Supporting Information

Synthesis, Structure, and Metal Complexation Behavior of a New Type of Functionalized Chiral Phenanthroline Derivative

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General Procedures. All reactions were performed under an inert atmosphere of either argon or prepurified nitrogen with stirring in flame-dried glassware. All NMR spectra (500 MHz for ^1H NMR and 125 MHz for ^{13}C NMR) were recorded in CDCl_3 , and chemical shifts were given relative to CDCl_3 (7.27 for ^1H NMR and 77.23 for ^{13}C NMR) unless otherwise stated. THF was dried by passage through copper-based catalyst and molecular sieve columns. 0.1 M Samarium (II) iodide solutions in THF were purchased from Strem and Aldrich.

Synthesis of 2-(2-Hydroxypropyl)-1,10-phenanthroline and 2,9-Bis(2-hydroxypropyl)-1,10-phenanthroline. In a flame-dried 25-mL round bottom flask, 36 mg (0.2 mmol) of 1,10-phenanthroline was dissolved in 2 mL of anhyd THF. To this solution was added 0.08 mL (1.1 mmol) of racemic propylene oxide and 5 mL (0.5 mmol) of 0.1 M SmI_2 in THF, and the solution was allowed to stir for 17 h at 23 $^\circ\text{C}$. The reaction was quenched with an excess of aq 1N HCl and partitioned between satd aq NaHCO_3 and CH_2Cl_2 . The layers were separated, and the aq layer was extracted with CH_2Cl_2 (2 x 20 mL). The organic layers were combined, dried over MgSO_4 , and

concentrated under reduced pressure. Two major products were isolated by column chromatography (50:1, CH₂Cl₂, MeOH, neutral alumina oxide) giving 10 mg (21%) of 2-(2-hydroxypropyl)-1,10-phenanthroline as an off-white solid and 10 mg (17%) of 2,9-bis(2-hydroxypropyl)-1,10-phenanthroline as an off-white solid consisting of a 2:1 mixture of diastereomers. 2-(2-Hydroxypropyl)-1,10-phenanthroline: mp = 134-136 °C; TLC R_f = 0.25 (1% MeOH in NH₃ satd CH₂Cl₂, neutral alumina); ¹H NMR (500 MHz, CDCl₃) δ 9.15 (dd, *J* = 4.4, 1.8 Hz, 1H), 8.21 (dd, *J* = 8.1, 1.7 Hz, 1H), 8.16 (d, *J* = 8.2 Hz, 1H), 7.75 (d, *J* = 8.8 Hz, 1H), 7.73 (d, *J* = 8.8 Hz, 1H), 7.59 (dd, *J* = 8.1, 4.3 Hz, 1H), 7.51 (d, *J* = 8.2 Hz, 1H), 5.46 (s, 1H), 4.50 (m, 1H), 3.26 (dd, *J* = 14.8, 3.2 Hz, 1H), 3.20 (dd, *J* = 15.0, 9.0 Hz, 1H), 1.38 (d, *J* = 6.2 Hz, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 161.0, 150.6, 145.9, 145.3, 136.7, 136.0, 128.9, 127.1, 126.4, 126.2, 123.9, 123.1, 67.5, 46.2, 23.5; IR (film) 3338, 2965, 1618, 1590, 1559, 1508, 1492, 1452, 1394, 1119, 943, 843, 741 cm⁻¹; HRMS (FAB⁺, *m/z*) calcd for C₁₅H₁₅N₂O (M + H⁺) 239.1184, found 239.1173. 2,9-Bis(2-hydroxypropyl)-1,10-phenanthroline (2:1 mixture of diastereomers): major and minor diastereomer TLC R_f = 0.35 (1% MeOH in NH₃ satd CH₂Cl₂, neutral alumina); major diastereomer ¹H NMR (500 MHz, CDCl₃) δ 8.16 (d, *J* = 8.2 Hz, 2H), 7.72 (s, 2H), 7.46 (d, *J* = 8.2, 2H), 6.00 (s, 2H), 4.51 (m, 2H), 3.18 (m, 4H), 1.37 (d, *J* = 6.4 Hz, 6H); minor diastereomer ¹H NMR (500 MHz, CDCl₃) δ 8.17 (d, *J* = 8.2 Hz, 2H), 7.74 (s, 2H), 7.47 (dd, *J* = 8.2 Hz, 2H), 6.00 (s, 2H), 4.51 (m, 2H), 3.18 (m, 4H), 1.39 (d, 6.2 Hz, 6H); major diastereomer ¹³C NMR (125 MHz, CDCl₃) δ 161.2, 144.5, 136.7, 127.3, 125.8, 123.9, 67.0, 45.6, 23.3; IR (film) 3340, 2967, 1619, 1591, 1552, 1497, 1422, 1370, 1120, 1053, 940, 860, HRMS (FAB⁺, *m/z*) calcd for C₁₈H₂₁N₂O₂ (M + H⁺) 297.1603, found 297.1621.

2-(2-Hydroxy-3,3-dimethylbutyl)-1,10-phenanthroline (7). The procedure for **5** and **6** was followed using racemic 3,3-dimethyl-1,2-epoxybutane. The residual oil was purified by column chromatography (3:1, Hex/EtOAc, basic alumina) to give 190 mg (34%) of **7** as a yellow solid: mp = 141-144 °C; TLC R_f = 0.50 (1:1 EtOAc/Hex, basic alumina); ^1H NMR (500 MHz, CDCl_3) δ 9.16 (dd, J = 4.3, 1.7 Hz, 1H), 8.22 (dd, J = 8.1, 1.7 Hz, 1H), 8.19 (d, J = 8.2 Hz, 1H), 7.77 (d, J = 8.8 Hz, 1H), 7.75 (d, J = 9.0 Hz, 1H), 7.60 (dd, J = 8.0, 4.4 Hz, 1H), 7.55 (d, J = 8.2 Hz, 1H), 3.87 (dd, J = 10.8, 2.0 Hz, 1H), 3.26 (m, 1H), 3.16 (dd, J = 14.8, 10.6, 1H), 1.08 (s, 9H); ^{13}C NMR (125 MHz, CDCl_3) δ 162.0, 150.7, 145.9, 145.2, 136.9, 136.0, 129.0, 127.1, 126.3, 126.2, 123.8, 123.2, 78.8; 39.1, 35.2, 26.3; IR (KBr) 3352, 3062, 2966, 2944, 1508, 1492, 1390, 1064, 845, 740 cm^{-1} ; HRMS (FAB $^+$, m/z) calcd for $\text{C}_{18}\text{H}_{20}\text{N}_2\text{O}$ ($\text{M} + \text{H}^+$) 281.1654, found 281.1667.

2-[3,3-Dimethyl-2-(phenylaminocarbonyloxy)butyl]-1,10-phenanthroline (8).

In a flame-dried, 50-mL round bottom flask, 0.029 mg (0.103 mmol) of **7** and 0.018 mg (0.147 mmol) of DMAP were dissolved in 15 mL of anhyd THF. 0.40 mL (0.230 mmol)

of DIPEA was added to the solution, followed by 0.1 mL (0.920 mmol) of phenyl isocyanate. The solution was stirred at 23 °C for 24 h. The reaction mixture was quenched with H₂O (20 mL), followed by the addition of CH₂Cl₂ (25 mL). The layers were separated, and the aq layer was extracted with CH₂Cl₂ (3 x 20 mL). The organic layers were combined, dried over MgSO₄, and concentrated under reduced pressure to give a yellow solid. The residual oil was purified by column chromatography (1:1, EtOAc/Hex, basic alumina) followed by an additional column chromatography (EtOAc, silica) yielding 24 mg (58%) of **8** as a yellow solid. Purer material was isolated by recrystallization from CH₂Cl₂ and hexanes at -40 °C: mp = 144-146 °C; TLC R_f = 0.35 (1:1 EtOAc/Hex, basic alumina); ¹H NMR (500 MHz, CDCl₃) δ 9.17 (dd, *J* = 4.4, 1.8 Hz, 1H), 8.20 (dd, *J* = 8.1, 1.7 Hz, 1H), 8.17 (d, *J* = 8.2 Hz, 1H), 7.71 (m, 3H), 7.58 (dd, *J* = 8.0, 4.4 Hz, 1H), 7.07 (m, 4H), 6.88 (t, *J* = 7.1 Hz, 1H), 6.70 (s, 1H), 5.30 (dd, *J* = 11.1, 2.7 Hz, 1H), 3.59 (dd, *J* = 14.6, 11.0 Hz, 1H), 3.52 (m, 1H), 1.12 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 160.1, 153.7, 150.3, 146.2, 145.7, 138.1, 136.7, 136.3, 129.0, 128.9, 127.4, 126.8, 126.0, 123.0, 122.9, 122.8, 118.5, 81.1, 40.2, 35.6, 26.4; IR (KBr) 3230, 3184, 3121, 3057, 3030, 3012, 1709, 1600, 1553, 1231, 849, 756 cm⁻¹; HRMS (FAB⁺, *m/z*) calcd for C₂₅H₂₅N₃O₂ (M + H⁺) 400.2025, found 400.1987.

***R,R*-2,9-Bis(2-hydroxybutyl)-1,10-phenanthroline Copper(II) Triflate Complex [6(Cu)].** In a flame-dried, 5-mL round bottom flask, 14 mg (0.043 mmol) of **6** and 15.9 mg (0.044 mmol) of Cu(OTf)₂ were combined with 2.0 mL of dry CH₂Cl₂. The solution was stirred for 18 h at 23 °C. The solution was filtered through a 0.45-μm filter and then concentrated under vacuum to give 31 mg (>99%) of a blue-green solid. The solid was dissolved in wet CH₂Cl₂ and evaporated in open air at 23 °C to give blue X-ray quality crystals.

***R,R*-2,9-Bis(2-hydroxybutyl)-1,10-phenanthroline Zinc (II) Triflate Complex [6(Zn)].** In a flame-dried, 5-mL round bottom flask, 20.6 mg (0.063 mmol) of **6** and 22.3 mg (0.061 mmol) of Zn(OTf)₂ were combined with 4.0 mL of dry CH₂Cl₂. The solution was stirred for 4.5 h at 23 °C. The solution was filtered through a 0.45-μm filter and then concentrated under vacuum to give 30 mg (70%) of a red solid. The solid was recrystallized by slow liquid-liquid diffusion using CH₂Cl₂ and hexanes in a 5-mm tube to give 8.5 mg of red X-ray quality crystals.

X-Ray Crystallography Data.

Data for **6** (Figure S1) were collected to 0.78 Å. Cell parameters were refined using 5 206 reflections with $I \geq 10\sigma(I)$ and $2.320^\circ \leq \theta \leq 27.226^\circ$ harvested from the entire data collection. In total, 24 392 reflections were measured, of which 2 207 were unique. The

solid state structure of this ligand and its complexes (vide infra) merit some discussion regarding their supramolecular features. This ligand forms a one dimensional α -network of $p2_1$ rod group symmetry parallel to the short, 4.87 Å, a axis of the unit cell. The core of this α -network is established by a chain of hydroxyl groups (Figure S2). The chain structure is a common structural motif¹ for hydroxyl groups and establishes both the $p2_1$ symmetry and the intermolecular spacing. The second hydroxyl group forms a bifurcated hydrogen bond to the two pyridyl nitrogen atoms of the neighboring molecule in the stack. The two OH-N bifurcated hydrogen bonds, 2.248 Å and 2.410 Å, are somewhat long compared to literature values. A search of the Cambridge Structural Database² reveals 32 examples of phenanthrolines forming bifurcated hydrogen bonds, using 2.5 Å as the maximum distance for the longer bond. With this criterion the shorter bond averages 2.12 Å, and the longer bond averages 2.37 Å.

Data for **6(Cu)** (Figure S3) were collected to 0.76 Å. Cell parameters were refined using 9 554 reflections with $I \geq 10\sigma(I)$ and $2.181^\circ \leq \theta \leq 28.802^\circ$ harvested from the entire data collection. In total, 25 621 reflections were measured, of which 10 535 were unique. The supramolecular chemistry of the Cu(OTf)₂ complex is dominated by hydrogen bonds from the coordinated hydroxyl groups to a single oxygen atom of one of the axial triflate ligands of a neighboring Cu complex (Figure S4). The hydrogen bonds between the two complexes are reciprocal meaning that the two molecules form a discrete dimer held together by a total of four hydrogen bonds. The dimer has a pseudo centrosymmetric structure, but since only a single enantiomer is present, this structure can be achieved only by having two independent molecules in the asymmetric unit.

Data for **6(Zn)** (Figure S5) were collected to 0.68 Å. Cell parameters were refined using 9 995 reflections with $I \geq 10\sigma(I)$ and $2.807^\circ \leq \theta \leq 31.496^\circ$ harvested from the entire data collection. In total, 39 130 reflections were measured, of which 15 820 were unique. The supramolecular chemistry of the Zn(OTf)₂ complex is similar to that of the Cu complex, but there are some slight differences. As mentioned above, one triflate ligand has a rotational disorder. The predominant conformer is shown in Figure S6. This triflate ligand accepts single hydrogen bonds to each of its two uncoordinated oxygen atoms. This is in contrast to the reciprocal hydrogen bonds in the other half of the dimer where both hydrogen bonds are to a single oxygen atom. In the Cu(OTf)₂ dimer and in the minor conformer of the Zn complex, both sets of hydrogen bonds are to a single triflate.

Table 1. Crystallographic Details

	5a	5a(Zn)	5a(Cu)
chemical formula	C ₂₀ H ₂₄ N ₂ O ₂	C ₂₂ H ₂₂ F ₆ N ₂ O ₈ S ₂ Zn	C ₂₂ H ₂₂ CuF ₆ N ₂ O ₈ S ₂
formula weight	324.41	685.91	684.08
space group	<i>P</i> 2 ₁ 2 ₁ 2 ₁ (No. 19)	<i>P</i> 1 (No. 1)	<i>P</i> 2 ₁ (No. 4)
<i>a</i> (Å)	4.8517(2)	10.1629(3)	14.4152(8)
<i>b</i> (Å)	17.1800(7)	10.1911(4)	11.3319(7)
<i>c</i> (Å)	20.4254(9)	14.7036(5)	18.1339(10)
α (°)	90	70.770(2)	90
β (°)	90	71.313(2)	114.561(4)
γ (°)	90	88.929(2)	90
<i>V</i> Å ³	1702.50(12)	1355.66(8)	2694.2(3)
<i>Z</i>	4	2	4
<i>T</i> (°C)	100(2)	100(2)	100
λ (Å)	0.71073	0.71073 Å	0.71073
D _{obsd} (g cm ⁻³)	1.266	1.680	1.687
μ (cm ⁻¹)	0.082	1.151	1.057
<i>R</i> 1(<i>F</i> , <i>I</i> > 2σ(<i>I</i>))	0.0598	0.0396	0.0577
<i>wR</i> 2(<i>F</i> ²)	0.1905	0.1035	0.1446

$$wR2 = \sqrt{\frac{\sum [w(F_o^2 - F_c^2)^2]}{\sum [w(F_o^2)^2]}}; R1 = \frac{\sum \|F_o\| - |F_c|}{\sum |F_o|}; GooF = S = \sqrt{\frac{\sum [w(F_o^2 - F_c^2)^2]}{(n - p)}}$$

n = number of reflections, p = number of parameters refined

Table 2. Selected bond lengths [Å] and angles [°] for **6(Cu)**.

Cu(1)-O(1)	1.947(5)	Cu(1)-N(1)	1.956(6)
Cu(1)-O(2)	1.974(4)	Cu(1)-N(2)	1.997(6)
Cu(1)-O(3)	2.442(5)	Cu(1)-O(6)	2.454(6)
Cu(2)-O(10)	1.966(4)	Cu(2)-O(9)	1.977(5)
Cu(2)-N(3)	1.979(6)	Cu(2)-N(4)	1.983(5)
Cu(2)-O(11)	2.390(5)	Cu(2)-O(14)	2.461(5)

O(1)-Cu(1)-N(1)	92.8(2)	O(1)-Cu(1)-O(2)	91.9(2)
N(1)-Cu(1)-O(2)	175.3(2)	O(1)-Cu(1)-N(2)	173.6(2)
N(1)-Cu(1)-N(2)	83.9(2)	O(2)-Cu(1)-N(2)	91.4(2)
O(10)-Cu(2)-O(9)	90.88(19)	O(10)-Cu(2)-N(3)	176.5(3)
O(9)-Cu(2)-N(3)	92.2(2)	O(10)-Cu(2)-N(4)	92.1(2)
O(9)-Cu(2)-N(4)	176.0(2)	N(3)-Cu(2)-N(4)	84.7(2)
O(10)-Cu(2)-O(11)	91.91(19)	O(9)-Cu(2)-O(11)	91.3(2)
N(3)-Cu(2)-O(11)	89.7(2)	N(4)-Cu(2)-O(11)	91.2(2)

Table 3. Selected Bond Lengths and Angles for **6(Zn)**.

Zn(1)-O(3)	2.000(3)	Zn(1)-O(1)	2.038(5)
Zn(1)-O(2)	2.048(3)	Zn(1)-N(2)	2.063(3)
Zn(1)-N(1)	2.130(3)	Zn(1')-N(1)	1.939(6)
Zn(1')-O(1')	2.028(12)	Zn(1')-N(2)	2.109(5)
Zn(1')-O(2)	2.182(6)	Zn(1')-O(6)	2.246(7)
Zn(1')-O(3)	2.280(7)	Zn(2)-O(9)	2.011(2)
Zn(2)-N(4)	2.056(2)	Zn(2)-O(10)	2.059(2)
Zn(2)-O(14)	2.087(2)	Zn(2)-N(3)	2.094(2)
Zn(2)-O(11)	2.447(5)		

O(3)-Zn(1)-O(1)	98.73(16)	O(3)-Zn(1)-O(2)	98.14(15)
O(1)-Zn(1)-O(2)	92.65(19)	O(3)-Zn(1)-N(2)	95.15(13)
O(1)-Zn(1)-N(2)	165.22(14)	O(2)-Zn(1)-N(2)	90.35(12)
O(3)-Zn(1)-N(1)	103.98(14)	O(1)-Zn(1)-N(1)	91.97(16)
O(2)-Zn(1)-N(1)	156.43(14)	N(2)-Zn(1)-N(1)	79.75(12)
N(1)-Zn(1')-O(1')	92.3(4)	N(1)-Zn(1')-N(2)	83.1(2)
O(1')-Zn(1')-N(2)	167.9(4)	N(1)-Zn(1')-O(2)	166.2(3)
O(1')-Zn(1')-O(2)	97.1(4)	N(2)-Zn(1')-O(2)	85.6(2)
N(1)-Zn(1')-O(6)	87.2(3)	O(1')-Zn(1')-O(6)	81.2(3)
N(2)-Zn(1')-O(6)	87.4(2)	O(2)-Zn(1')-O(6)	84.2(2)
N(1)-Zn(1')-O(3)	100.7(2)	O(1')-Zn(1')-O(3)	105.7(4)
N(2)-Zn(1')-O(3)	86.2(2)	O(2)-Zn(1')-O(3)	86.5(3)
O(6)-Zn(1')-O(3)	169.2(3)	O(9)-Zn(2)-N(4)	170.87(9)
O(9)-Zn(2)-O(10)	94.75(9)	N(4)-Zn(2)-O(10)	91.92(9)
O(9)-Zn(2)-O(14)	95.48(8)	N(4)-Zn(2)-O(14)	90.05(8)
O(10)-Zn(2)-O(14)	95.72(9)	O(9)-Zn(2)-N(3)	91.00(9)
N(4)-Zn(2)-N(3)	80.76(9)	O(10)-Zn(2)-N(3)	161.23(9)
O(14)-Zn(2)-N(3)	101.50(9)	O(9)-Zn(2)-O(11)	80.12(12)
N(4)-Zn(2)-O(11)	94.02(12)	O(10)-Zn(2)-O(11)	87.08(14)
O(14)-Zn(2)-O(11)	174.98(13)	N(3)-Zn(2)-O(11)	76.31(14)

Figure S1. Thermal ellipsoid plot for **6**. H-atoms and second molecule of asymmetric unit omitted for clarity. Ellipsoids drawn at 50% probability level.

Figure S2. Hydroxy Group Chain of **6**

Figure S3. Thermal ellipsoid plot for **6(Cu)**. H-atoms and second molecule of asymmetric unit omitted for clarity. Ellipsoids drawn at 50% probability level.

Figure S4. Copper H-bonded dimer **6(Cu)**

Figure S5. Thermal ellipsoid plot for **6(Zn)**. H-atoms and minor parts of disorder omitted for clarity. Only one of two molecules of asymmetric unit shown. Ellipsoids drawn at 50% probability.

Figure S6. Zinc H-bonded dimer **6(Zn)**

References:

- (1) (a) Nguyen, T. L.; Scott, A.; Dinkelmeyer, B.; Fowler, F. W.; Lauher, J. W. *New J. Chem.* **1998**, 129. (b) Brock, C. P.; Duncan, L. L. *Chem. Mater.* **1994**, 6, 1307.
- (2) Allen, F. H. *Acta Crystallogr., Sect. B* **2002**, 58, 380.