Perfect Control of Diastereomeric Complexation of C_2-Symmetric Chiral 1,1'-Bis(oxazolinyl)ferrocene Ligands

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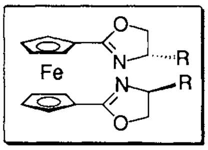
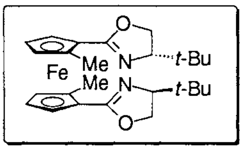
Upon complexation with Pd(II), both chiral 1,1'-bis(oxazolinyl)ferrocene ligand **1** and its planar chiral derivative **2** afforded the corresponding 1:2 ligand-Pd(II) complex. On the other hand, upon complexation with copper(I) chloride, both **1** and **2** afforded only one of the two possible diastereomeric 1:1 ligand-Cu(I) complexes. The twists of the two Cp rings of the copper(I) complexes of **1** and **2** are opposite to each other, which is ascribed to the effect of the planar chirality in **2**.

Chiral oxazoline ligands derived from readily available amino acids have found widespread use in metal-catalyzed asymmetric reactions and extensive efforts have been devoted to the preparation of the derivatives with an efficient structure.[1] Our recent attention has been focused on the preparation and application of novel multichiral oxazoline ligands. We have shown that an effective chiral environment of this kind of ligands for asymmetric reactions can be constructed by combination of the chiralities of the oxazoline moiety and the backbone, such as dioxolane,[2] biaryl,[3] or ferrocene.[4] In a previous paper, we described the preparation of novel C_2-symmetric bisoxazoline ferrocene ligands, 1,1'-bis(oxazolinyl)ferrocenes **1**, and their highly diastereoselective dilithiation which led to several new C_2-symmetric bisoxazoline ligands possessing a planar chirality including 1,1'-bis(oxazolinyl)-2,2'-dimethylferrocene **2**.[4a] This paper describes the perfect control of the diastereomeric complexation of oxazolinylferrocene ligands by a combination of chiralities of the oxazoline moiety and the ferrocene backbone, which ligands have primarily a possibility to afford a diastereomeric mixture induced by the opposite twists of two Cp rings on complexing with a metal.



1a: R=*t*-Bu
b: R=*i*-Pr
c: R=Ph



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At first, the complexation behavior of ligands **1** toward Pd(II) in acetonitrile was examined. Upon the addition of 1 molar equiv. of dichlorobis(acetonitrile)palladium to ligand **1a** dissolved in acetonitrile-d_3, the ^{1}H NMR spectrum showed complicated signals due to a mixture of resulted substances along with **1a** and there was no evidence of the formation of an N,N-chelating complex. However, when an additional 1 molar equiv. of dichlorobis(acetonitrile)palladium was added, only one set of signals was observed in the ^{1}H NMR spectrum, which was assigned as a 1:2 C_2-symmetric complex **3a**. Further addition of Pd(II) did not affect the ^{1}H NMR spectrum (Figure 1). Ligands **1b**, **1c**, and the planar chiral ligand **2** bearing two methyl groups showed a similar complexation behavior to that of **1a** toward dichlorobis(acetonitrile)palladium to afford **3b**, **3c**, and **4**, respectively. These results show that this kind of ligands **1** and **2** do not form the expected 1:1 N,N-chelating complex with Pd(II) but form exclusively 1:2 complexes **3** and **4** (Scheme 1).

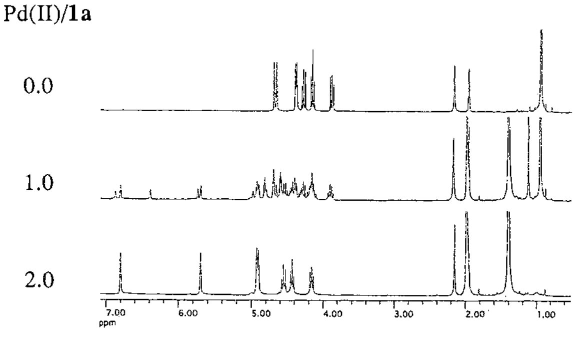
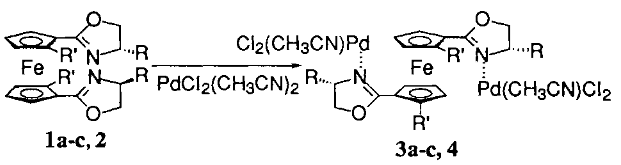


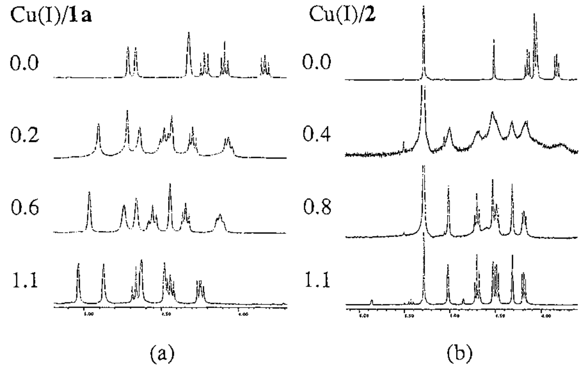
Figure 1. ^{1}H NMR study of the complexation behavior of the ligand **1a** toward $Pd(II)Cl_2(CH_3CN)_2$ in CD_3CN.



(**1a**, **3a**: R=*t*-Bu, R'=H, **1b**, **3b**: R=*i*-Pr, R'=H
1c, **3c**: R=Ph, R'=H, **2**, **4**: R=*t*-Bu, R'=Me)

Scheme 1.

Next, the complexation of ligands **1** with a copper(I) triflate benzene complex $[Cu(I)OTf(C_6H_6)_{0.5}]$ in dichloromethane-d_2 was examined and it was found that the complexation behavior of **1** toward Cu(I) was quite different from that toward Pd(II). Upon treating ligand **1a** with a different portion of the Cu(I) complex in dichloromethane-d_2, most of the proton signals of the ligand shifted gradually to the downfield in proportion to the amount of Cu(I) (Figure 2a), indicating the rapid equilibrium between the free ligand and the ligand-Cu(I) complex on the NMR time-scale. Even when more than 1 molar equiv. of Cu(I) was added, further downfield shift of the proton signals was not observed, showing the formation of a 1:1 N,N-chelating complex of ligand **1a** with Cu(I) in solution. A CPK model examination suggests that two 1:1 N,N-chelating complexes **5a** and **6a** may be formed due to the opposite twists of the two Cp rings (Scheme 2). In fact, only one of them was observed on the NMR spectrum. The structure of this complex was assigned to be **5a** by the analysis of NOE.[5] This fact can be rationalized by the steric effect. Thus, two types of steric repulsions, one between the two *t*-butyl groups on the oxazoline rings and the other between these *t*-butyl groups and the OTf group coordinated to Cu(I), work to a less extent in **5a** than in **6a**. In the same way, the *iso*-propyl ligand **1b** gave the

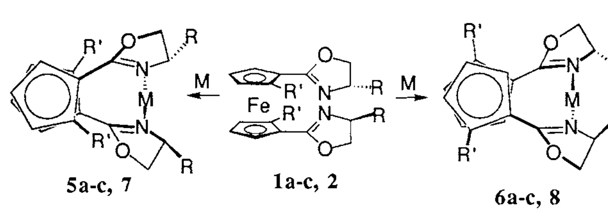


(a) (b)

Figure 2. ^{1}H NMR study of the complex formation of the ligands **1a** and **2** toward $[Cu(I)OTf(C_6H_6)_{0.5}]$ in CD_2Cl_2.

same result as **1a**, that is, it afforded only one diastereomeric complex **5b**. However, different from **1a** and **1b**, ligand **1c** bearing a phenyl group on the oxazoline ring formed two kinds of 1:1 N,N-chelating complexes **5c** and **6c** in a ratio of 65:35, perhaps due to a smaller difference in steric repulsion between them compared to **1a** and **1b**.

Next, in order to investigate the possibility of changing the twists of the two Cp rings of copper-bis(oxazolinyl)ferrocene complexes, we studied the dimethyl ligand **2** in which the methyl groups were introduced to the two ferrocene rings of the ligand **1a**. In the same way as the case of **1**, the complexation of the dimethyl ligand **2** with $[Cu(I)OTf(C_6H_6)_{0.5}]$ in CD_2Cl_2 was examined by ^{1}H NMR (Figure 2b). When 1 molar equiv. of Cu(I) was added, two sets of signals in a ratio of 90:10 appeared. And further addition of Cu(I) did not change the chemical shifts nor the ratio of the two sets of signals. Interestingly, the structure of the major complex was assigned to be **8** rather than **7** by the analysis of NOE.[6] The twist direction of the two Cp rings of **8** derived from **2** was opposite to that of **5** from **1**. This may be due to the steric repulsion in **7** between the methyl group on one Cp ring and the oxazoline group on the other Cp ring. Therefore, in this case, the twist of the two Cp rings in the complex was found to be dominated by the planar chirality in the ligand.



5a-c, 7 **1a-c, 2** **6a-c, 8**

(**1a**, **5a**, **6a**: R=*t*-Bu, R'=H, **1b**, **5b**, **6b**: R=*i*-Pr, R'=H
1c, **5c**, **6c**: R=Ph, R'=H, **2**, **7**, **8**: R=*t*-Bu, R'=Me)

Scheme 2.

The control of the twist of the two Cp rings was found to be also influenced by the kind of counter anion. Thus, when copper(I) chloride was used, the perfect control of diastereomeric complexation resulted (Table 1). No polynuclear complex was found in mass spectroscopy and the NOE's paterns of these complexes were similar to those of the triflate complexes. All the four ligands **1a,b,c**, and **2** showed the formation of only one of the two possible diastereomers, keeping opposite twists for **1** and **2** each other.

Table 1. The ratio of 5(7) : 6(8) on the complexation of bis(oxazolinyl)ferrocene with copper(I) chloride in $CDCl_3$[a]

Ligand	1a	1b	1c	2
5(7) : 6(8)	100 : 0	100 : 0	100 : 0	0 : 100

[a] Determined by ^{1}H NMR.

In summary, we have studied the complexation behavior of 1,1'-bis(oxazolinyl)ferrocenes **1** and their planar chiral derivative, 1,1'-bis(oxazolinyl)-2,2'-dimethylferrocene **2**, toward palladium(II) and copper(I). It was found that both **1** and **2** afforded 1:2 (ligand : Pd(II)) complexes upon complexation with dichlorobis(acetonitrile)palladium. Upon complexation with copper(I) chloride, both **1** and **2** afforded only one of two possible 1:1 (ligand : Cu(I)) complexes, and the twist of Cp rings of **1** and **2** was perfectly controlled to opposite directions by the combination of chiralities of the oxazoline moiety and the ferrocene backbone, respectively.

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5 For this complex, NOE was observed between the *t*-Bu protons of the oxazoline group and the proton of the R' position at the other Cp ring (0.1%) (Scheme 2). ^{1}H NMR study on deuterated **1a**(R'=D) also supported the formation of **5a**. Compound **5a** : ^{1}H NMR (400 MHz, CD_2Cl_2) δ 0.97 (s, 18H), 4.24 (q, 2H, *J*=7.0, 9.8 Hz), 4.44 (q, 2H, *J*=7.0, 9.8 Hz), 4.48 (m, 2H), 4.62 (m, 2H), 4.66 (t, 2H, *J*=9.8 Hz), 4.87 (m, 2H), 5.03 (m, 2H). MS (FAB) m/z 499 ($[M-OTf]^+$).
6 For the major complex, NOE was observed between the *t*-Bu protons and the *ortho*-proton to the oxazoline group at the same Cp ring bearing this *t*-Bu group (0.2%), between the methyl protons and its *ortho*-proton at the same Cp ring (0.9%), and between the methyl protons and the proton which is on the other Cp ring and is located just below the methyl group (0.7%). No NOE was observed between the *t*-Bu protons and methyl protons. Compound **8** : ^{1}H NMR (400 MHz, CD_2Cl_2) δ 0.98 (s, 18H), 2.03 (s, 6H), 4.19 (q, 2H, *J*=6.6, 9.8 Hz), 4.31 (t, 2H, *J*=2.6 Hz), 4.48 (q, 2H, *J*=6.6, 9.8 Hz), 4.52 (d, 2H, *J*=2.6 Hz), 4.70 (t, 2H, *J*=9.8 Hz), 5.01 (d, 2H, *J*=2.6 Hz). MS (FAB) m/z 527 ($[M-OTf]^+$).