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New Chiral Zinc Complexes: Synthesis, Structure, and Induction of Axial Chirality

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Supporting Information

ABSTRACT: We describe an efficient methodology for the preparation of new chiral zinc complexes by assembling dynamically racemic biphenol derivatives and chiral 1,2-diamines with suitable zinc(II) precursors. Mononuclear and dinuclear zinc(II) complexes were formed from differently substituted biphenols. The solid-state and solution structural characterization of the resulting compounds allowed us to demonstrate a preferential sense of induced axial chirality for mononuclear complexes, a phenomenon that was not observed for the dinuclear ones.

Numerous examples of coordination complexes involved in chirality-transfer processes,[1] in which the chirality is transferred from an enantiomerically pure ligand to a metal center, are known in the literature.[2] However, the transfer of chiral information in coordination compounds from a chiral unit to a stereochemically labile moiety or ligand has been explored to a lesser extent. Noteworthy results within this field were reported independently by Mikami and Noyori,[3] Nakanishi et al.,[4] Gagné et al.,[5] and Kubo et al.,[6] who exemplified the induction of axial chirality mediated by metal—ligand interactions. Walsh and co-workers elegantly demonstrated the effect of manipulating chiral environments around a catalytically active metal center.[7] They employed an enantiopure BINOL derivative as the only chiral inducer in the Lewis acid catalyzed enantioselective addition of dialkylzinc reagents to benzaldehyde. Optimization of the catalyst enantioselectivity and activity was further achieved by employing a series of achiral activators (meso and dynamically racemic diimines and achiral diamines), thus eliminating the need for a second enantiopure ligand. Of particular interest for this work were the cases in which coordination to the zinc center led to the freezing of axially chiral conformations.[7a] Metal—ligand interactions are also increasingly being used to construct the backbone of asymmetric catalysts involving the attachment of building blocks by metal—ligand bonding.[8] In most cases, these building blocks contain the stereogenic elements and functional groups required for the desired catalysis as well as the motifs necessary for the assembly. Reports on the generation of catalysts by stereoselective metal—ligand-mediated assembly are scarce in the literature.[8d]

We previously reported on the supramolecular directed induction and control of chirality in biaryl derivatives by means of hydrogen-bonding and aromatic interactions[9a] and by the formation of copper(II) complexes.[9b] We describe here the preparation of new chiral zinc complexes involving the efficient transfer of chiral information from an enantiopure building block to a dynamically racemic biaryl unit.

Our concept of transferring chirality by metal—ligand interactions relies on the interplay of three linked components: a dynamically racemic ligand, a chiral building block, and a structural metal center. Regarding the dynamically racemic ligand, 2,2′-biphenol derivatives bearing methyl ester groups[10] were the compounds of choice. Enantiopure 1,2-diamines were chosen as the chiral building blocks because of their ready availability and excellent coordinative behavior. We envisaged that metal centers adopting the tetrahedral geometry could facilitate the transfer of chirality from the chiral to dynamically racemic units. Moreover, defined complexes of 1:1:1 stoichiometry were desired. Following our previous studies in this field,[9] zinc(II) was chosen as the structural metal. Two different zinc precursors were used: diethylzinc (Et_2Zn; method A) and zinc bis[bis(trimethylsilyl)amide] ($Zn[N(TMS)_2]_2$; method B), both of which act as the zinc(II) source and deprotonating agent for the biphenol derivative. Both methods led to efficient procedures for the preparation of [Zn(2,2′-biphenolate)(1,2-diamine)] complexes (Scheme 1). Comparison of the X-ray and IR data demonstrated that both procedures furnished the same products with similar yields.[11] Single-crystal X-ray diffraction analysis of the zinc(II) complexes prepared gave unexpected results. Surprisingly, 3,3′-methyl-substituted biphenol **1** furnished mononuclear complexes **4** with 1:1:1 stoichiometry, while biphenol **2**, which lacks ortho substituents, led to dinuclear complexes **5**. Furthermore, this behavior was independent of the zinc source or steric bulk of the N substituent of diamines **3**.

Complex **4a**, which is derived from **3a** and biphenol **1** (82% and 81% yield with methods A and B, respectively), is presented as a model mononuclear complex. The solid-state structure of compound **4a** (Figure 1) revealed a mononuclear C_2-symmetric zinc(II) complex in which the configuration of the biphenolate unit was found to be a*R*, i.e., the (1*R*,2*R*)-

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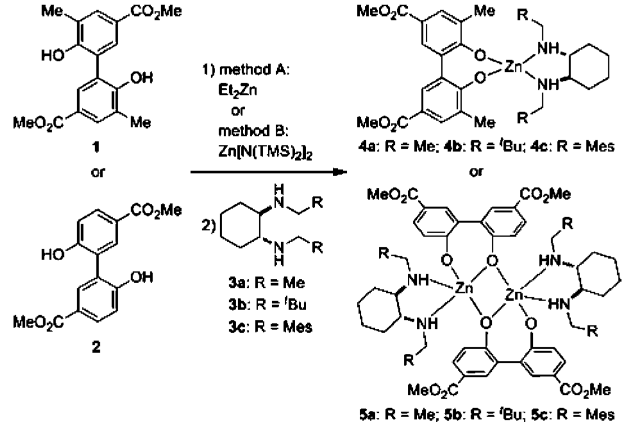
Scheme 1. Synthesis of Chiral Zinc(II) Complexes 4 and 5



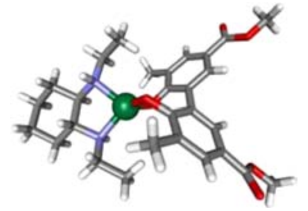


Figure 1. X-ray structure of **4a** (see the SI for the ORTEP plot). Cocrystallized solvent molecules are omitted for clarity. Color code: blue, N; green, Zn; red, O; gray, C; white, H.

diamine induced an a*R* sense of axial chirality. The diamine nitrogen atoms became stereodefined upon binding to zinc(II) and both had the *S* configuration. Synthesis of the enantiomer of **4a** using the enantiomeric (1*S*,2*S*)-diamine resulted in a complex with an *S*-configured biphenolate, as proven by X-ray analysis.[11] This finding confirms that the absolute configuration of enantiopure diamines **3** determines the induced axial chirality in the mononuclear complexes **4**.

The crystallinity of complex **4a** also allowed collection of powder X-ray diffraction (PXRD) data from the isolated material. The experimental PXRD pattern was found to be in very good agreement with the pattern calculated from the single-crystal structure (Figure 2), which ultimately indicates that the major crystalline material present in the isolated batch of **4a** corresponds to the structure of the measured single crystal.

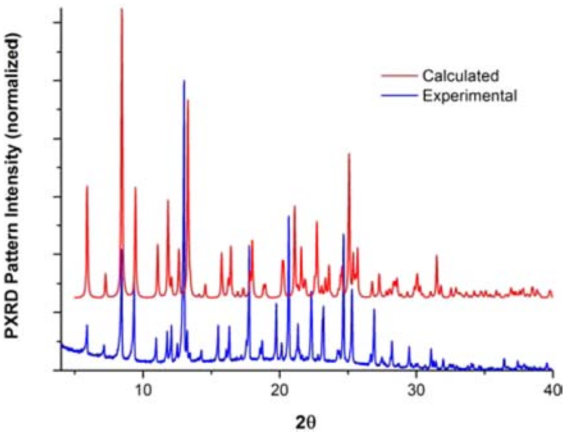


Figure 2. PXRD patterns of zinc(II) complex **4a**.

Analogously, the solid-state structure of the mononuclear complex **4b** is consistent with that of **4a**, as determined by single-crystal X-ray diffraction.[11] It was found that in the solid state a preferential a*R* sense of axial twist was also induced in the biphenolate unit upon using the bulkier neopentyl-substituted (1*R*,2*R*)-diamine **3b**. Structural studies on the mononuclear complexes **4a** and **4b** were also carried out in solution by NMR, IR, UV–vis, electronic circular dichroism (CD), and mass spectrometry.[11] For instance, the 2D NOESY NMR spectrum of **4b** provided evidence for the spatial proximity between the N substituents of the diamine and the methyl groups in the biphenolate fragment. No changes in the NMR spectra attributable to fluxional equilibria or interconversion between diastereomers were observed, even at low temperature (−78 °C). CD spectra of complex **4a** in tetrahydrofuran (THF) showed a series of Cotton effects, consisting of a negative couplet centered at about 275 nm and a negative band at 215 nm, which demonstrates that the biaryl unit was twisted with a predominant screw sense in solution (Figure 3). The CD curve for ***ent*-4a**, derived from the enantiomeric (1*S*,2*S*)-diamine, was almost a perfect mirror image of the one discussed above, thus confirming again that the induced preferential sense of axial twist directly depends on the configuration of the diamine. The same conclusion was drawn upon analysis of the CD spectra of complex **4b**.

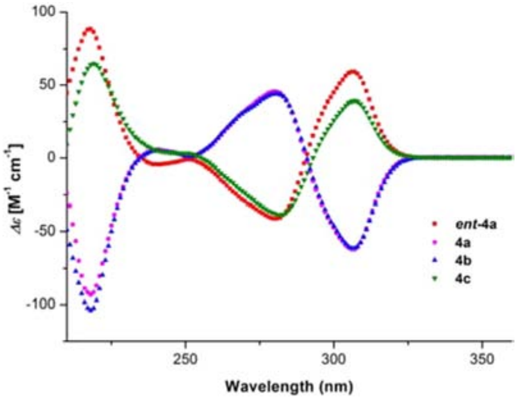


Figure 3. CD spectra of **4a**, **4b**, **4c**, and ***ent*-4a** measured in anhydrous THF at 25 °C.

In order to study further the influence of the N substituent on the induction of axial chirality, zinc(II) complex **4c**, which incorporates an aromatic group in this position, was prepared by following methods A and B (64% and 65% yield, respectively). On the basis of complexes **4a** and **4b**, an a*R* preferential sense of axial twist was expected to be induced by (1*R*,2*R*)-diamine **3c**. Strikingly, complex **4c** showed a positive couplet followed by a positive single band, instead of the sequence (−, +, −) found for **4a** and **4b** (Figure 3). Interestingly, the spectrum of **4c** is closely similar (position and relative intensity of all Cotton effects) to the one of ***ent*-4a**. Consequently, the biphenolate unit in such a complex, derived from the chiral inducer (1*R*,2*R*)-diamine **3c**, predominantly adopted an a*S* configuration. The use of the corresponding enantiomeric (1*S*,2*S*)-diamine rendered the opposed enantiomer of complex **4c**, which displayed an inverted CD curve.[11] This particular behavior, in which aromatic N substituents present in the chiral inducers are capable of inverting the preferential sense of axial twist induced in dynamically racemic biaryls, was previously observed in closely related supramolecular complexes.[9a,12]

Surprisingly, the synthetic outcome of the complexation event between the 3,3′-unsubstituted biphenol **2** and the enantiopure (1*R*,2*R*)-diamines **3** with a suitable zinc(II) source did not follow the same trend as that for the 3,3′-substituted biphenol **1**. Defined dinuclear 2:2:2 complexes **5** (Scheme 1) were formed in high yields when the biaryl compound was unsubstituted in the *o*-OH positions. Dinuclear complexes **5a** and **5c**, derived from biphenol **2** and ethyl- and 2,4,6-trimethylbenzyl-substituted diamines **3a** and **3c**, respectively, were efficiently obtained (yields ranging from 75% to 85%; see the Supporting Information, SI) and could be crystallized. The resultant solid-state structures (see the SI for the X-ray structures of **5a** and **5c**) did not show a mononuclear complex but instead dinuclear ones, in which the two zinc(II) centers were coordinated in a square-pyramidal fashion by two diamines and two biphenolate units. One of the oxygen atoms of each biphenolate ligand was bound as a *μ*-oxo-bridged ligand. Strikingly, the solid-state structure of the dinuclear complexes **5a** and **5c** showed the two biphenol units with opposed configurations (a*R* and a*S*). Furthermore, the two chiral diamine ligands also showed bindings different from those observed in the mononuclear complexes. These chiral units were not coordinated in a C_2-symmetric fashion as in **4** (both tetrahedral nitrogen atoms of **4** had the same configuration), but instead the two nitrogen atoms of one diamine unit adopted opposed configurations. Comparison of the experimental and calculated PXRD patterns again confirmed the crystallographic purity of the sample, thus indicating that most of the material present in the crystalline form corresponded to the solid-state structure of compound **5c**.[11]

Structural studies on complexes **5** by NMR evidenced a pronounced dynamic behavior in solution.[11] NMR analyses revealed dynamic exchanges on the NMR time scale, which resulted in significant line broadening and a poor signal-to-noise ratio. Dimerization equilibria between monomeric and homo- and heterochiral dimeric complexes, which could potentially take place in solution, might be responsible for this dynamic behavior.[13]

In summary, the induction of axial chirality mediated by zinc(II) as the structural metal has been investigated. Mononuclear complexes **4**, derived from biphenol **1**, were found to show a preferential sense of induced axial twist, which was controlled by the absolute configuration of the chiral inducer. The 2,4,6-trimethylbenzyl-substituted diamine **3c** induced a reverse axial chirality as a result of the aromatic substituents. Dinuclear complexes **5**, derived from biphenol **2**, did not show preferential induction of axial chirality and exhibited a pronounced dynamic behavior in solution.

The present work constitutes an example of how very subtle changes in the ligand topology (Me vs H groups in **1** and **2**, respectively) strongly influence the monomeric versus dimeric nature of the complexes obtained, as well as the coordination geometry of the $Zn^{II}(d^{10})$ metal ion. This, in turn, has been demonstrated to be a key feature in discriminating the axial chirality in the resulting complexes. Work is in progress to exploit this strategy in the preparation of supramolecular chiral catalysts suitable for asymmetric transformations of interest.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Experimental details, characterization data, NMR spectra, and X-ray data in CIF format. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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(10) An ester group was incorporated in the biphenyl-2,2′-diol subunit, allowing for the simple transformation into a wide variety of binding groups for future catalytic applications.

(11) See the SI for details.

(12) A reversed induction of ligand conformations upon changes in the chiral inducer has been observed in octahedral zinc complexes: Seitz, M.; Stempfhuber, S.; Zabel, M.; Schutz, M.; Reiser, O. *Angew. Chem., Int. Ed.* **2005**, *44*, 242.

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