

## Supplementary Material

for

# Pseudo-Allosteric Regulation of the Anion Binding Affinity of a Macrocyclic Coordination Complex

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## Experimental Section

### General Methods and Instrument Details

All reactions were carried out under an inert atmosphere of nitrogen using standard Schlenk techniques or an inert atmosphere glove box unless otherwise noted. Diethyl ether, CH<sub>2</sub>Cl<sub>2</sub>, and hexanes were purified by published methods.<sup>1</sup> All solvents were deoxygenated with N<sub>2</sub> bubbling prior to use. Deuterated solvents were purchased from Cambridge Isotope Laboratories Inc. and used as received. [Rh(nbd)<sub>2</sub>]BF<sub>4</sub> and [RhCl(nbd)]<sub>2</sub> (nbd = norbornadiene) were purchased from Strem Chemicals and used as received. 4-(2-(Diphenylphosphino)ethylthio)phenylamine was synthesized according to literature methods.<sup>2</sup> All other chemicals were used as received from Aldrich Chemical Company. <sup>1</sup>H

NMR and  $^{13}\text{C}\{^1\text{H}\}$  NMR spectra were recorded on a Varian Mercury 300 MHz FT-NMR spectrometer and referenced relative to residual proton resonances in  $\text{CD}_2\text{Cl}_2$ .  $^{31}\text{P}\{^1\text{H}\}$  NMR spectra were recorded on a Varian Mercury 300 MHz FT-NMR spectrometer at 121.53 MHz and referenced relative to an external 85%  $\text{H}_3\text{PO}_4$  standard. All chemical shifts are reported in ppm. UV-vis spectra were recorded on a Varian Cary 50 Bio spectrophotometer in  $\text{CH}_2\text{Cl}_2$ . Electrospray ionization mass spectrometry (ESI-MS) were recorded on a Micromas Quatro II triple quadrupole mass spectrometer. Elemental analyses were performed by Quantitative Technologies Inc. Whitehouse, NJ, USA.

### Synthetic Methods

**[Rh(nbd)<sub>2</sub>]B(C<sub>6</sub>F<sub>5</sub>)<sub>4</sub>**. NBD (460.5 mg, 5.0 mmol) and  $\text{LiB}(\text{C}_6\text{F}_5)_4\cdot\text{Et}_2\text{O}$  (380.0 mg, 0.5 mmol) in  $\text{CH}_2\text{Cl}_2$  (2 mL) were added to a solution of  $[\text{RhCl}(\text{nbd})]_2$  (115.3 mg, 0.25 mmol) in  $\text{CH}_2\text{Cl}_2$  (3 mL). The solution was stirred for 2 days before the resulting mixture was filtered through Celite. The crude product was purified by recrystallization twice from  $\text{CH}_2\text{Cl}_2$ ,  $\text{Et}_2\text{O}$ , and hexanes (315.6 mg, 65%).  $^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  5.61 (s, olefinic, 4H), 4.30 (s, CH, 2H), 1.69 (s,  $\text{CH}_2$ , 2H). ESI-MS( $m/z$ ):  $[\text{M}-\text{B}(\text{C}_6\text{F}_5)_4]^+ = 287.0$ , Calcd for  $[\text{C}_{14}\text{H}_{16}\text{Rh}]^+ = 287.2$ . Anal. Calcd for  $\text{C}_{38}\text{H}_{16}\text{BF}_{20}\text{Rh}$ : C, 47.24; H, 1.67, Found: C, 47.12; H, 1.23.

### ***N,N'*-Bis{4-(2-diphenylphosphanylethylthio)phenyl}pyridine-2,6- dicarboxamide (5).**

To a  $\text{CH}_2\text{Cl}_2$  (5 mL) solution of 2,6-pyridinedicarbonyl dichloride (102.0 mg, 0.5 mmol) and  $\text{NEt}_3$  (0.17 mL, 1.2 mmol) was added 4-(2-(diphenylphosphino)ethylthio)phenylamine (337.4 mg, 1.0 mmol) at 0 °C. The resulting solution was stirred for 2 days at room temperature before aqueous  $\text{NaHCO}_3$  solution was added. The organic layer was extracted with  $\text{CH}_2\text{Cl}_2$ , washed with brine, and dried over  $\text{MgSO}_4$ . The solvent was removed under reduced pressure, and the resulting material was purified by silica gel chromatography ( $\text{CH}_2\text{Cl}_2:\text{EtOAc} = 40:1$ ). Analytically pure product was obtained by recrystallization from

CH<sub>2</sub>Cl<sub>2</sub> and hexanes (302.4 mg, 75%). <sup>1</sup>H NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 9.53 (s, N-H, 2H), 8.44 (d, disubstituted pyridine, 2H, *J* = 8 Hz), 8.13 (t, disubstituted pyridine, 1H, *J* = 8 Hz), 7.70 (d, C<sub>6</sub>H<sub>4</sub>, 4H, *J* = 8 Hz), 7.40-7.28 (m, C<sub>6</sub>H<sub>4</sub> and PPh<sub>2</sub>, 24H), 2.96 (m, OCH<sub>2</sub>, 4H), 2.37 (m, CH<sub>2</sub>PPh<sub>2</sub>, 4H). <sup>13</sup>C{<sup>1</sup>H} NMR (CD<sub>2</sub>Cl<sub>2</sub>): 161.6 (s), 149.4 (s), 140.3 (s), 138.4 (d, *J*<sub>C-P</sub> = 14 Hz), 136.3 (s), 133.2 (d, *J*<sub>C-P</sub> = 19 Hz), 132.3 (s), 131.2 (s), 129.3 (s), 129.1 (d, *J*<sub>C-P</sub> = 7 Hz), 126.1 (s), 121.2 (s), 31.3 (d, *J*<sub>C-P</sub> = 22 Hz), 28.6 (d, *J*<sub>C-P</sub> = 15 Hz). <sup>31</sup>P{<sup>1</sup>H} NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ -16.3 (s). Anal. Calcd for C<sub>47</sub>H<sub>41</sub>N<sub>3</sub>O<sub>2</sub>P<sub>2</sub>S<sub>2</sub>: C, 70.04; H, 5.13; N, 5.21, Found: C, 69.69; H, 4.95; N, 5.16.

**Closed macrocyclic complex – B(C<sub>6</sub>F<sub>5</sub>)<sub>4</sub> (6a).** To a CH<sub>2</sub>Cl<sub>2</sub> (15 mL) solution of [Rh(nbd)<sub>2</sub>]B(C<sub>6</sub>F<sub>5</sub>)<sub>4</sub> (96.6 mg, 0.10 mmol) was added drop wise compound **5** (80.6 mg, 0.10 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (15 mL) over 10 min. The resulting solution was stirred for 6 h before the solvent was evaporated. The product was recrystallized from CH<sub>2</sub>Cl<sub>2</sub>/hexanes (152.7 mg, 96%). <sup>1</sup>H NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 9.50 (s, N-H, 4H), 8.34 (d, disubstituted pyridine, 4H, *J* = 8 Hz), 8.05 (t, disubstituted pyridine, 2H, *J* = 8 Hz), 7.72 (d, C<sub>6</sub>H<sub>4</sub>, 8H, *J* = 8 Hz), 7.44-7.27 (m, PPh<sub>2</sub> and C<sub>6</sub>H<sub>4</sub>, 48H), 2.77 (m, OCH<sub>2</sub>, 8H), 2.56 (m, CH<sub>2</sub>PPh<sub>2</sub>, 8H). <sup>31</sup>P{<sup>1</sup>H} NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 65.1 (d, *J*<sub>Rh-P</sub> = 162 Hz). ESI-MS(*m/z*): [M-2B(C<sub>6</sub>F<sub>5</sub>)<sub>4</sub>]<sup>2+</sup> = 908.6, Calcd for [C<sub>94</sub>H<sub>82</sub>N<sub>6</sub>O<sub>4</sub>P<sub>4</sub>Rh<sub>2</sub>S<sub>4</sub>]<sup>2+</sup> = 908.1. Anal. Calcd for C<sub>142</sub>H<sub>82</sub>B<sub>2</sub>F<sub>40</sub>N<sub>6</sub>O<sub>4</sub>P<sub>4</sub>Rh<sub>2</sub>S<sub>4</sub>: C, 53.70; H, 2.60; N, 2.65, Found: C, 53.66; H, 2.24; N, 2.55.

**Closed macrocyclic complex – BF<sub>4</sub> (6b).** To a CH<sub>2</sub>Cl<sub>2</sub> (50 mL) solution of [Rh(nbd)<sub>2</sub>]BF<sub>4</sub> (56.1 mg, 0.15 mmol) was added drop wise compound **5** (120.9 mg, 0.15 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (50 mL) over 10 min. The resulting solution was stirred for 6 h before the solvent was evaporated. The product was recrystallized from CH<sub>2</sub>Cl<sub>2</sub>/hexanes (147.7 mg, 99%). <sup>1</sup>H NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 9.92 (s, N-H, 4H), 8.28 (d, disubstituted pyridine, 4H, *J* = 8 Hz), 7.97 (d, C<sub>6</sub>H<sub>4</sub>, 8H, *J* = 8 Hz), 7.87 (t, disubstituted pyridine, 2H, *J* = 8 Hz), 7.47-7.29 (m, PPh<sub>2</sub> and C<sub>6</sub>H<sub>4</sub>, 48H), 2.74 (m, OCH<sub>2</sub>, 8H), 2.57 (m, CH<sub>2</sub>PPh<sub>2</sub>, 8H). <sup>31</sup>P{<sup>1</sup>H} NMR (CD<sub>2</sub>Cl<sub>2</sub>): δ 65.3

(d,  $J_{\text{Rh-P}} = 161$  Hz). ESI-MS( $m/z$ ):  $[\text{M-BF}_4]^+ = 1904.4$ , Calcd for  $[\text{C}_{94}\text{H}_{82}\text{BF}_4\text{N}_6\text{O}_4\text{P}_4\text{Rh}_2\text{S}_4]^+ = 1904.2$ . Anal. Calcd for  $\text{C}_{94}\text{H}_{82}\text{B}_2\text{F}_8\text{N}_6\text{O}_4\text{P}_4\text{Rh}_2\text{S}_4 \cdot \text{CH}_2\text{Cl}_2$ : C, 54.96; H, 4.08; N, 4.05, Found: C, 54.94; H, 3.90; N, 4.12.

**Closed macrocyclic complex – Cl (7).** Compound **5** (40.3 mg, 0.050 mmol) in  $\text{CH}_2\text{Cl}_2$  (5 mL) was added drop wise over 10 min to a  $\text{CH}_2\text{Cl}_2$  (5 mL) solution of  $[\text{RhCl}(\text{CO})_2]_2$  (9.7 mg, 0.025 mmol). The resulting solution was stirred for 30 min before the solvent was evaporated. The product was recrystallized from  $\text{CH}_2\text{Cl}_2$ /hexanes (48.2 mg, 97%).  $^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  11.40 (s, N-H, 4H), 8.01 (m, disubstituted pyridine and  $\text{C}_6\text{H}_4$ , 12H), 7.70 (m, disubstituted pyridine, 2H,  $J = 8$  Hz), 7.23 (m,  $\text{PPh}_2$ , 40H), 7.19 (d,  $\text{C}_6\text{H}_4$ , 8H,  $J = 8$  Hz), 2.78 (m,  $\text{OCH}_2$ , 8H), 2.60 (m,  $\text{CH}_2\text{PPh}_2$ , 8H).  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  65.7 (d,  $J_{\text{Rh-P}} = 162$  Hz). ESI-MS( $m/z$ ):  $[\text{M-Cl}]^+ = 1851.3$ , Calcd for  $[\text{C}_{94}\text{H}_{82}\text{ClN}_6\text{O}_4\text{P}_4\text{Rh}_2\text{S}_4]^+ = 1851.2$ . Anal. Calcd for  $\text{C}_{94}\text{H}_{82}\text{Cl}_2\text{N}_6\text{O}_4\text{P}_4\text{Rh}_2\text{S}_4 \cdot \text{CH}_2\text{Cl}_2$ : C, 57.82; H, 4.29; N, 4.26, Found: C, 58.18; H, 4.38; N, 4.30.

**Open macrocyclic complex (8).** To a  $\text{CH}_2\text{Cl}_2$  (5 mL) solution of complex **6a** (63.5 mg, 0.02 mmol) was added  $^t\text{BuNC}$  (19.9 mg, 0.24 mmol) in  $\text{CH}_2\text{Cl}_2$  (5 mL). The resulting solution was stirred for 2 h before the volatiles were evaporated. The product was recrystallized from  $\text{CH}_2\text{Cl}_2$ /hexanes (63.1 mg, 99%).  $^1\text{H}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  9.61 (s, N-H, 4H), 8.38 (d, disubstituted pyridine, 4H,  $J = 8$  Hz), 8.07 (t, disubstituted pyridine, 2H,  $J = 8$  Hz), 7.65 (d,  $\text{C}_6\text{H}_4$ , 8H,  $J = 8$  Hz), 7.42 (br,  $\text{PPh}_2$ , 40H), 7.16 (d,  $\text{C}_6\text{H}_4$ , 8H,  $J = 8$  Hz), 2.89 (m,  $\text{OCH}_2$ , 8H), 2.57 (m,  $\text{CH}_2\text{PPh}_2$ , 8H).  $^{31}\text{P}\{^1\text{H}\}$  NMR ( $\text{CD}_2\text{Cl}_2$ ):  $\delta$  18.2 (br). ESI-MS( $m/z$ ):  $[\text{M-2B}(\text{C}_6\text{F}_5)_4\text{-2}(\text{tBuNC})]^{2+} = 991.2$ , Calcd for  $[\text{C}_{104}\text{H}_{100}\text{N}_8\text{O}_4\text{P}_4\text{Rh}_2\text{S}_4]^{2+} = 991.2$ . Anal. Calcd for  $\text{C}_{162}\text{H}_{118}\text{B}_2\text{F}_{40}\text{N}_{10}\text{O}_4\text{P}_4\text{Rh}_2\text{S}_4$ : C, 55.46; H, 3.39 N, 3.99, Found: C, 55.54; H, 3.12; N, 3.90.<sup>3</sup>

**X-ray crystallography.** Crystals of **6a** and **7** were mounted on fiber loops and cooled to 100 K. In both cases the centrosymmetric space group option was selected based on the results of the refinement. The structures were solved by direct methods, refined with anisotropic thermal parameters, and contained idealized hydrogen atoms, except for the fractional and disordered CH<sub>2</sub>Cl<sub>2</sub> molecule in **6a** and **7**. All software is contained in the SMART, SAINT and SHELXTL software libraries of the Bruker XRD corporation. Disordered CH<sub>2</sub>Cl<sub>2</sub>, the recrystallization solvent, was rendered using SQUEEZE. Found 623e/uc. Calculated for 16 CH<sub>2</sub>Cl<sub>2</sub>, 672e/uc. Solvent is included in the formula and intensive properties.

**Determination of the binding constant.** The binding constants of **6a** and **8** for Cl<sup>-</sup>, respectively, were determined by UV-Vis spectroscopy in CH<sub>2</sub>Cl<sub>2</sub> (303 nm for **6a** and 312 nm for **8**), employing the titration methodology (Figure S-1 and S-2). (tBu)<sub>4</sub>NCl was used as the Cl<sup>-</sup> source. The concentration of the complex was 5 × 10<sup>-4</sup> M<sup>-1</sup>. The data were modeled with the nonlinear curve-fitting program Dynafit<sup>4</sup> (Because the experiments were carried out by UV-vis spectroscopy and the binding constants were based upon small changes in absorbance, there could be significant error associated with these values. However, there is no doubt that the association constant of complex **8** is larger than that for complex **6a**).

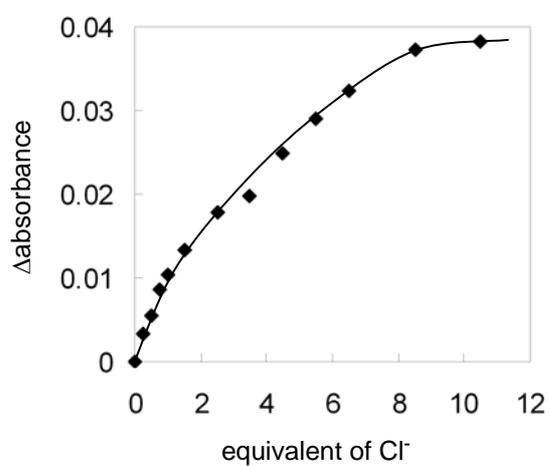


Fig. S-1 Titration plot of **6a** with  $\text{Cl}^-$

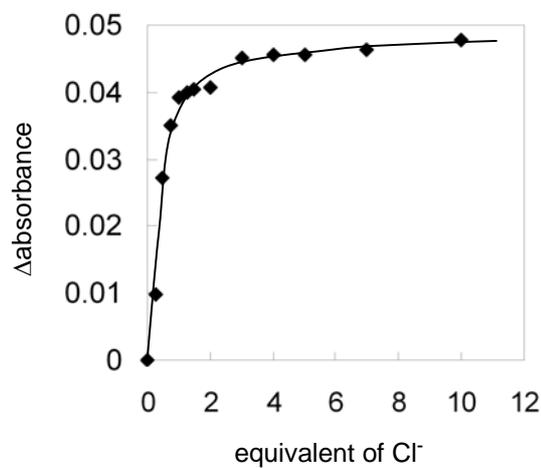


Fig. S-2 Titration plot of **8** with  $\text{Cl}^-$

**The Job plot for a determination of stoichiometry.** Figure S-3 shows a Job plot which is based upon  $^1\text{H}$  NMR chemical shift data for the amide N-H signal in  $\text{CD}_2\text{Cl}_2$  for macrocycle **8** complexing  $\text{Cl}^-$  ( $[\mathbf{8}] + [(\text{tBu})_4\text{NCl}] = 10 \text{ mM}$ ).<sup>5</sup>

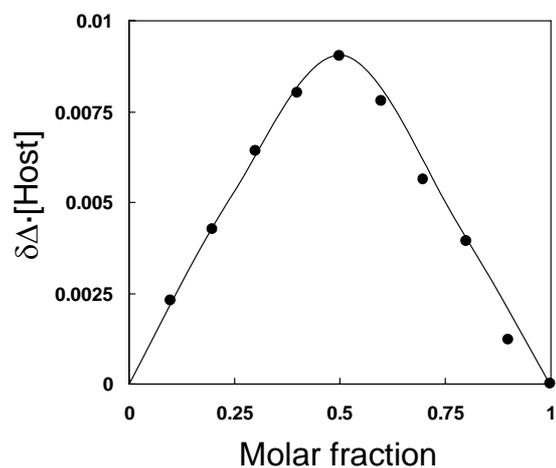


Fig. S-3 Job plot for complexation of **8** with  $\text{Cl}^-$

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