

Electronic supplementary information

Novel Binding Regioselectivity in the Interpenetration of a Non-symmetric Axle into a Non-symmetric Pillar[5]arene Wheel

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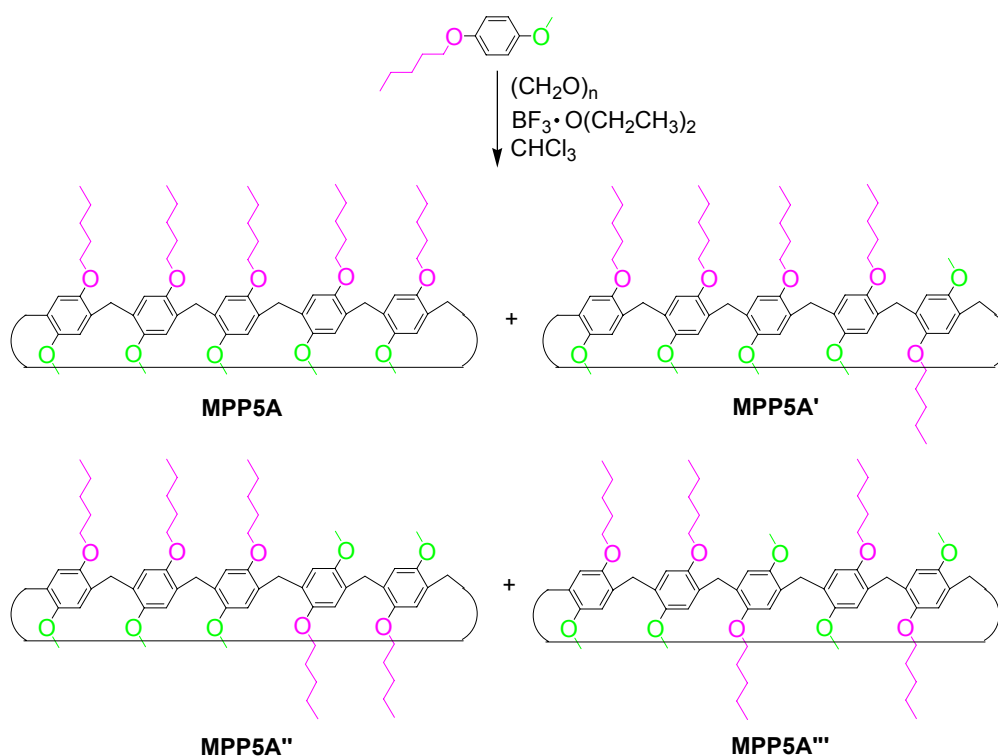
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Experimental Section

Materials and methods.

All commercial reagents were used as purchased from commercial sources without further purification. MeP5A, and DPP5A were prepared by condensation of the corresponding 1,4-dialkoxybenzene with paraformaldehyde and $\text{BF}_3 \cdot \text{O}(\text{C}_2\text{H}_5)_2$ as a catalyst.^[S1] ^1H NMR, ^{13}C NMR and 2D NOESY spectra were recorded on a Bruker AV500 instrument. High-resolution mass spectra (HRMS) were performed on a Bruker MicroTOF II spectrometer.

Synthesis of MPP5A.



To a solution of 1-methoxy-4-pentyloxybenzene (5 g 25.8 mmol) and paraformaldehyde (2.3 g 77 mmol) in CHCl_3 (150 mL), $\text{BF}_3 \cdot \text{O}(\text{C}_2\text{H}_5)_2$ (3.3 ml, 26 mmol) was added. The reaction mixture was stirred at 25 °C for about 2 hours and the progress was monitored using TLC detection. The solution was poured into water and washed with saturated aqueous Na_2CO_3 and

NaCl, The organic layer was dried over anhydrous Na₂SO₄. The crude product was purified by column chromatograph (petroleum ether/ethyl acetate) to afford MPP5A and its three constitutional isomers, (MPP5A', MPP5A'', and MPP5A'''). The total reaction yield is 80 %. The structure of MPP5A was conveniently confirmed since its ¹H NMR spectrum was clear and analyzable. The other three isomers are not suitable wheel molecules to investigate the binding regioselectivity. Their structures could not be determined because their crystal structures were not obtained and their NMR spectra were complicated. The ¹H NMR and ¹³C NMR spectra of MPP5A (0.31 g, 6.0 %) are shown in Figure S5 and S6. m.p. 140–142°C. ¹H NMR (500 MHz, CDCl₃): δ (ppm) = 6.84 (s, 5H), 6.77 (s, 5H), 3.83 (t, *J* = 6.5 Hz, 10H), 3.77 (s, 10H), 3.67 (s, 15H), 1.80 (m, 10H), 1.51 (m, 10H), 1.40 (m, 10H), 0.93 (t, *J* = 7.3 Hz, 15H); ¹³C NMR (125 MHz, CDCl₃): δ (ppm): 150.6, 150.1, 128.2, 128.2, 114.8, 114.1, 68.3, 55.7, 29.8, 29.6, 28.5, 22.6, 14.1; HRMS (ESI-TOF): *m/z* calcd for [C₆₅H₉₀O₁₀+K]⁺: 1069.6171; found 1069.6146.

Copies of ^1H NMR and ^{13}C NMR spectra of the pillar[5]arene hosts.

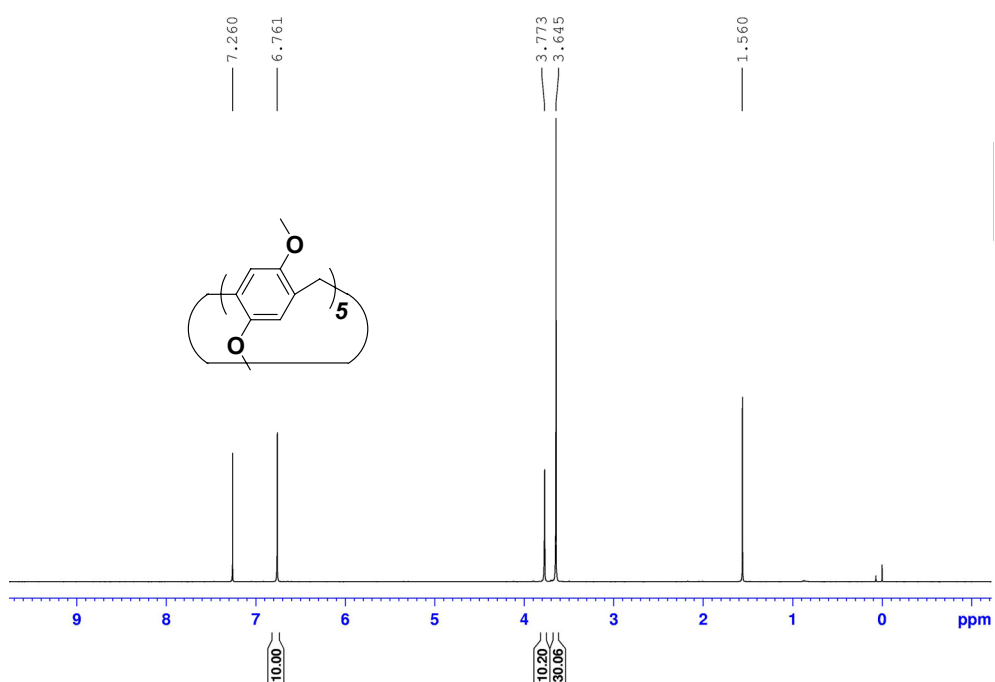


Figure S1. ^1H NMR spectrum (500 MHz) of DMP5A in CDCl_3 .

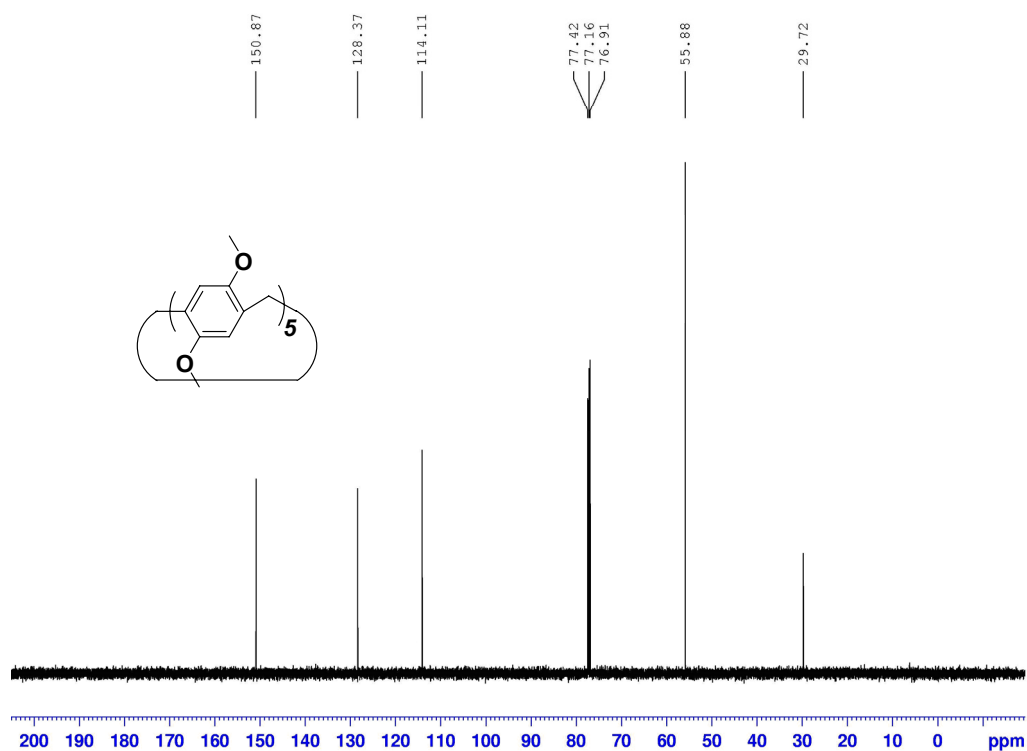


Figure S2. ^{13}C NMR spectrum (125 MHz) of DMP5A in CDCl_3 .

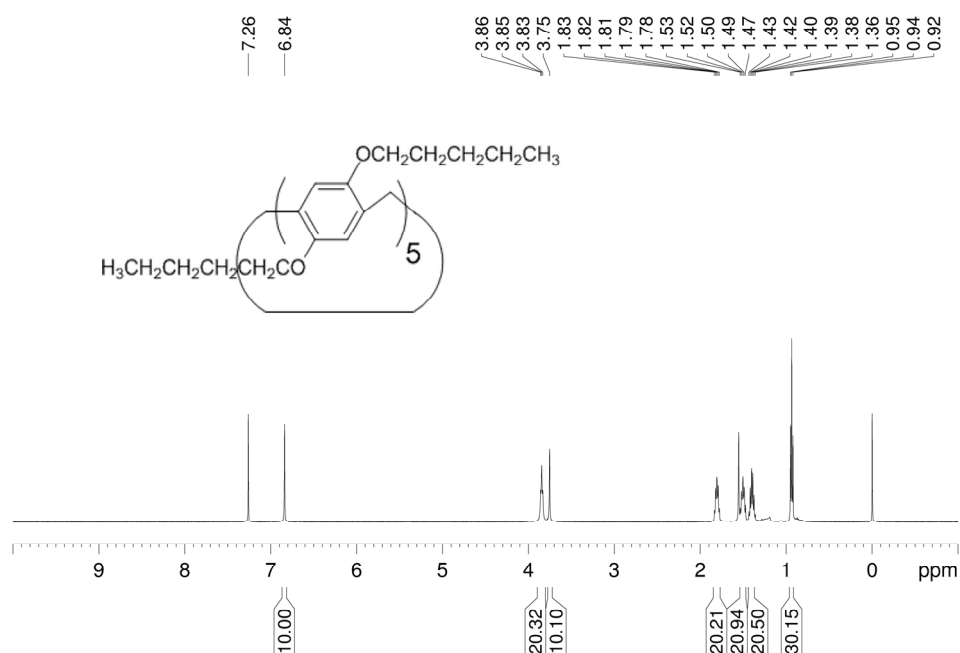


Figure S3. ¹H NMR spectrum (500 MHz) of DPP5A in CDCl₃.

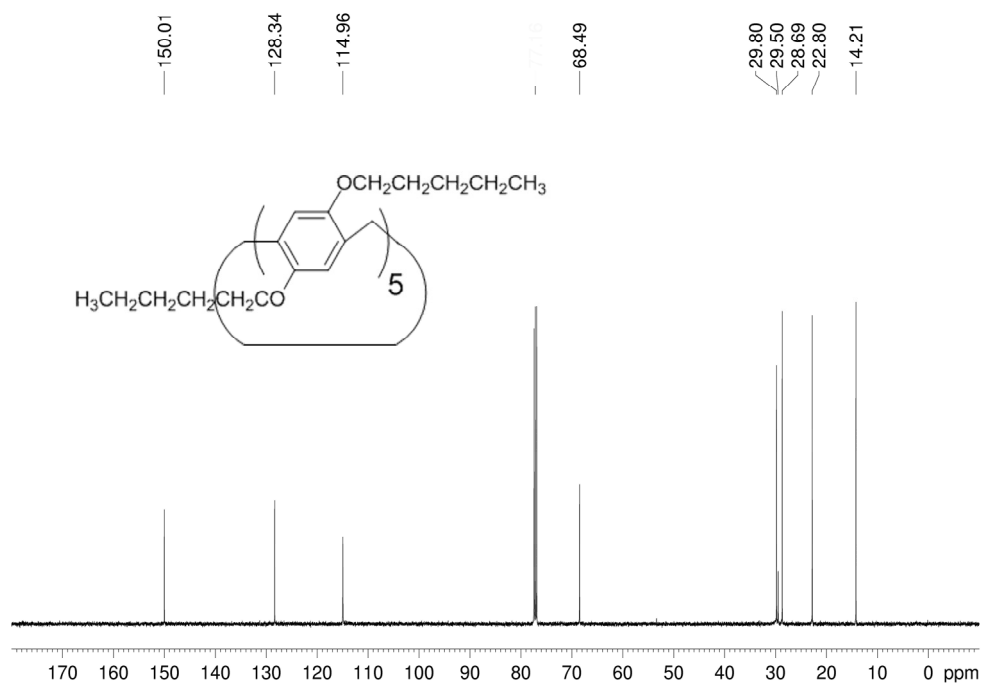


Figure S4. ¹³C NMR spectrum (125 MHz) of DPP5A in CDCl₃.

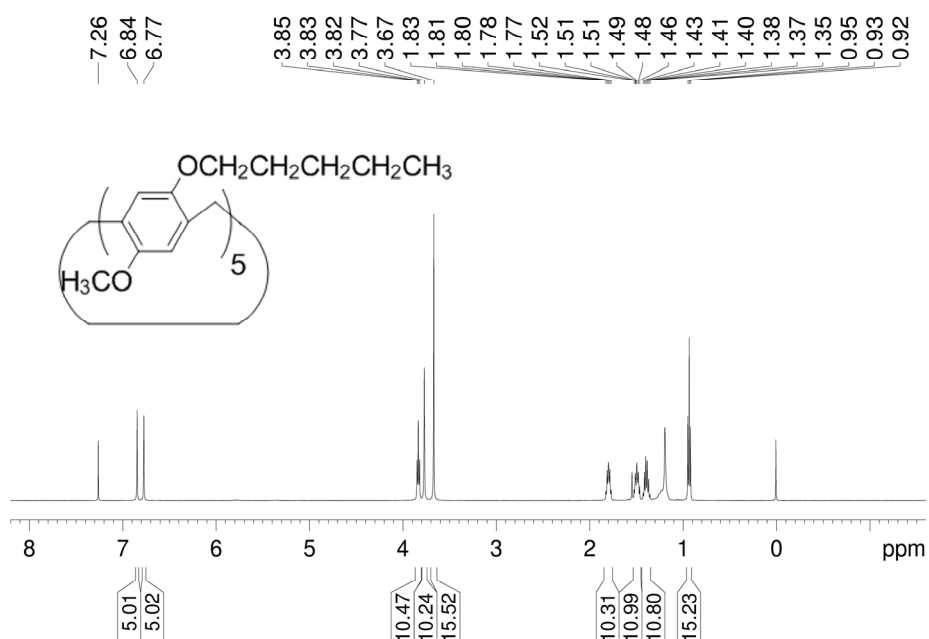


Figure S5. ¹H NMR spectrum (500 MHz) of MPP5A in CDCl₃.

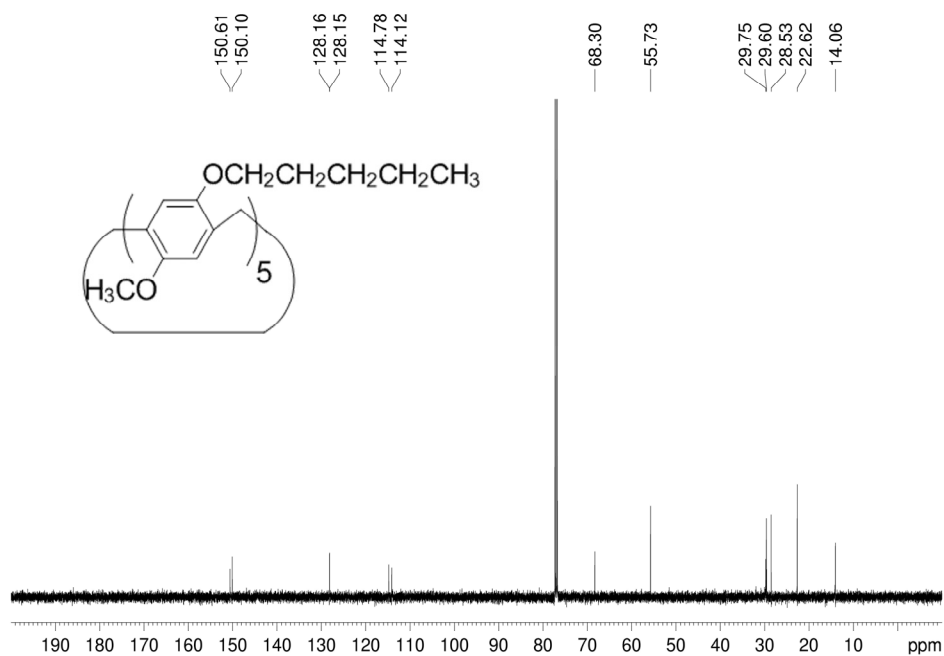


Figure S6. ¹³C NMR spectrum (125 MHz) of MPP5A in CDCl₃.

2D NOESY analysis of MPP5A.

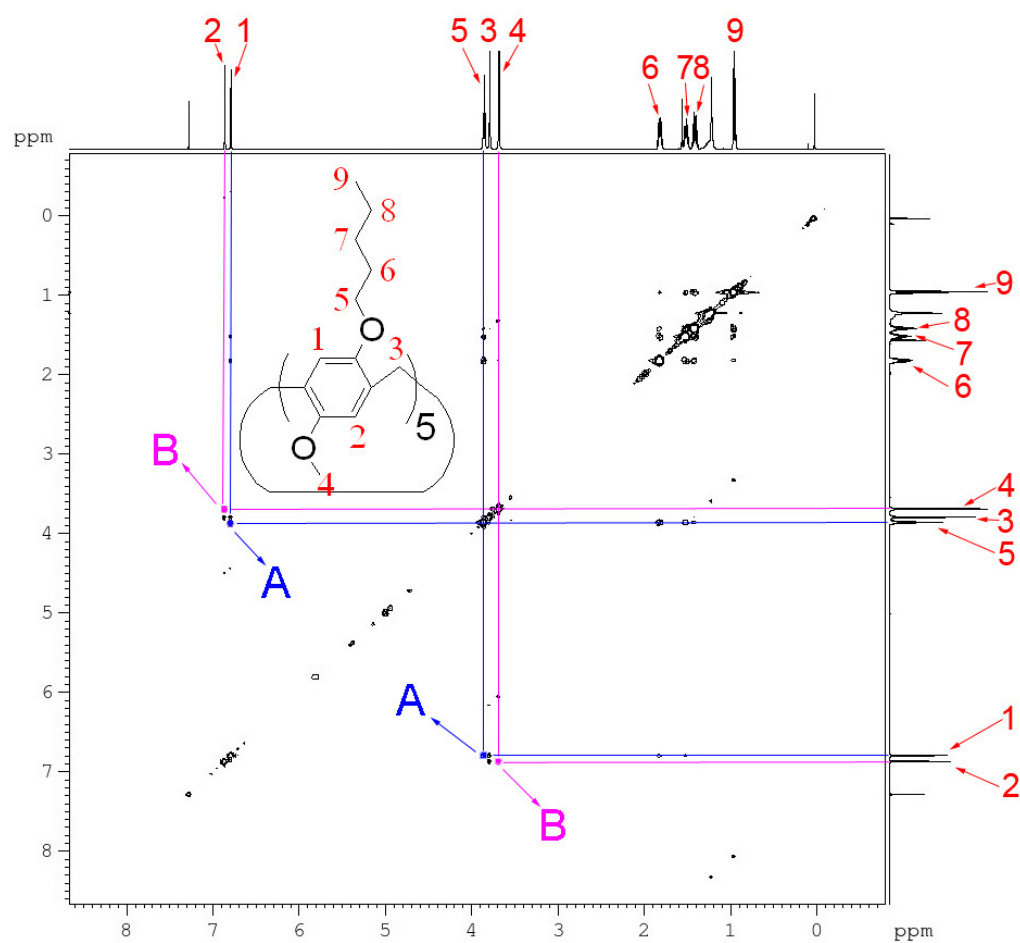


Figure S7. 2D NOESY (500 MHz, 298 K) analysis of MPP5A (15 mM) in CDCl₃.

^1H NMR spectra of guest **2 and **3** in the absence and presence of MPP5A host.**

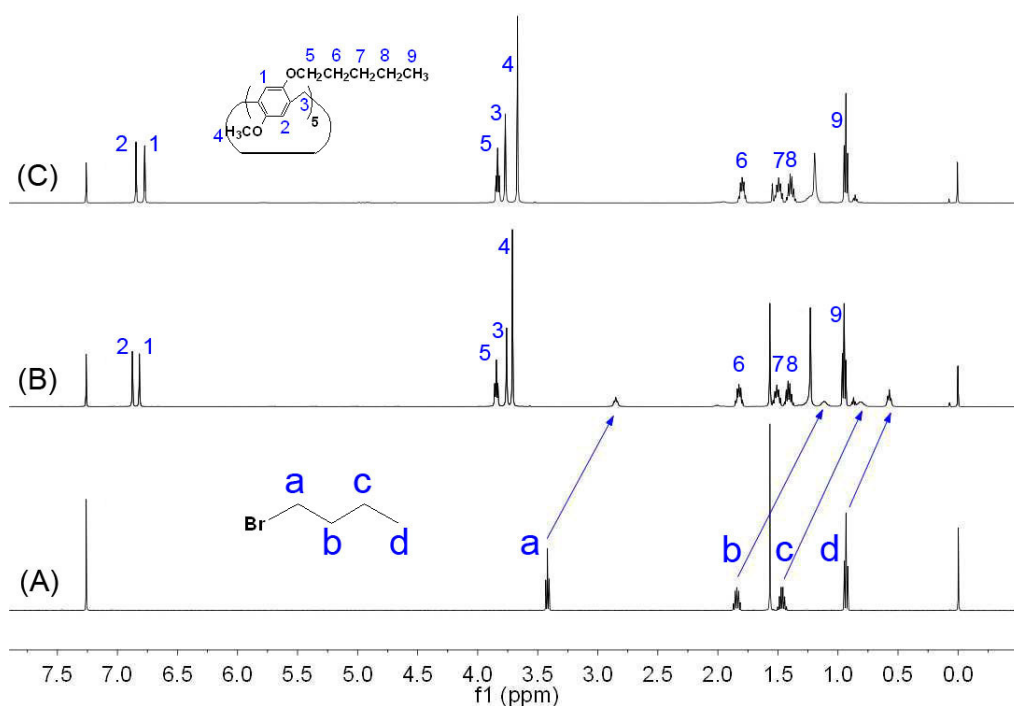


Figure S8. ^1H NMR spectra (500 MHz, 298 K) of (a) 1-bromobutane (**2**), (b) **2** + MPP5A, and (c) MPP5A in CDCl_3 at 4.8–5.4 mM.

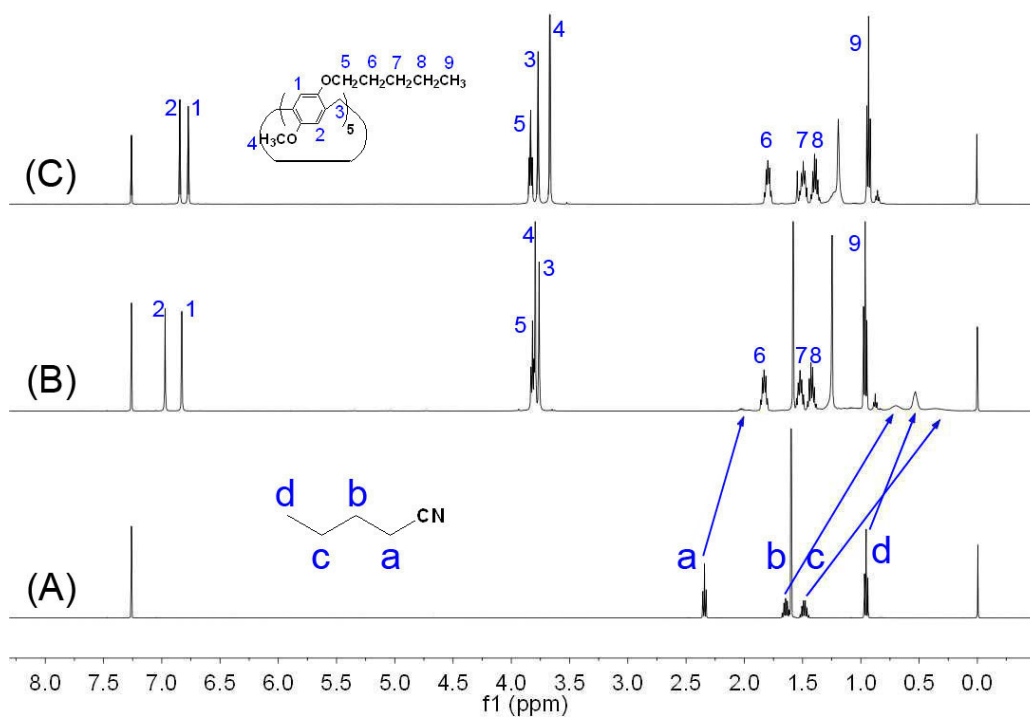


Figure S9. ^1H NMR spectra (500 MHz, 298 K) of (a) 1-butyl cyanide (**3**), (b) **3** + MPP5A, and (c) MPP5A in CDCl_3 at 4.8–5.2 mM.

X-ray crystal data and crystal structure of 1⊂MPP5A complex.

Crystal data for 1⊂MPP5A complex. Colorless, $C_{71}H_{100}BrCl_2NO_{10}$, FW 1278.32, Triclinic, space group P-1, $a = 11.901(3)$, $b = 15.078(3)$, $c = 20.832(5)$, $\alpha = 85.587(4)^\circ$, $\beta = 87.401(4)^\circ$, $\gamma = 70.094(4)^\circ$, $V = 3503.9(13) \text{ \AA}^3$, $Z = 4$, $D_c = 1.212 \text{ g cm}^{-3}$, $T = 173(2) \text{ K}$, $\mu = 0.718 \text{ mm}^{-1}$, 20540 measured reflections, 12159 independent reflections, 770 parameters, 3 restraint, $F(000) = 1364$, $R_1 = 0.1408$, $wR_2 = 0.3348$ (all data), $R_1 = 0.1040$, $wR_2 = 0.2949$ [$I > 2\sigma(I)$], max. residual density $1.689 \text{ e \AA}^{-3}$, and goodness-of-fit (F^2) = 1.011. CCDC 963332.

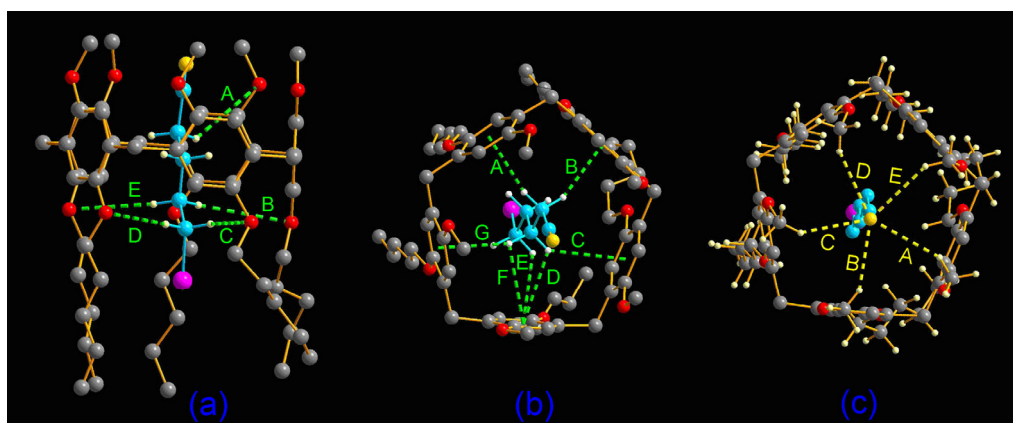


Figure S10. Crystal structure of interpenetrated complex 1⊂MPP5A. MPP5A host is dark gray; guest 1 is sky-blue; oxygen atoms are red; bromine atom is magenta; and nitrogen atom is yellow. Dashes represent C-H...O, C-H... π , and C-H...N hydrogen bonds. (A) C-H...O hydrogen-bond parameters: H...O distances ($\text{\AA}$), C-H...O angles ($^\circ$) A, 3.50, 134; B, 3.39, 145; C, 2.68, 146; D, 2.75, 174; E, 3.11, 172. (B) C-H... π parameters: H...ring centre distances ($\text{\AA}$), C-H...ring angles [$^\circ$]: A, 2.67, 166; B, 2.65, 154; C, 3.11, 141; D, 3.50, 116; E, 3.09, 118; F, 3.30, 103; G, 2.91, 156. (C) C-H...N hydrogen-bond parameters: H...N distances ($\text{\AA}$), C-H...N angles ($^\circ$) A, 3.17, 147; B, 2.92, 150; C, 2.92, 143; D, 3.13, 154; E, 3.13, 145.

Determination of the association constants.

(1). For 5-bromopentanenitrile $\subset$ pillar[5]arene host-guest complexes, chemical exchange is slow on the NMR time scale and peaks are observed for both complexed and uncomplexed species in the NMR spectra. (Figure 1 in the manuscript) So association constants for these complexes could be determined by integration from a 1 : 1 mixture using the ^1H NMR single point method (Table 1).^{[S2][S3]}

$$K_a = \frac{[\text{P5A}\cdot\text{G}]_c}{[\text{P5A}]_{uc}[\text{G}]_{uc}}$$

NMR experiments using five independently prepared solutions at host's and guest's concentrations of 0.10, 0.30, 0.50, 0.75, and 1.0 mM were performed.

(2). For 1-bromobutane and 1-butyl cyanide, chemical exchange is fast on the NMR time scale (Figure S11 and S12). To determine the association constants, NMR titrations were done with solutions which had a constant concentration of DMP5A, MPP5A, DPP5A host and varying concentrations of guest. Using the nonlinear curve-fitting method, the association constant was obtained for each host-guest combination from the following equation^[S4]:

$$A = (A_\infty/[\text{P5A}]_0) (0.5[\text{G}]_0 + 0.5([\text{P5A}]_0 + 1/K_a) - (0.5 ([\text{G}]_0^2 + (2[\text{G}]_0(1/K_a - [\text{P5A}]_0)) + (1/K_a + [\text{P5A}]_0)^2)^{0.5}))$$

Where A is the chemical shift change of aromatic proton (H_1) on pillar[5]arene host at $[\text{guest}]_0$, A_∞ is the chemical shift change of H_1 when the host is completely complexed, $[\text{host}]_0$ is the fixed initial concentration of the host, and $[\text{guest}]_0$ is the initial concentration of guest.

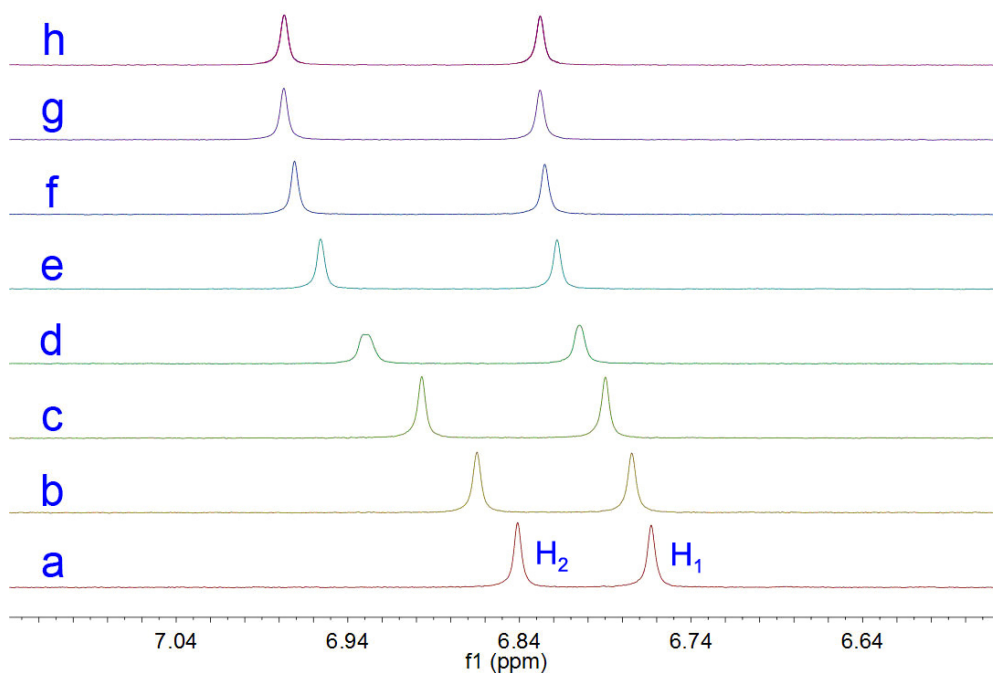


Figure S11. Partial ^1H NMR spectra (500 MHz, CDCl_3 , 298 K) of MPP5A at a concentration of 1.0 mM upon addition of 1-butyl cyanide: (a) 0 mM, (b) 0.50 mM, (c) 1.4 mM, (d) 3.2 mM, (e) 6.5 mM, (f) 12 mM, (g) 19 mM, and (h) 28 mM.

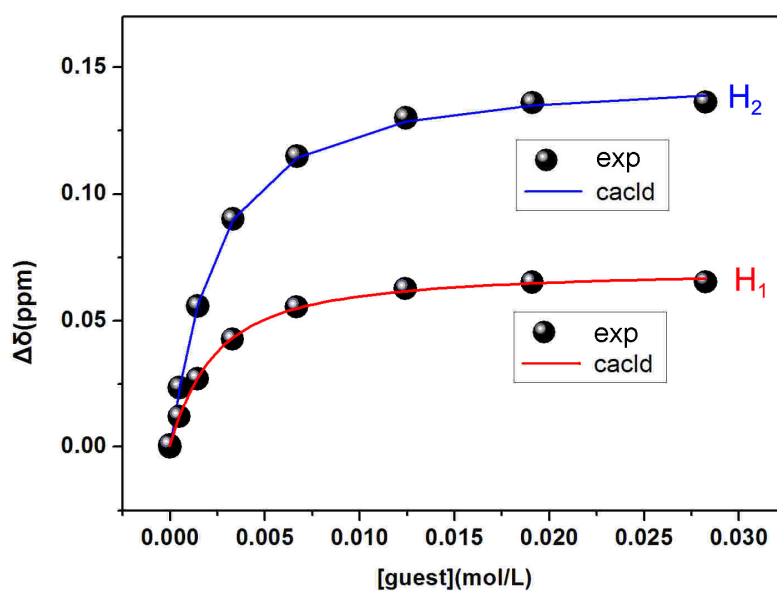


Figure S12. The non-linear curve-fitting (NMR titrations) for the complexation of MPP5A

host (1.0 mM) with 1-butyl cyanide in CDCl₃ at 298 K. The concentration of 1-butyl cyanide was 0, 0.50, 1.4, 3.2, 6.5, 12, 19, 28 mM.

References.

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- [S1] T. Ogoshi, S. Kanai, S. Fujinami, T. Yamagishi, Y. Nakamoto, *J. Am. Chem. Soc.*, 2008, **130**, 5022–5023.
- [S2] J. C. Adrian, Jr., C. S. Wilcox, *J. Am. Chem. Soc.* 1991, **113**, 678–680.
- [S3] Association constants determined using the ¹H NMR single point methods. See: (a) A. B. Braunschweig, C. M. Ronconi, J.-Y. Han, F. Arico, S. J. Cantrill, J. F. Stoddart, S. I. Khan, A. J. P. White, D. J. Williams, *Eur. J. Org. Chem.* 2006, 1857–1866.; b) S. J. Loeb, J. A. Wisner, *Angew. Chem. Int. Ed.* 1998, **37**, 2838–2840; c) S. J. Loeb, J. Tiburcio, S. J. Vella, *Org. Lett.* 2005, **7**, 4923–4926; d) J.-M. Zhao, Q.-S. Zong, T. Han, J.-F. Xiang, C.-F. Chen, *J. Org. Chem.* 2008, **73**, 6800–6806; e) L. Li, G. J. Clarkson, *Org. Lett.* 2007, **9**, 497–500; f) D. Castillo, P. Astudillo, J. Mares, F.J. González, A. Vela, J. Tiburcio, *Org. Biomol. Chem.* 2007, **5**, 2252–2256; g) C. Li, Q. Xu, J. Li, F. Yao, X. Jia, *Org. Biomol. Chem.* 2010, **8**, 1568–1576.
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