Conformationally Driven, Propeller-like Chirality in Labile Coordination Complexes

James W. Canary,* Craig S. Allen,
Jesus M. Castagnetto, and Yihan Wang

Department of Chemistry, New York University
Washington Square, New York, New York 10003

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Chiral coordination complexes are frequently utilized in asymmetric synthesis and chiral discrimination technologies.[1] Recently, C_3-symmetric chiral ligands have shown great potential for enantioselective reactions, yet few such compounds are available.[2] We report a convenient strategy for the design of conformationally flexible, robust ligands that wrap around Zn(II) and Cu(II) ions to form pseudo-C_3-symmetric complexes with helical asymmetry dictated by the configuration at a single carbon atom. The strategy should be adaptable to a wide variety of ligand/metal systems.

The coordination chemistry of the ligand tris(pyridylmethyl)amine (TPA, **1**)[3] has been studied with many different metal ions;[4,5] for example, copper[4] and iron[6] complexes of TPA bind and activate molecular oxygen and iron complexes of TPA have been used to functionalize alkanes.[6] Crystallographic data indicate that Zn(II) and Cu(II) complexes of TPA usually display 5-coordinate, trigonal bipyramidal metal ions.[4,7] The ligand occupies four coordination sites, leaving one apical site available for anion or solvent coordination (e.g., **2**). Enantiomeric conformations are adopted in which the pyridine rings occupy equatorial positions and are tilted with respect to the central axis of the molecule such that they display a propeller-like,[8] C_3-symmetrical arrangement. These conformations would be expected to interconvert rapidly at room temperature in solution. TPA derivatives with sterically bulky substituents show a greater degree of "twist".[7] The goal of the present study was to discover a means to control the direction of the propeller twist, providing a route to coordination complexes with highly asymmetric environments around the electrophilic coordination site of the metal ion.

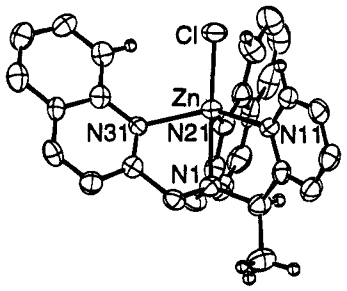
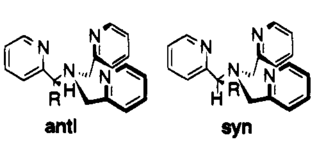
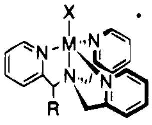


Figure 1. ORTEP representation of racemic [Zn(α-MeBQPA)Cl]$^+$. Some hydrogen atoms have been included in calculated positions for clarity. Selected bond lengths (Å) and angles (deg): Zn−Cl, 2.271(2); Zn−N(1), 2.197(6); Zn−N(11), 2.150(6); Zn−N(21), 2.147(6); Zn−N(31), 2.155(6); Cl−Zn−N(1), 166.2(2); Cl−Zn−N(11), 94.4(2); Cl−Zn−N(21), 114.1(2); Cl−Zn−N(31), 101.5(2); N(1)−Zn−N(11), 76.0(2); N(1)−Zn−N(21), 79.3(2); N(1)−Zn−N(31), 76.4(2); N(11)−Zn−N(21), 115.7(2); N(11)−Zn−N(31), 122.7(2); N(21)−Zn−N(31), 106.9(2); N(1)−Zn−N(11)−C(12), 8.3(5); N(1)−Zn−N(21)−C(22), 13.9(5); N(1)−Zn−N(31)−C(32), 25.8(5).

Examination of CPK molecular models indicated that Zn(II) and Cu(II) complexes of tripodal ligands containing an alkyl substituent on one arm should possess helical asymmetry (defined by the tilt of the pyridine rings with respect to the N−M−X axis) with the handedness dictated by the configuration of the chiral carbon atom. The compounds α-MeTPA (**3**)[13] and α-MeBQPA (bis(2-quinolylmethyl)-2-pyridyl-1-ethylamine, **4**) were selected to test this hypothesis. Two binding conformations are possible for each ligand, the "anti" conformation in which the α-substituent points away from the pyridyl groups and the "syn" conformation in which the α-substituent points toward one pyridyl group. The syn conformation should be less stable due to the presence of a *syn*-pentane-type interaction between the α-substituent and one of the pyridyl groups.[10] Molecular mechanics calculations of [Zn(α-MeTPA)Cl]$^+$ and [Zn(α-MeBQPA)Cl]$^+$ also indicated that the "anti" conformation would be more stable than the "syn" isomer[11] and that the complex with a carbon center configuration of "*R*" would display a Λ (left-handed) propeller-like twist.[11]



1 (R=H, TPA)
3 (R=Me, α-MeTPA)



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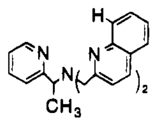

4 (α-MeBQPA)

The ligands were synthesized (procedures are included in the supporting information),[7,12] and the [Zn(L)Cl]ClO$_4$ complexes were prepared.[7] X-ray structures of racemic [Zn(α-MeTPA)Cl](ClO$_4$)[13] and [Zn(α-MeBQPA)Cl](ClO$_4$)[14] each show anti conformations of the ligands and the predicted helical twists relative to the asymmetric carbon center. The latter structure is shown in Figure 1. The complex displays an average N(1)−Zn−N−C torsion angle of 16°,

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Table 1. Optical Rotation Data and Ratios of Circular Dichroic to Isotropic Extinction Coefficients (*g* Numbers) for α-MeBQPA[a] and Three Coordination Complexes

compd	$[\alpha]^{25}_{D}$ (deg·mL·g^{-1}· dm^{-1})[b]	$[\Phi]^{25}_{D}$ (deg·cm^{2}· dmol^{-1})[b]	*g* (Δε/ε)[c]
α-MeBQPA	167.03	675.66	0.01
[Cd(α-MeBQPA)I_2]	166.74	1284.75	0.82
[Zn(α-MeBQPA)Cl]ClO_4	631.75	3820.89	6.3
[Cu(α-MeBQPA)Cl]ClO_4	720.43	4343.93	3.7

[a] Prepared from (*S*)-(−)-1-(2-pyridylethyl)amine. [b] Acetonitrile, *c* = 0.2−1.2. [c] Methanol, 295 K, λ = 243 nm ($\pi \rightarrow \pi^*$ transition).

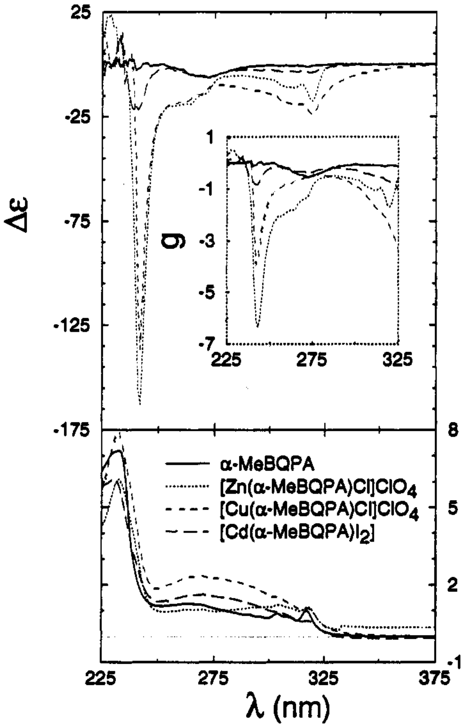

Figure 2. Circular dichroism spectra, UV/vis spectra (×10^{-4}), and *g* numbers (Δε/ε, ×10^{3}) for α-MeBQPA, [Cd(α-MeBQPA)I_2], [Zn(α-MeBQPA)Cl]ClO_4, and [Cu(α-MeBQPA)Cl]ClO_4 (optical isomer of ligand synthesized from (*S*)-2-pyridyl-1-ethylamine).

Ligands **3** and **4** were prepared in enantiomerically pure form, and the optical properties of the free ligands and three coordination complexes were studied in solution. The optical rotation data for the series of compounds involving **4** appears in Table 1. The optical rotations of the trigonal bipyramidal [Zn(L)Cl]ClO_4 and [Cu(L)Cl]ClO_4 complexes are greatly enhanced over that of the conformationally mobile free ligand. The [Cd(L)I_2] complex, showing a small rotation, was studied as a control experiment since the expected octahedral geometry[7b] would not produce the propeller-like asymmetry. Circular dichroism spectra of optically pure [Zn(α-MeTPA)Cl](ClO_4) and [Cu(α-MeTPA)Cl](ClO_4) also gave CD spectra with a significantly enhanced signal compared with those of free ligand and [Cd(α-MeTPA)I_2]. The ratio of circular dichroic to isotropic absorbance (Δε/ε, or *g* number,[1] Table 1 and Figure 2), also called the anisotropy or dissymmetry factor,[15] is large for the zinc and copper complexes and small for the free ligand or cadmium complex. Thus, both the optical rotation and CD data are consistent with the presence of a pronounced helical twist in the solution structures of the Zn(II) and Cd(II) complexes.

^{1}H NMR experiments in acetone-d_6 solution also provide data to corroborate propeller formation by the pyridine rings in that the $Zn(ClO_4)_2$ complexes of compounds **3** and **4** act as chiral solvating agents[1] for sulfoxides and sulfides. Acetone-d_6 solutions of **3** or **4**, $Zn(ClO_4)_2$, and a racemic sulfoxide were prepared and analyzed by ^{1}H NMR. For example, the racemic substrate methyl (methylmercapto)methyl sulfoxide was resolved under these conditions using enantiomerically pure **3**. Analogous experiments with either **1** or enantiomerically pure 2-(pyridylmethyl)-2-pyridyl-1-ethylamine resulted in no differentiation. The "absence" of the third arm in the latter compound removes the steric influence that causes the ligand to fold into the helical shape. Ligand **4** is more effective than **3**, giving baseline resolution of methyl vinyl sulfoxide and other substrates.

In summary, both solid state and solution data show the asymmetric, propeller-like conformation of TPA derivatives **3** and **4** when complexed with zinc and copper(II) ions, with the handedness of the helical twist dictated by the configuration of one carbon atom. Studies of applications of these chiral materials are underway.

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Supporting Information Available: Text, tables, and figures giving synthetic procedures, CD data, calculated structures, and X-ray data (tables of bond lengths and angles) (40 pages); listings of structure factors (18 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, can be ordered from the ACS, and can be downloaded from the Internet; see any current masthead page for ordering information and Internet access instructions.

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(14) Crystallographic data for [Zn(α-MeBQPA)Cl](ClO_4): monoclinic, space group *C*2/*c*, *a* = 33.515(5) Å, *b* = 9.836(2) Å, and *c* = 15.657(3) Å, β = 90.19(2)°, *V* = 5162(2) Å^3, *Z* = 8, ρ = 1.556 g/cm^3, *t* = 193 K. Data were collected on a Rigaku AFC-6R diffractometer, with graphite monochromated Cu Kα radiation, to maximum 2θ = 119.0°, giving 4034 unique reflections. The structure was solved by direct methods and refined to *R* = 0.059, R_w = 0.067 for 2504 reflections with $I > 3.00\sigma(I)$.

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