Electronic supplementary information

Molecular Binding Behavior of Bipyridium Derivatives by Water-soluble Carboxylato-biphen[3]arene

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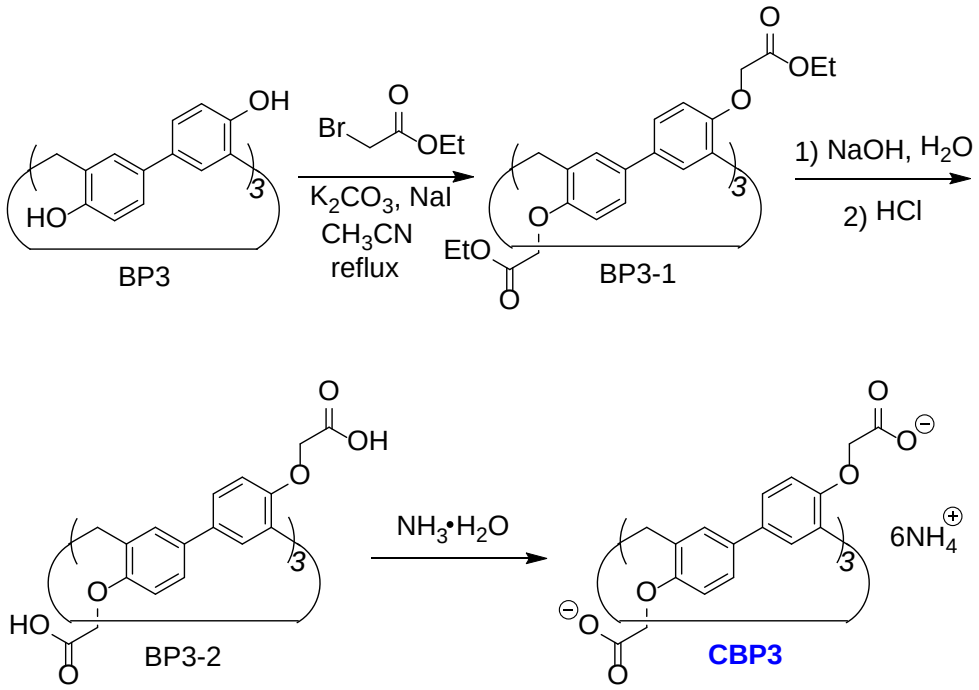
Contents

Materials and methods.

per-Hydroxylated biphen[3]arene (BP3) was synthesized according to our previously reported method.[S 1] Dicationic guests **1**·2I, **2**·2Br–**5**·2Br and **6**·2Cl were prepared by literature methods and recrystallized and dried under reduced pressure before use.[S2] UV-vis spectra were recorded in a conventional 1 cm path (1 × 0.25 cm) quartz cell on a UV spectrophotometer equipped with a temperature controller to keep the temperature at 25 °C. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker AV500 instrument. High-resolution mass spectra (HRMS) were recorded on a Bruker Daltonics, Inc. APEXIII 7.0 TESLA FTMS instrument.

Synthesis.



Ethoxycarbonyl substituted biphen[3]arene (BP3-1). To a solution of BP3 (1.19 g, 2.00 mmol) in 40 mL CH_3CN (40 mL) was added K_2CO_3 (2.76 g, 20 mmol), and the mixture was stirred for 0.5 h under nitrogen atmosphere. Then ethyl bromoacetate (2.67 g, 16 mmol) and a small amount of NaI (~ 10 mg) were added. The mixture was heated to 80 °C for 30 hours. The cooled reaction mixture was filtered and washed with dichloromethane. The

solvent was removed under vacuum. The resulting residue was dissolved in dichloromethane (50 mL), and then extracted with water (25 mL × 2). The organic layer was dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by recrystallization in dichloromethane and *n*-pentane to afford BP3-1 as a white solid. (1.33 g, 60 %). ^{1}H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.24 (dd, *J* = 2.38, 8.48 Hz, 6H), 7.04 (d, *J* = 2.19 Hz, 6H), 6.75 (d, *J* = 8.48 Hz, 6H), 4.61 (s, 12H), 4.21 (q, *J* = 7.23, 14.30 Hz, 12H), 4.13 (s, 6H), 1.24 (t, *J* = 6.96, 14.20 Hz, 18H). ^{13}C NMR (125 MHz, CD_2Cl_2): δ (ppm): 169.40, 155.52, 134.70, 130.35, 129.39, 125.89, 112.48, 66.46, 61.53, 29.34, 14.36. HRMS (ESI): $C_{63}H_{66}O_{18}Na^+$, calcd *m/z* 1133.4141; found *m/z* 1133.4163.

Carboxylic acid substituted biphen[3]arene (BP3-2). A solution of BP3-1 (445 mg, 0.40 mmol) in 20 mL of THF and 20 mL of aqueous sodium hydroxide (40 %) was stirred at reflux for 8 h. THF was removed by evaporation under vacuum. The cooled solution was diluted with water (20 mL) and then acidified with aqueous HCl solution. The precipitated product was collected by filtration, washed with cold water and dried under vacuum to get BP3-2 as a white solid (336 mg, 89%). ^{1}H NMR (500 MHz, DMSO-d_6) spectrum: δ (ppm): 13.00 (br, 3H), 7.22 (dd, *J* = 1.94, 8.43 Hz, 6H), 6.89 (d, *J* =2.25 Hz, 6H), 6.84 (d, *J* =8.56 Hz, 6H), 4.67 (s, 12H)，3.97 (s, 6H). ^{13}C NMR (125 MHz, DMSO-d_6): δ (ppm): 170.84, 155.32, 133.76, 129.61, 128.77, 125.76, 112.59, 65.62, 28.72. HRMS (ESI): $C_{51}H_{42}O_{18}Na^+$, calcd *m/z* 965.2263; found *m/z* 965.2280.

Carboxylato-biphen[3]arene (CBP3). BP3-2 (217 mg, 0.23 mmol) was added to 30 mL of ammonium hydroxide solution (25 − 28 %), and stirred at room temperature for 4h. Then the solvent was removed under vacuum to quantitatively obtain CBP3 as a white solid. ^{1}H NMR (500 MHz, D_2O): δ (ppm): 7.37 (s, 6H), 7.14 (s, 6H), 6.85 (s, 6H), 4.42 (s, 12H), 4.05 (s, 6H). ^{13}C NMR (125 MHz, D_2O): δ (ppm): 176.18, 154.87, 132.79, 129.47, 127.91, 125.32, 112.46, 67.04, 28.60.

Copies of ^{1}H NMR and ^{13}C NMR spectra of the host molecules.

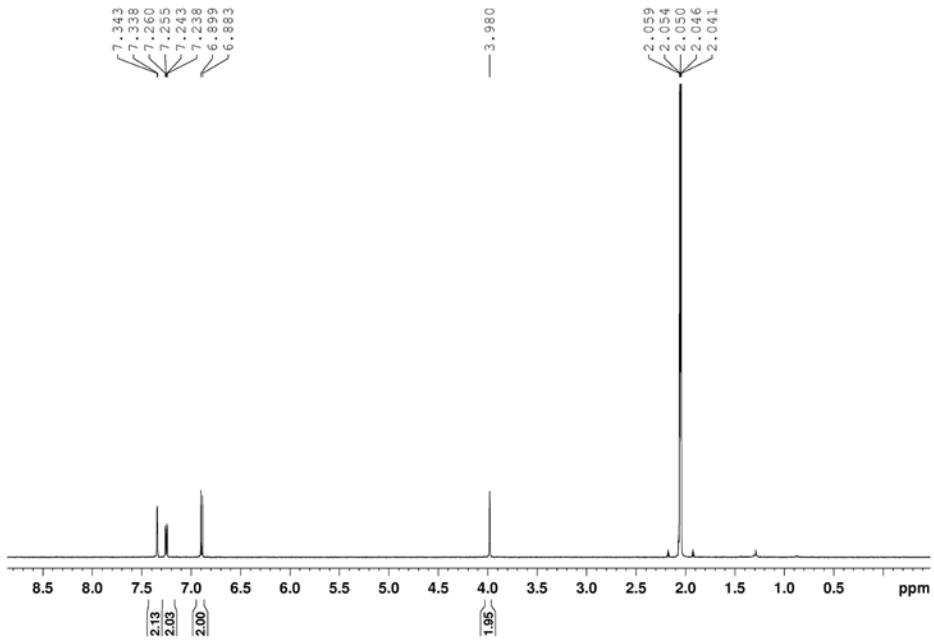


Figure S1. ^{1}H NMR spectrum (500 MHz) of BP3 in $(CD_3)_2CO$.

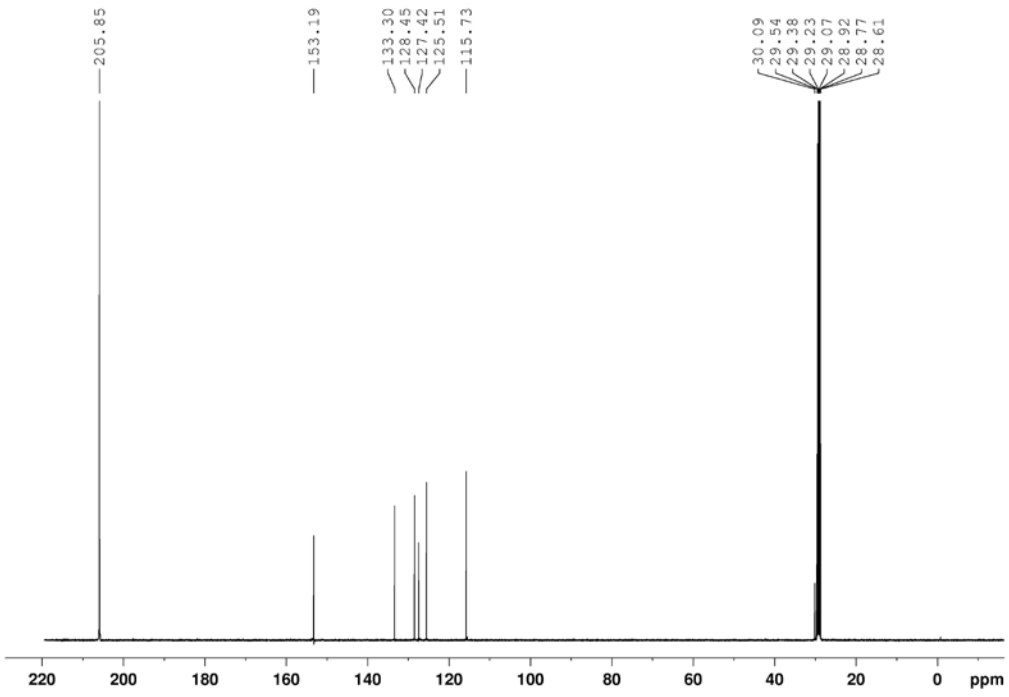


Figure S2. ^{13}C NMR spectrum (125 MHz) of BP3 in $(CD_3)_2CO$.

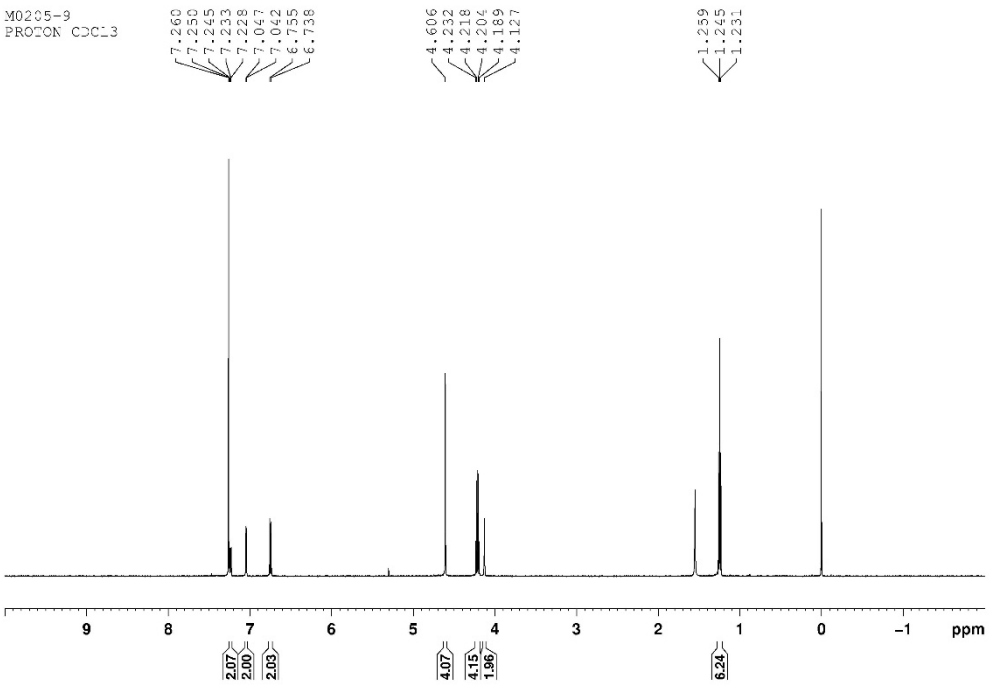


Figure S3. ^{1}H NMR spectrum (500 MHz) of BP3-1 in $CDCl_3$.

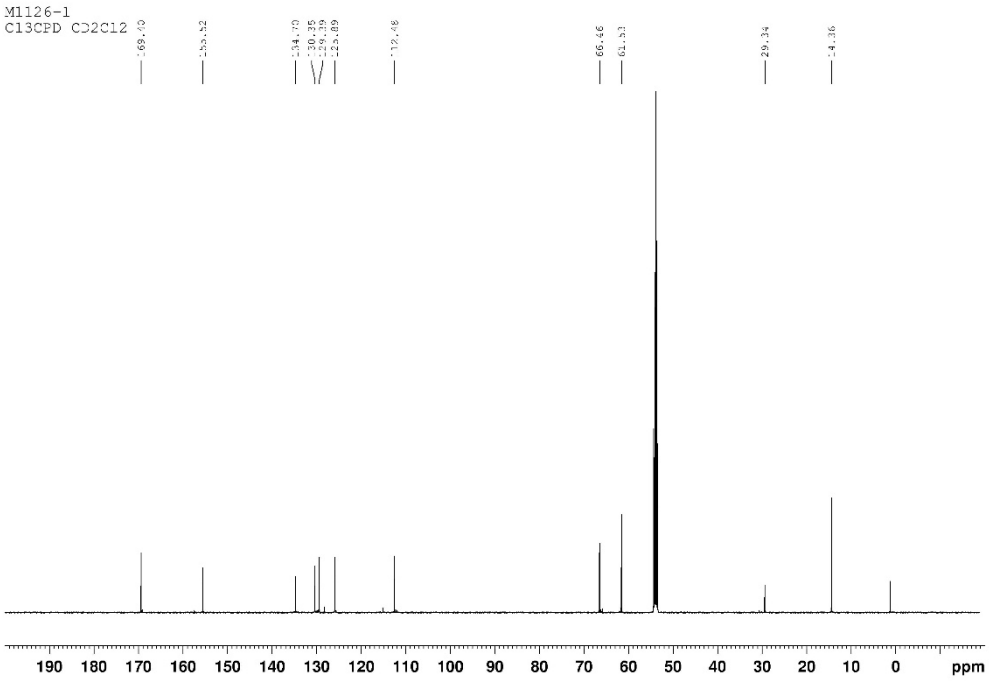


Figure S4. ^{13}C NMR spectrum (125 MHz) of BP3-1 in CD_2Cl_2.

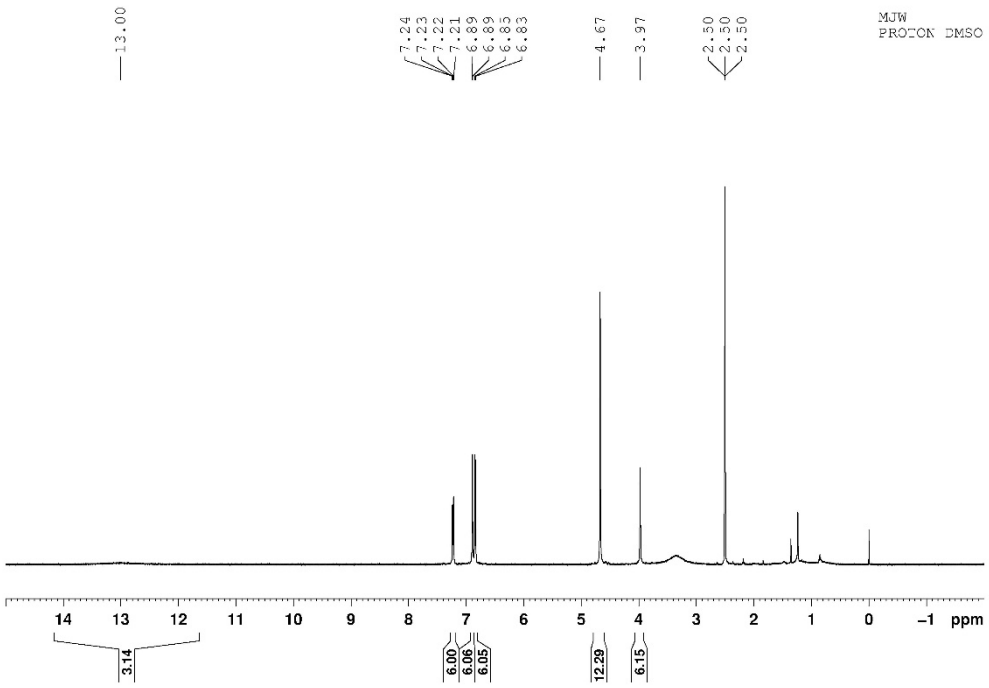


Figure S5. ^{1}H NMR spectrum (500 MHz) of BP3-2 in DMSO-d_6.

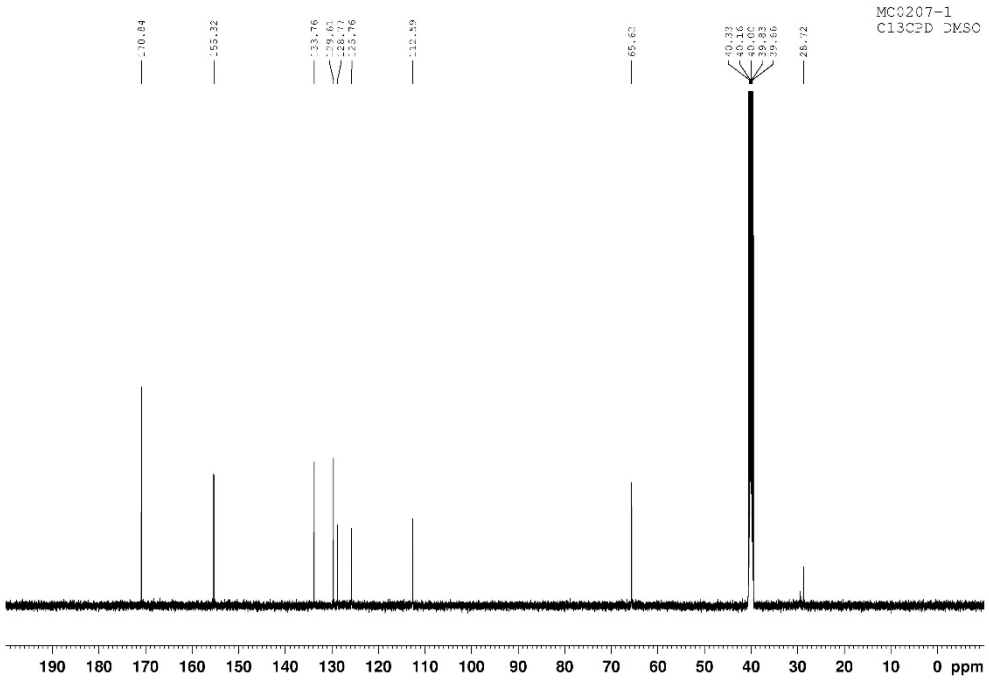


Figure S6. ^{13}C NMR spectrum (125 MHz) of BP3-2 in DMSO-d_6.

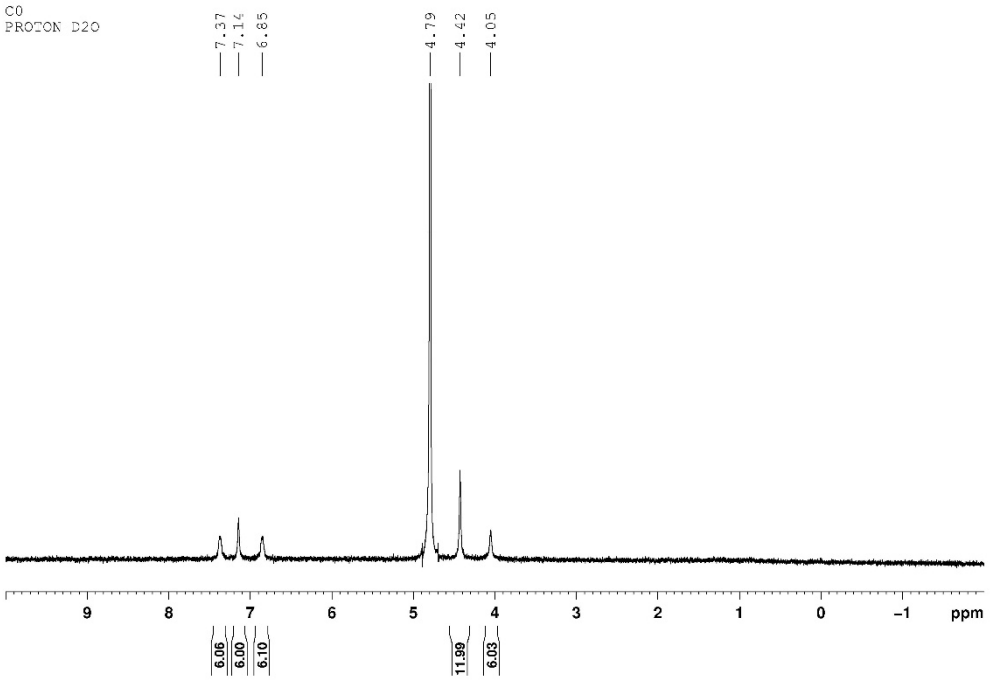


Figure S7. ^{1}H NMR spectrum (500 MHz) of CBP3 in D_2O.

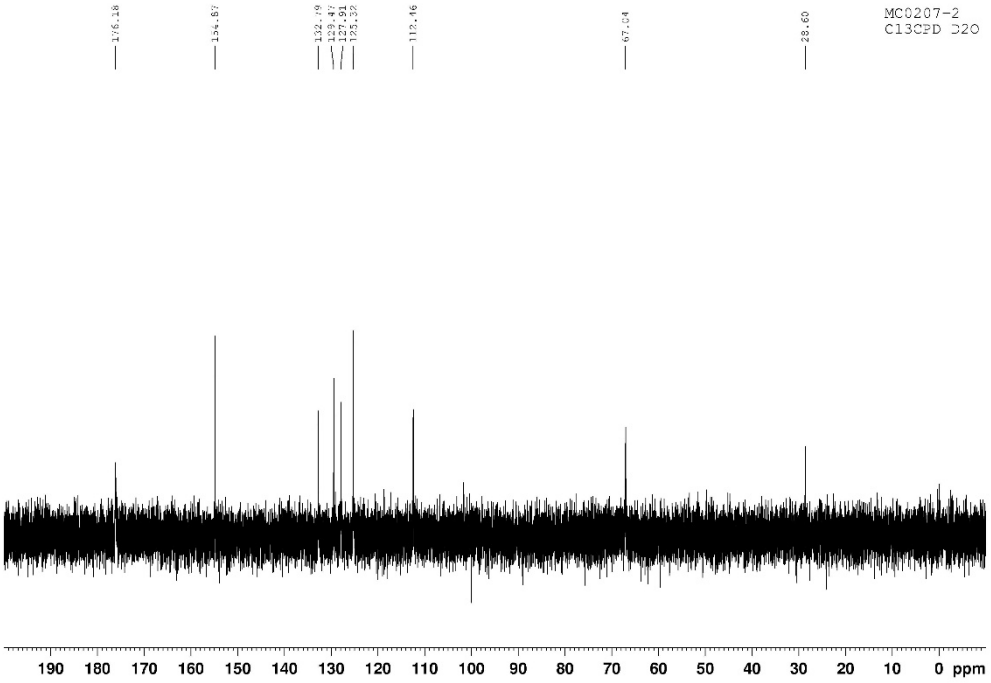


Figure S8. ^{13}C NMR spectrum (125 MHz) of CBP3 in D_2O.

^{1}H NMR spectra of 5^{2+} in the absence and presence of CBP3.

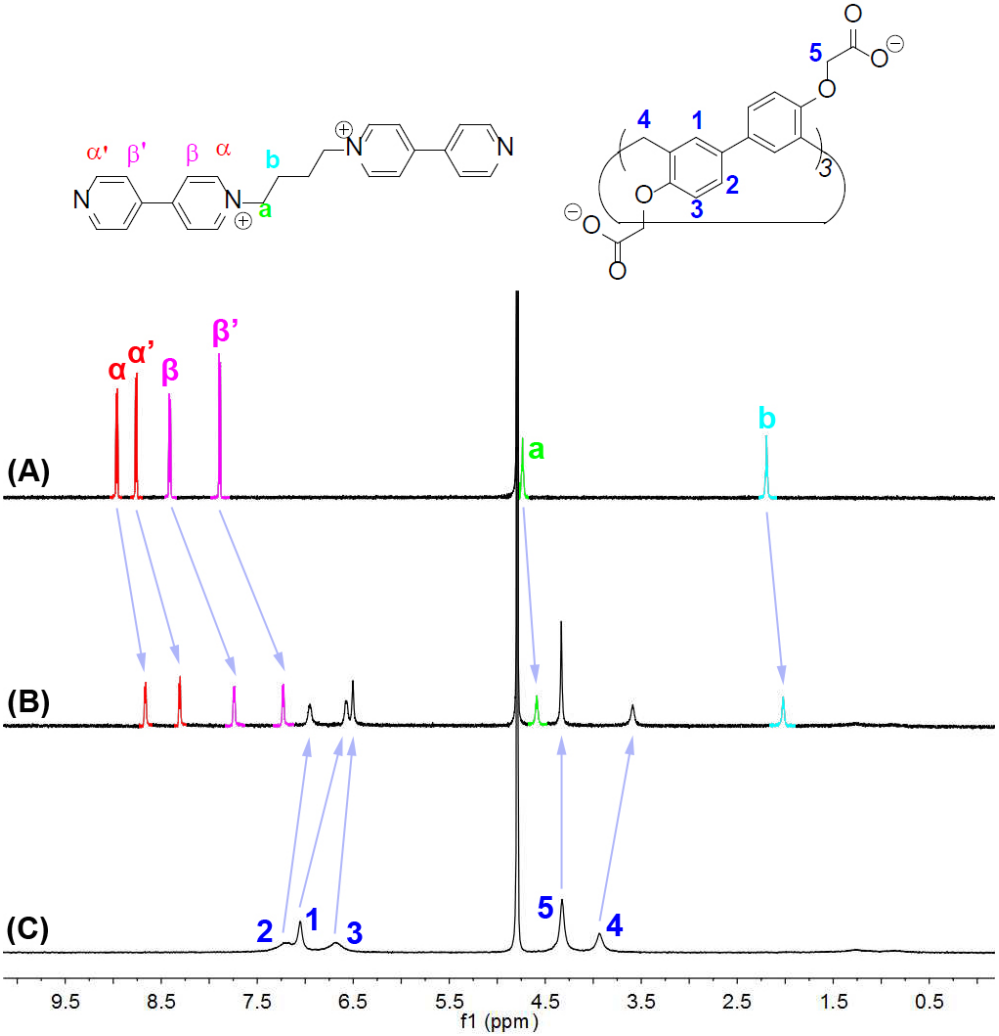


Figure S9. ^{1}H NMR spectra (500 MHz) of (A) $\mathbf{5}^{2+}$, (B) $\mathbf{5}^{2+}$ + CBP3, and (C) CBP3 in D_2O at 2.7–3.1 mM.

Job plots.

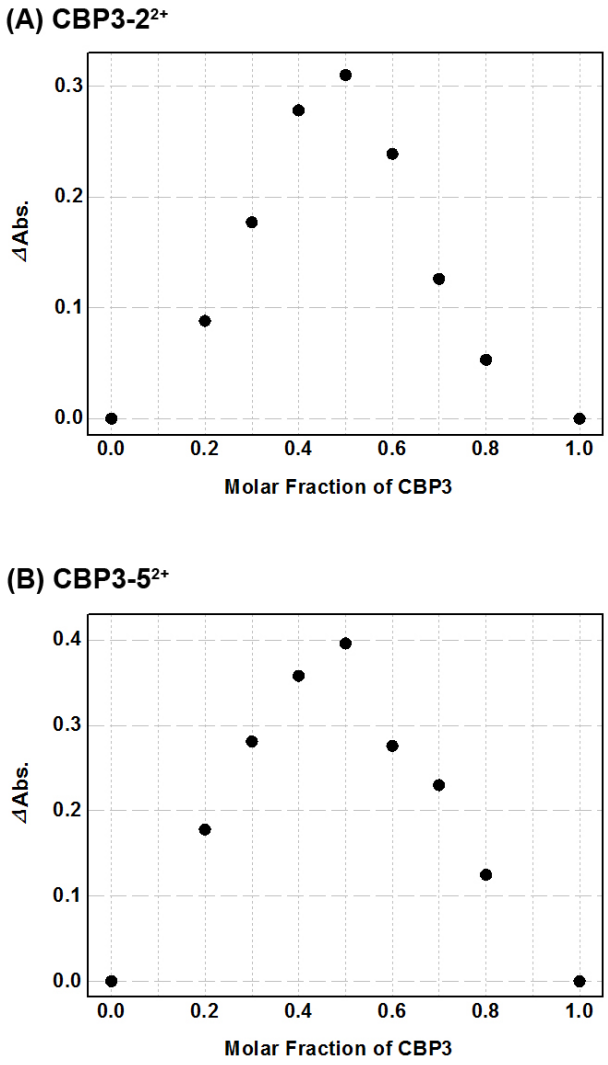


Figure S10. Job plot showing the 1 : 1 stoichiometry of the complexes in aqueous solution by plotting the *Δ Abs.* values at λ = 456 nm for **2**·2Br−CBP3 pair (A) and 380 nm for **5**·2Br−CBP3 (B) against the mole fraction of CBP3. ([CBP3] + [guest] = 4.0 mM).

Determination of the association constants.

In the present host-guest systems, chemical exchange is fast on the NMR time scale. To determine the association constant, NMR titrations were done with solutions which had a constant concentration of CBP3 and varying concentrations of guest. Assuming 1:1 inclusion complexation stoichiometry between CBP3 and the guests, the association constants (K_a) could be calculated by analyzing the sequential changes in chemical shift changes of CBP3 host that occurred with changes in guest concentration. Using the nonlinear curve-fitting method, the association constant was obtained for each host-guest combination from the following equation[3]:

$$A = (A_\infty/[H]_0)\ (0.5[G]_0 + 0.5([H]_0+1/K_a) - (0.5\ ([G]_0^2+(2[G]_0(1/K_a - [H]_0)) + (1/K_a + [H]_0)^2)^{0.5}))$$

Where A is the chemical shift change of H_4 on CBP3 host at $[G]_0$, A_∞ is the chemical shift change of H_1 when the host is completely complexed, $[H]_0$ is the fixed initial concentration of the CBP3 host, and $[G]_0$ is the initial concentration of guest.

For each guest examined, the plot of A as a function of $[G]_0$ gave an excellent fit ($R > 0.98$), verifying the validity of the 1:1 inclusion complexation stoichiometry assumed. Additionally, the 1:1 inclusion complexation stoichiometry has also been proved by job's experiments (Figure S10).

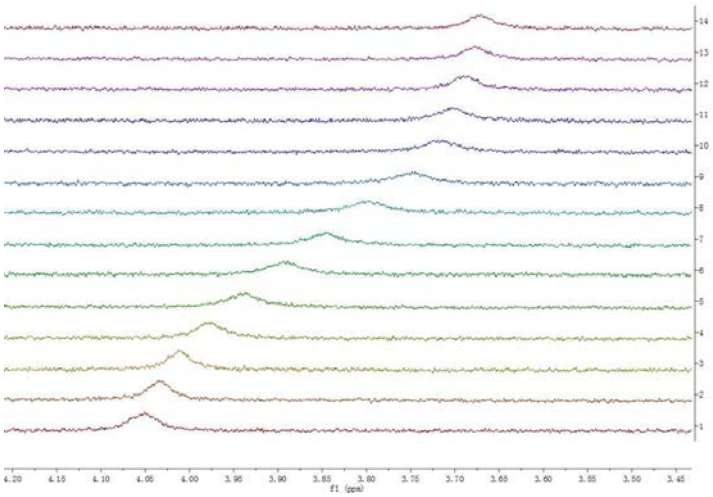


Figure S11. Partial ^{1}H NMR spectrum (500 MHz, D_2O, 298 K) of CBP3 at a concentration of 0.50 mM upon addition of **2**·2Br. From bottom to top, the concentration of **2**·2Br was 0, 0.03, 0.08, 0.13, 0.19, 0.25, 0.32, 0.42, 0.52, 0.63, 0.79, 1.08, 1.69, 2.08 mM.

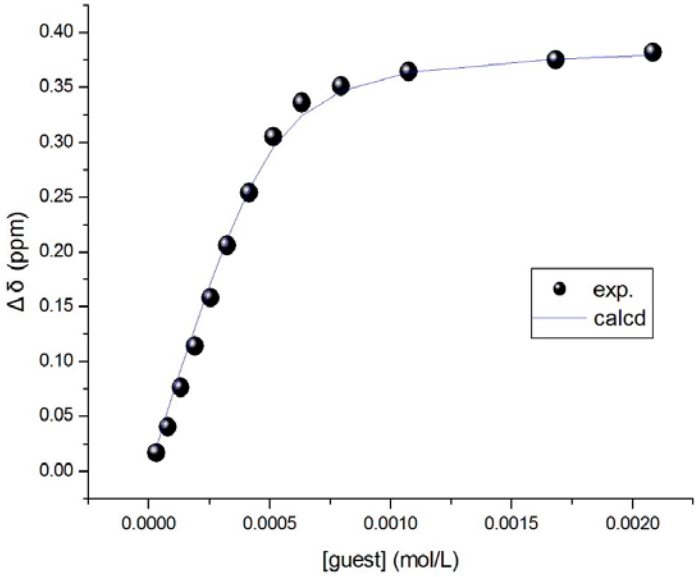


Figure S12. The non-linear curve-fitting (NMR titrations) for the complexation of CBP3 host (0.50 mM) and **2**·2Br in D_2O at 298 K. The concentration of **2**·2Br was 0.03, 0.08, 0.13, 0.19, 0.25, 0.32, 0.42, 0.52, 0.63, 0.79, 1.08, 1.69, 2.08 mM.

References.

[S1] H. Chen, J. Fan, X. Hu, J. Ma, S. Wang, J. Li, Y. Yu, X. Jia and C. Li, *Chem. Sci.*, 2015, **6**, 197–202.

[S2] a) M. I. Attalla, N. S. McAlpine and L. A. Summers, *Z. Naturforsch. B*, 1984, **39**, 74–78; b) J. Joseph, N. V. Eldho and D. Ramaiah, *Chem.–Eur. J.*, 2003, **9**, 5926–5935; c) M. Kwangyul and A. E. Kaifer, *Org. Lett.*, 2004, **6**, 185–188.

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