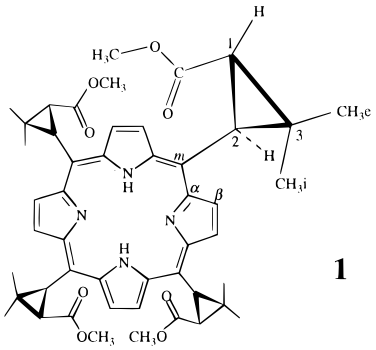



**Figure 1.** ORTEP view of the structure of Ru(CO)(EtOH)TMCP, **2**, showing the $C_2$ symmetry and ruffled conformation of the chiroporphyrin complex. The two symmetry-related sites of the disordered ethanol ligand are shown, but the hydrogen atoms are drawn for one site only. Hydrogen bonds are indicated by dotted lines. Selected bond distances (Å) and angles (deg): Ru(1)−N(1) = 2.026(5), Ru(1)−N(2) = 2.023(5), Ru(1)−C(1) = 1.839(9), Ru(1)−O(2) = 2.225(9), C(1)−O(1) = 1.126(12), O(2)−C(3) = 1.43(2), C(3)−C(2) = 1.60(2); N(1)−Ru(1)−N(2) = 88.9(2), N(1)−Ru(1)−N(1)$^b$ = 173.8(3), N(2)−Ru(1)−N(1)$^b$ = 90.7(2), N(2)−Ru(1)−N(2)$^b$ = 172.5(4), C(1)−Ru(1)−N(1) = 93.1(2), C(1)−Ru(1)−N(2) = 93.8(2), O(2)−Ru(1)−N(1) = 82.5-(3), O(2)−Ru(1)−N(2) = 97.1(3), C(1)−Ru(1)−O(2) = 168.2(2), O(2)−C(3)−C(2) = 104.4(10), Ru(1)−C(1)−O(1) = 180.0(9).

The stereochemistry of Ru(CO)(EtOH)TMCP, **2**, is confirmed by its X-ray structure[10] (Figure 1). The cyclopropyl substituents of the ruffled porphyrin are oriented alternatively toward either face of the macrocycle. The *cis* configuration of the ester and porphyrin groups on each cyclopropane constrains the methyl

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(7) This compound was obtained in 71% overall yield and >99% diastereomeric purity from its precursor (1*R*)-*cis*-hemicaronaldehyde ("biocartol") by an improved procedure described in the Supporting Information.

(8) Yield: 4% of **1**.

(9) (a) Analytical data for **2** are supplied in the Supporting Information. (b) Le Maux, P.; Bahri, H.; Simonneaux, G. *Tetrahedron* **1993**, *49*, 1401. (c) Le Maux, P.; Bahri, H.; Simonneaux, G.; Toupet, L. *Inorg. Chem.* **1995**, *34*, 4691.

(10) $C_{51}H_{58}N_4O_{10}Ru$, tetragonal, space group $P4_32_12$, $a$ = 13.324(4) Å, $c$ = 26.165(4) Å, $Z$ = 4, $T$ = 127 K. Initial coordinates of the porphyrin ligand were taken from the isomorphous structure of the corresponding chloromanganese(III) complex, the structure of which was solved by Patterson methods. Atoms of the axial ligands and ruthenium were found in a difference Fourier map. All non-hydrogen atoms were refined anisotropically on $F^2$ with SHELX [11] using the both Friedel reflection pairs (FAST area detector data). Hydrogen atoms were included as fixed, idealized contributors. The absolute configuration was assigned and confirmed by the Flack absolute structure parameter of 0.04(7). [12] Current $R_1$ = 0.085 (5099 observed data) and $wR_2$ = 0.184 for all 5474 data.

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ester groups to lie on the porphyrin ring, with the carbonyl oxygen atoms nearly eclipsing four α pyrrole carbon atoms. One methyl of the *gem*-dimethyl group in each cyclopropane also lies on the porphyrin ring, thus defining a $C_2$-symmetric groove of *ca.* 3−4 Å width along a $C_{meso}-C_{meso}$ axis on each face of the porphyrin. The carbonyl and ethanol axial ligands of ruthenium are accommodated within each of the two grooves; the latter is disordered with both the hydroxyl and methylene groups equally distributed over two $C_2$-related sites. This unusual off-axis location of the hydroxyl oxygen atom[13] is the result of a hydrogen bond to the neighbouring carbonyl oxygen atom (O···O distance 3.170 Å, O−H···O angle 162.34°, H···O═C angle 139.56°). Similarly, the conformation of the methylene group reflects a weak C−H···O hydrogen bond[14] to the other carbonyl group (O···C distance 3.177 Å, O···H−C angle 142.31°, H···O═C angle 153.74°).[15]

The $^1$H NMR spectrum of **2** at −50 °C shows the signature of the ethanol axial ligand as four sharp, well-resolved resonances at high field ($\delta = -1.44$ (*m*, 1H), −1.74 (*m*, 1H), −2.05 (*m*, 3H), −4.39 (*m*, 1H); Figure S1, see Supporting Information); they are assigned to either methylene proton and to the methyl and hydroxyl protons of coordinated ethanol, respectively, by a combination of $^1$H−$^1$H and $^{13}$C−$^1$H COSY experiments.[15] The two diastereotopic methylene protons located within the chiral groove are anisochronous in the slow exchange limit,[16] indicating that the conformation observed in the solid state is maintained in solution at low temperatures.

Axial ligand exchange was readily obtained by addition of excess (±)-2-octanol (*ca.* 6 equiv) to a $CD_2Cl_2$ solution of **2** at room temperature. At −50 °C the $^1$H NMR spectrum showed the expected resonances of coordinated 2-octanol in the region between −5 and 0 ppm (Figure S2; see Supporting Information). Particularly striking is the appearance of the hydroxylic protons as two well-resolved doublets ($\delta = -4.70$ and −4.60) of unequal intensities, immediately revealing enantioselective coordination to the chiral ruthenium(II) center with a selection ratio of *ca.* 2.2 (see inset of Figure S2). Detailed low-temperature $^1$H−$^1$H DQF−COSY experiments on the individual complexes of (*R*)- and (*S*)-2-octanol led to the diastereomeric assignments shown in the table of NMR data in the Supporting Information and to the identification of the (*R*)-enantiomer as the preferentially bound axial ligand. Selective binding of the (*R*)-enantiomer was similarly observed for 2-butanol (NMR data, Supporting Information) with a binding ratio $K_R/K_S = ca.$ 2, but not for 1-phenylethanol which apparently is unable to coordinate to the ruthenium(II) center of **2**.

The multipoint recognition site of secondary alcohols in **2** includes coordination of O to the Ru atom, C−H···O and O−H···O hydrogen bonding. However only the first two act on substituents of the chiral center ($^2$C*−O and $^2$C*−H). Since chiral recognition requires spatially oriented interactions on three points at least,[17] a third interaction must take place between the remaining methyl or *n*-hexyl substituents of the chiral center $^2$C* and the chiroporphyrin. The configuration of the *(R)*-2-octanol complex was deduced from the structure of **2** by keeping the H-bonded hydrogen atom on $^2$C and substituting the other hydrogen for a *n*-hexyl group. A model of the *(S)*-2-octanol complex was then obtained by permutation of the methyl and *n*-hexyl substituents on $^2$C. The *n*-hexyl substituent of the coordinated (*R*)-enantiomer lies within the groove of the porphyrin ring, whereas it points toward the outside of the porphyrin for the (*S*)-enantiomer[18] (Figure 2). We conclude that the complementary geometries of the *n*-hexyl substituent and linear groove result in increased van der Waals contacts for the (*R*)-2-octanol complex. Since Ru−O and H-bonding are likely similar in energy for the two diastereomeric complexes, these van der Waals interactions are the main contributor to the observed (*R*)-enantioselection.

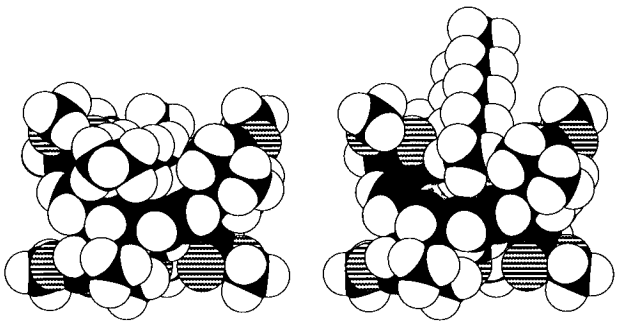

**Figure 2.** Molecular models (Chem3D), based on the atomic coordinates of **2**, of the complexes formed by the ruthenium(II) chiroporphyrin and the two enantiomers of 2-octanol viewed from the edge of the porphyrin. Left: (*R*)-2-octanol complex. Right: (*S*)-2-octanol complex.

With its ability to selectively interact with a *linear* alkyl chain, the ruthenium(II) chiroporphyrin complex **2** appears as a unique member in the class of enantioselective receptors, which generally use hydrogen bonding, $\pi-\pi$ interactions, coordination, or van der Waals interactions for the chiral recognition of *planar* aromatic or *spherical* aliphatic guests.[3,19] Besides its potential utility in chiral NMR shift reagents,[20] the chiroporphyrin unit may offer new opportunities for measuring enantiomer composition, determining absolute configuration, and resolving racemic mixtures. Some of these possibilities are currently being explored.

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**Supporting Information Available:** Additional references, a table of analytical data, text giving experimental details for the crystal structure determination and refinement, structural drawings, and tables of NMR data, and tables of crystallographic data, atomic coordinates and equivalent isotropic displacement parameters, bond lengths, bond angles, data collection parameters, anisotropic displacement parameters, hydrogen coordinates, and isotropic displacement parameters for Ru(CO)(EtOH)TMCP, **2** (18 pages). Ordering information is given on any current masthead page.

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