A dynamic [1]catenane with pH-responsiveness formed *via* threading-followed-by-complexation

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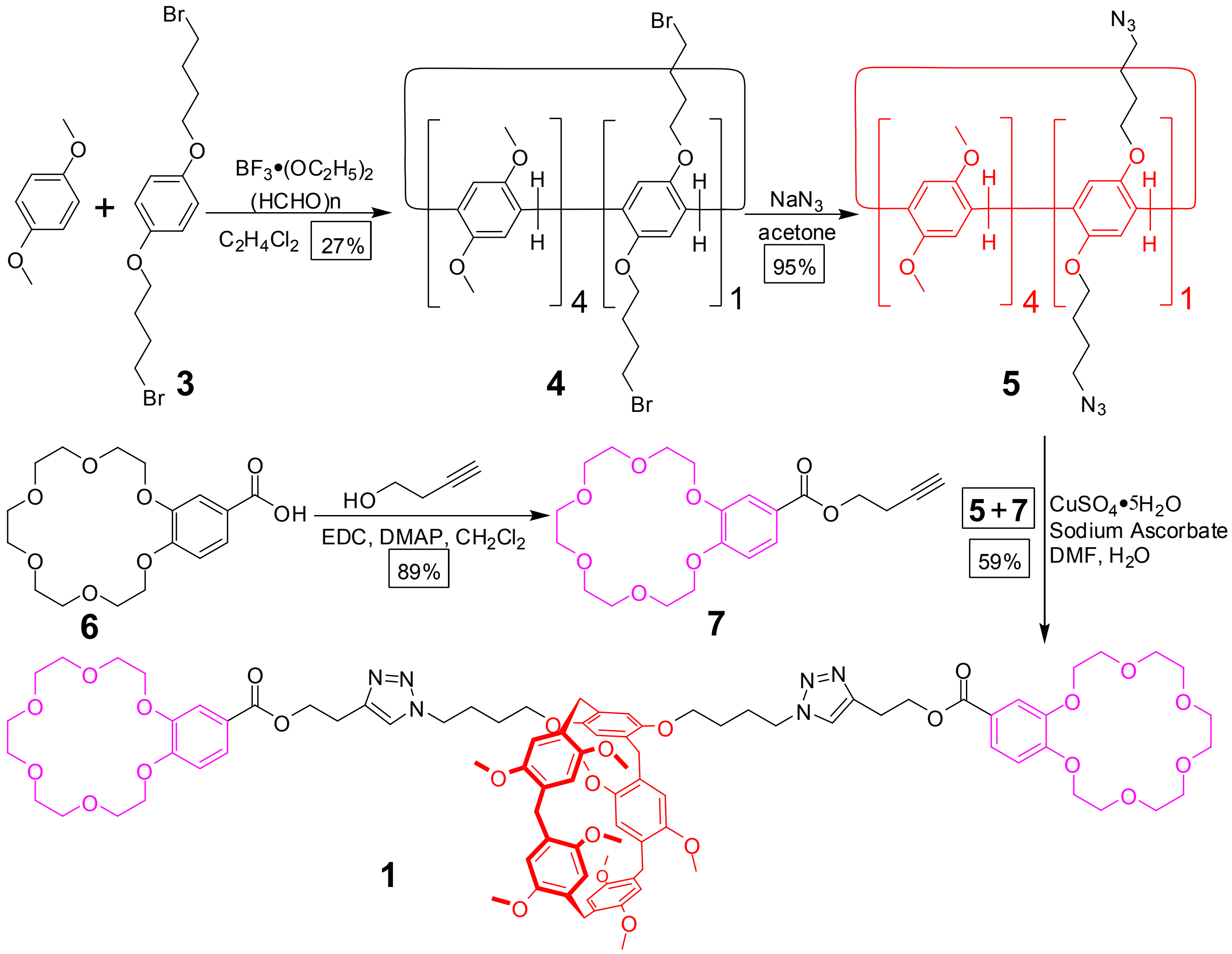
Electronic Supplementary Information (20 pages)

1. Materials and methods

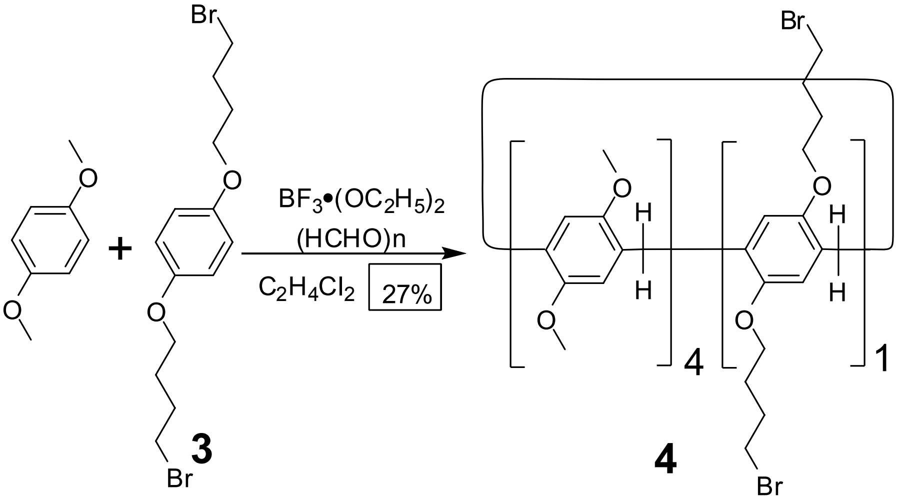
All reagents were commercially available and used as supplied without further purification. Solvents were either employed as purchased or dried according to procedures described in the literature. 1,4-Dimethoxybenzene and 3-butyn-1-ol were purchased from Aladdin-Reagent. Compounds **3**[S1] and **6**[S2] were synthesized according to the literature. NMR spectra were recorded with a Bruker Avance DMX 500 spectrophotometer or a Bruker Avance DMX 400 spectrophotometer with the deuterated solvent as the lock and the residual solvent or TMS as the internal reference. Low-resolution electrospray ionization (LRESI) mass spectra were obtained on a Bruker Esquire 3000 plus mass spectrometer (Bruker-Franzen Analytik GmbH, Bremen, Germany) equipped with an ESI interface and an ion trap analyzer. Elemental analysis data were obtained on a Vario Micro element analyzer. The melting points were collected on a SHPSIC WRS-2 automatic melting point apparatus.

*2. Synthesis of compound **1***



Scheme S1. Synthesis of compound **1**.

*2.1. Synthesis of compound **4***



To a solution of 1,4-bis(4-bromobutoxy)benzene (3.80 g, 20.0 mmol) and 1,4-dimethoxybenzene (5.50 g, 80.0 mmol) in 1,2-dichloroethane (200 mL), paraformaldehyde (3.00 g, 100 mmol) was added under nitrogen atmosphere. Then boron trifluoride diethyl etherate (12.6 mL, 100 mmol) was added to the solution and the mixture was stirred at room temperature for 4 h and concentrated by rotary evaporation. The resultant oil was dissolved in CH_2Cl_2 and washed twice with H_2O. The organic layer was dried over anhydrous Na_2SO_4 and evaporated to afford the crude product, which was isolated by flash column chromatography using petroleum ether/ethyl acetate (20:1, *v*/*v*) to give **4** (2.68 g, 27%) as a white solid. Mp 187.4–189.0 °C. The ^{1}H NMR spectrum of **4** is shown in Figure S1. ^{1}H NMR (400 MHz, chloroform-*d*, room temperature) δ (ppm): 6.74–6.79 (m, 8H), 6.71 (s, 2H), 3.82 (t, $J = 4.6$ Hz, 4H), 3.76 (s, 10H), 3.67 (s, 12H), 3.64 (s, 12H), 3.26 (t, $J = 4.6$ Hz, 4H), 1.82–1.94 (m, 4H), 1.72–1.81 (m, 4H). The ^{13}C NMR spectrum of **4** is shown in Figure S2. ^{13}C NMR (125 MHz, chloroform-*d*, room temperature) δ (ppm): 28.4, 29.0, 29.4, 29.5, 29.9, 33.3, 55.7, 55.8, 56.0, 67.4, 113.6, 113.9, 114.2, 114.9, 128.1, 128.2, 128.4, 128.6, 149.9 150.7, 150.8, and 150.9. LRESIMS is shown in Figure S3: *m*/*z* 1028.6 $[M + H_2O + NH_4]^+$. Anal. Calcd for $C_{51}H_{60}Br_2O_{10}$: C, 61.70; H, 6.09; found: C, 61.78; H, 6.17.

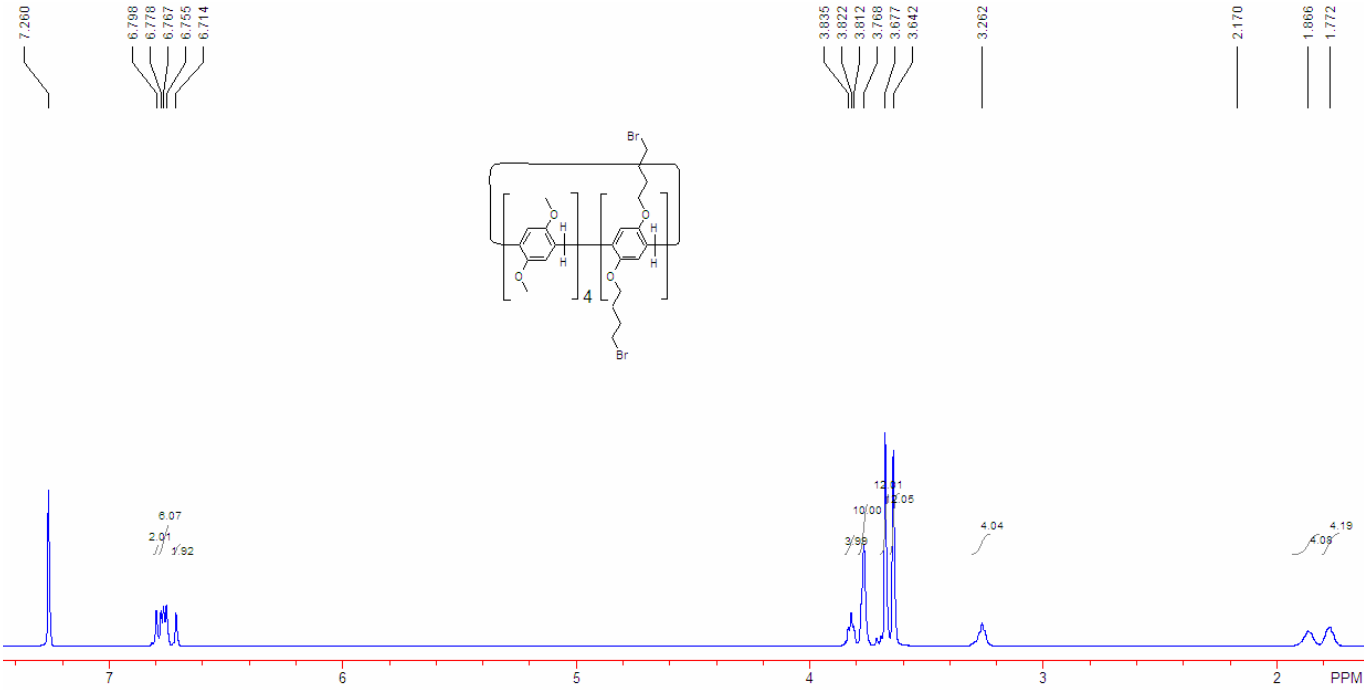


Figure S1. ^{1}H NMR spectrum (400 MHz, chloroform-*d*, room temperature) of **4**.

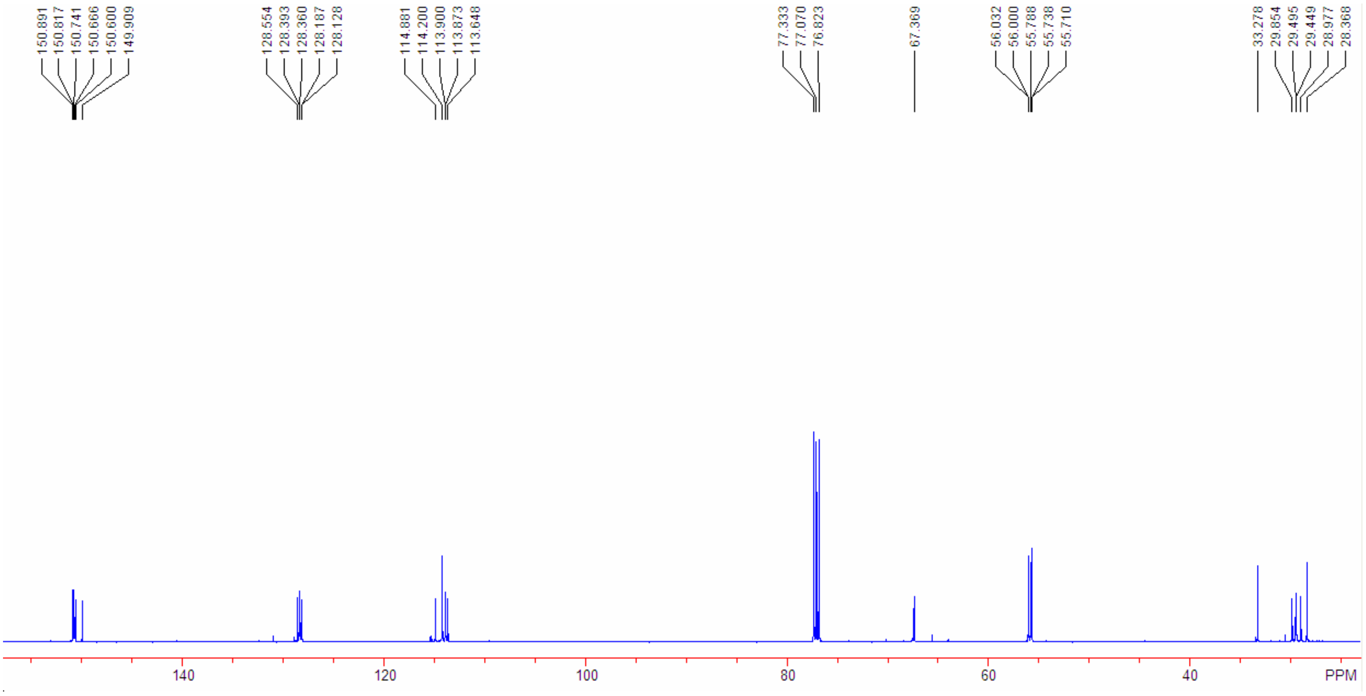


Figure S2. ^{13}C NMR spectrum (125 MHz, chloroform-*d*, room temperature) of **4**.

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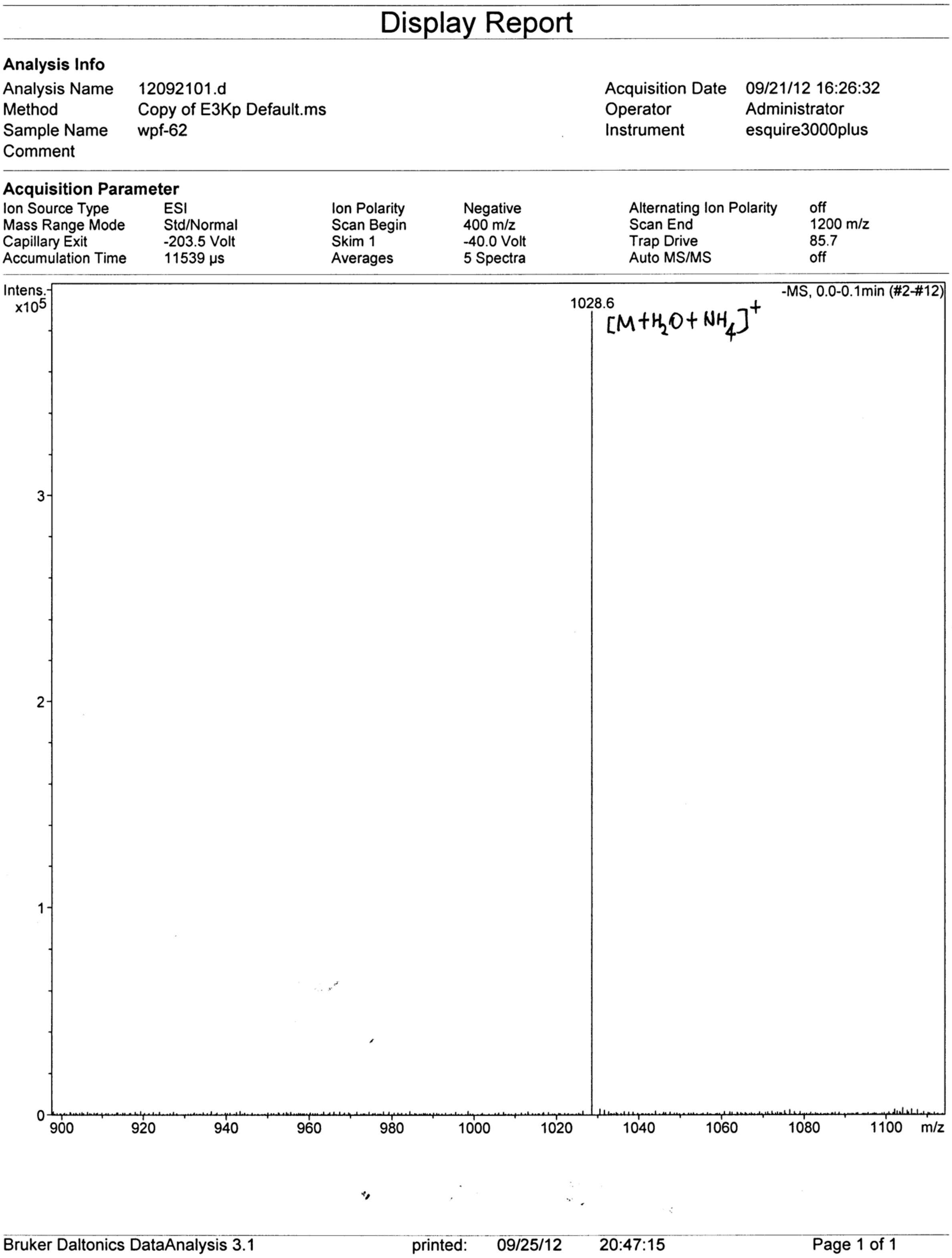

Display Report

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Comment			

Acquisition Parameter

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Mass Range Mode	Std/Normal	Scan Begin	400 m/z	Scan End	1200 m/z
Capillary Exit	-203.5 Volt	Skim 1	-40.0 Volt	Trap Drive	85.7
Accumulation Time	11539 µs	Averages	5 Spectra	Auto MS/MS	off

$[M+H_2O+NH_4]^+$

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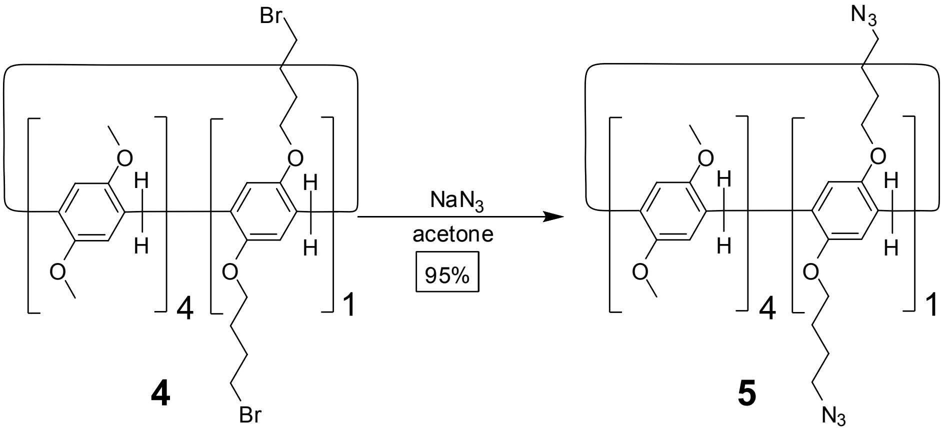
Figure S3. Electrospray ionization mass spectrum of **4**.

*2.2. Synthesis of compound **5***



Into a 250 mL round-bottomed flask were added **4** (1.99 g, 2.00 mmol) and sodium azide (0.520 g, 8.00 mmol) in 100 mL of acetone and 5.00 mL of H_2O. After heating at reflux for 24 h, water was added to quench the reaction. After removal of acetone, the solution was extracted with CH_2Cl_2 three times. The organic phases were combined, washed with water and brine, and then dried over anhydrous Na_2SO_4 overnight. After filtration and solvent evaporation, compound **4** was obtained as a white solid (1.75 g, 95%). Mp 152.4–154.0 °C. The ^{1}H NMR spectrum of **5** is shown in Figure S4. ^{1}H NMR (400 MHz, chloroform-*d*, room temperature) δ (ppm): 6.78–6.86 (m, 8H), 6.74 (s, 2H), 3.83 (t, J = 5.8 Hz, 4H), 3.79 (s, 10H), 3.74–3.64 (m, 24H), 3.02 (t, J = 5.8 Hz, 4H), 1.62–1.75 (m, 4H), 1.45–1.58 (m, 4H). The ^{13}C NMR spectrum of **5** is shown in Figure S5. ^{13}C NMR (125 MHz, chloroform-*d*, room temperature) δ (ppm): 25.5, 26.8, 29.5, 29.6, 29.8, 50.9, 55.7, 55.8, 55.9, 67.7, 113.8, 114.1, 114.2, 115.1, 128.1, 128.3, 128.4, 128.5, 149.9, 150.6 150.8, and 150.9. LRESIMS is shown in Figure S6: *m*/*z* 934.6 $[M + H_3O]^+$, 889.6 $[M - N_2]^+$. Anal. Calcd for $C_{51}H_{60}N_6O_{10}$: C, 66.79; H, 6.59; N, 9.16; found: C, 66.72; H, 6.60; N, 9.26.

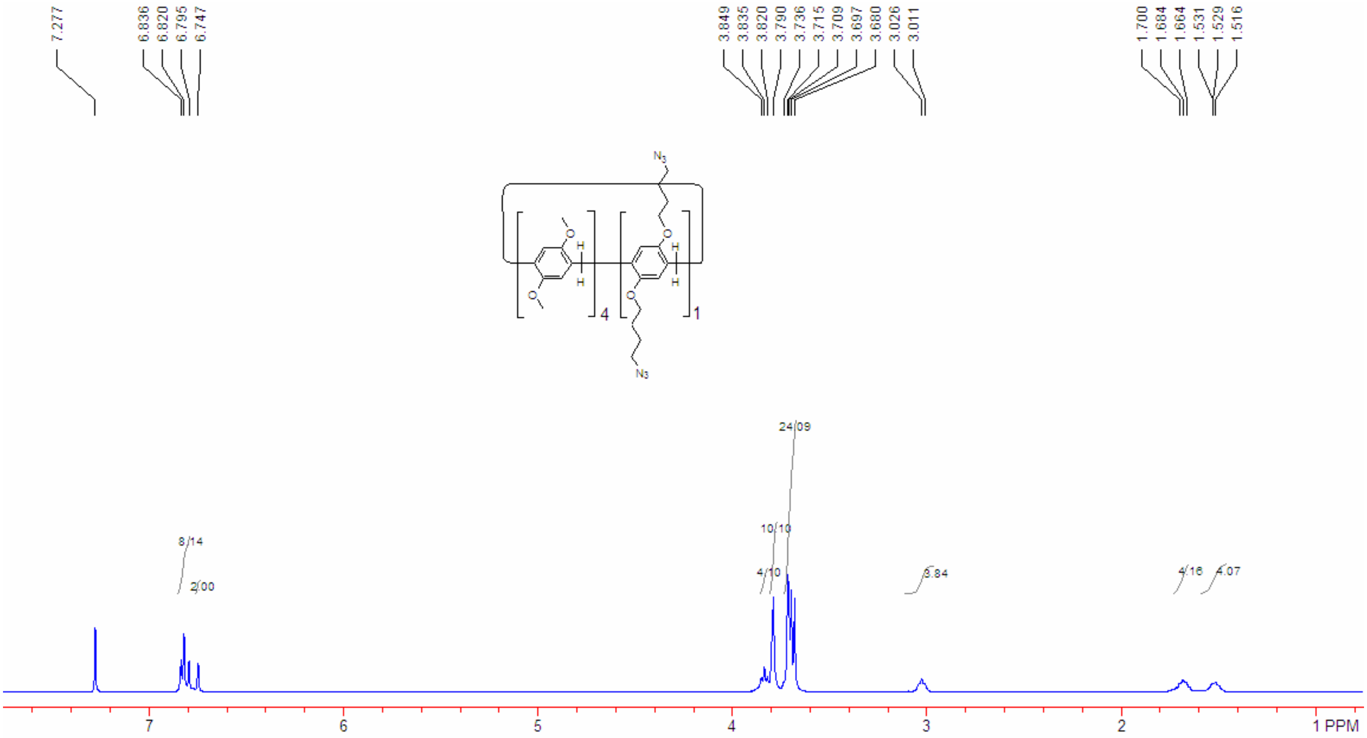


Figure S4. ^{1}H NMR spectrum (400 MHz, chloroform-*d*, room temperature) of **5**.

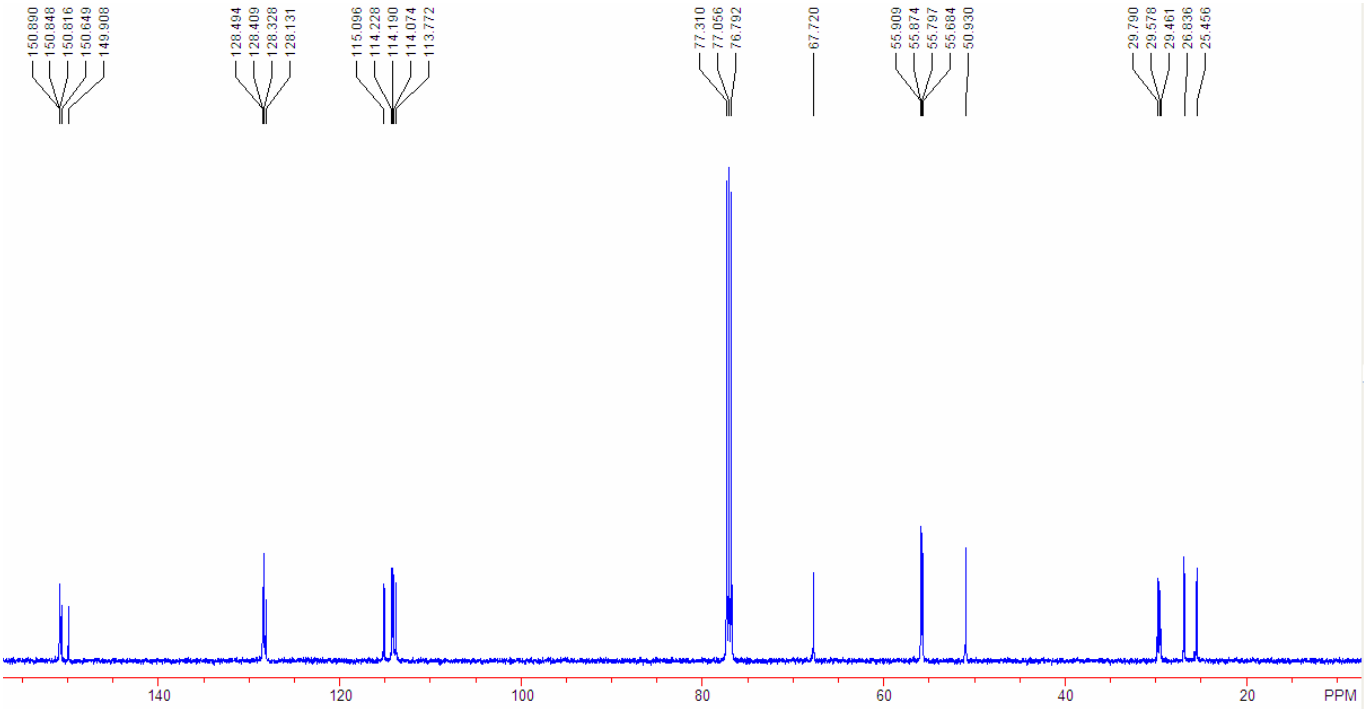
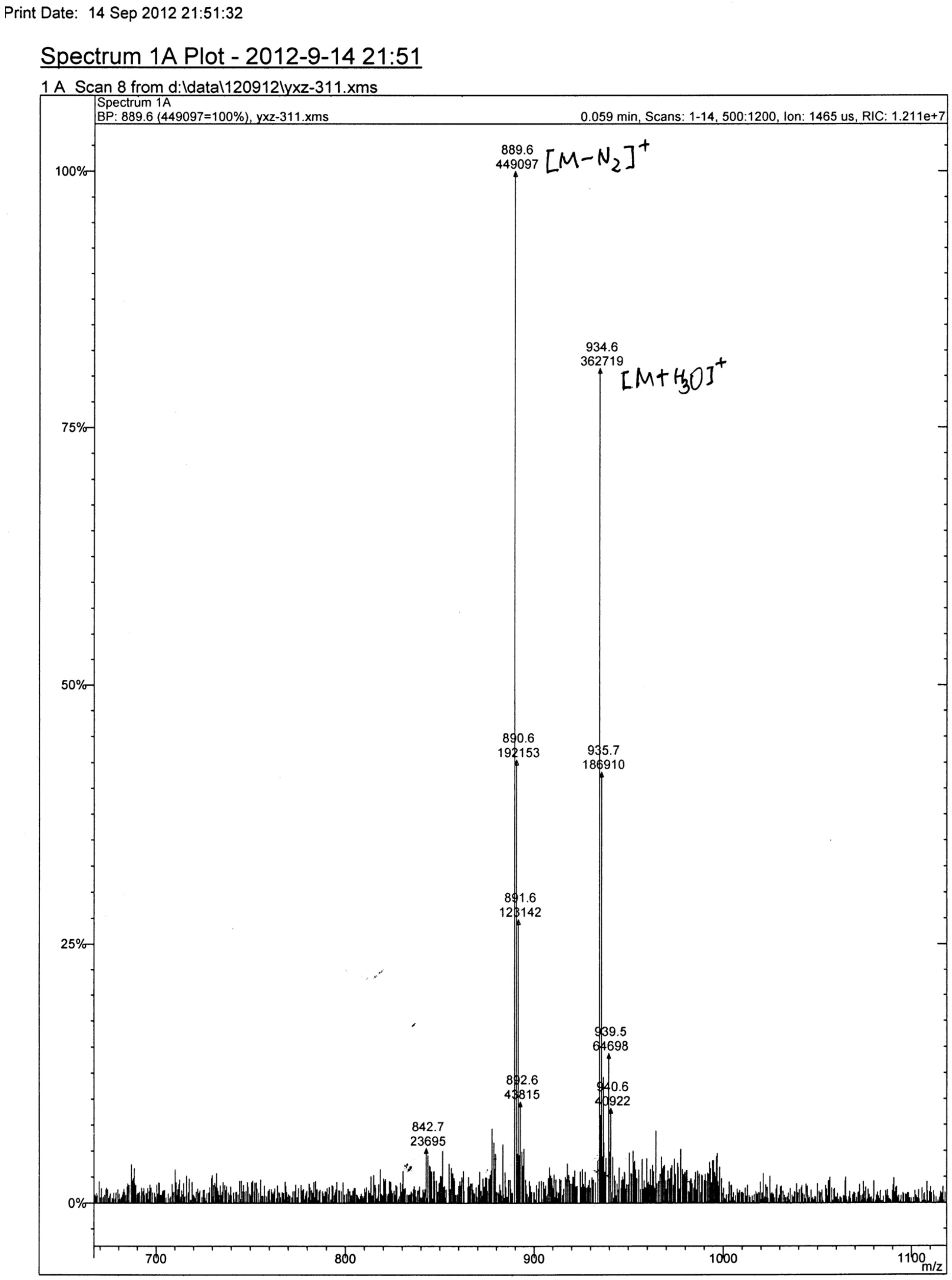


Figure S5. ^{13}C NMR spectrum (125 MHz, chloroform-*d*, room temperature) of **5**.



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Spectrum 1A
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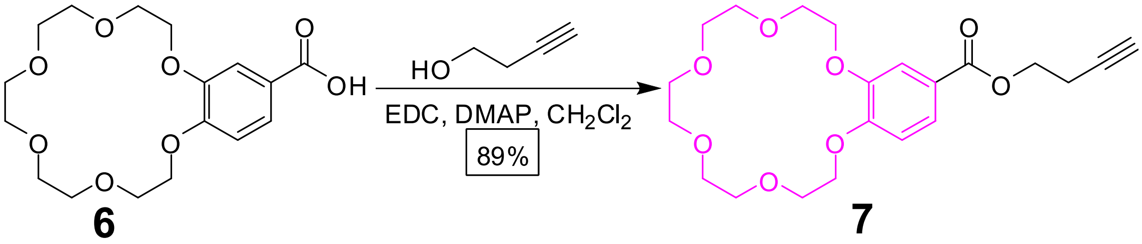
Figure S6. Electrospray ionization mass spectrum of **5**.

2.3. Synthesis of compound 7



A solution of **6** (3.55 g, 9.96 mmol), 3-butyn-1-ol (1.40 g, 19.9 mmol) and 4-dimethylaminopyridine (DMAP) (0.610 g, 4.98 mmol) in dichloromethane (100 mL) was stirred for 10 minutes at 0 °C. To this solution was added EDC (1.91 g, 9.96 mmol). The reaction mixture was stirred for 24 h at room temperature, filtered, and concentrated to give a pale yellow oil, which was purified by flash column chromatography (ethyl acetate/petroleum ether, 3:1 *v*/*v*) to afford **7** as a white solid (3.62 g, 89%). Mp 72.5–73.5 °C. The ^{1}H NMR spectrum of **7** is shown in Figure S7. ^{1}H NMR (400 MHz, chloroform-*d*, room temperature) δ (ppm): 7.68 (d, J = 8.8 Hz, 1H), 7.56 (s, 1H), 6.88 (d, J = 8.8 Hz, 1H), 4.40 (t, J = 3.6 Hz, 2H), 4.17–4.26 (m, 4H), 3.91–4.00 (m, 4H), 3.76–3.83 (m, 4H), 3.6–3.75 (m, 8H), 2.63–2.71 (m, 2H), 2.03 (d, J = 2.4 Hz, 1H). The ^{13}C NMR spectrum of **7** is shown in Figure S8. ^{13}C NMR (125 MHz, chloroform-*d*, room temperature) δ (ppm): 19.1, 62.4, 68.9, 69.1, 69.4, 69.5, 70.0, 70.7, 70.8, 70.9, 71.0, 80.1, 112.2, 114.6, 122.9, 124.0, 148.4, 153.2, and 166.1. LRESIMS is shown in Figure S9: *m*/*z* 447.4 $[M + K]^+$, 431.5 $[M + Na]^+$, 426.6 $[M + H_3O]^+$. HRESIMS: *m*/*z* calcd for $[M]^+$ $C_{21}H_{28}O_8$, 408.1784; found 408.1786, error 0.5 ppm.

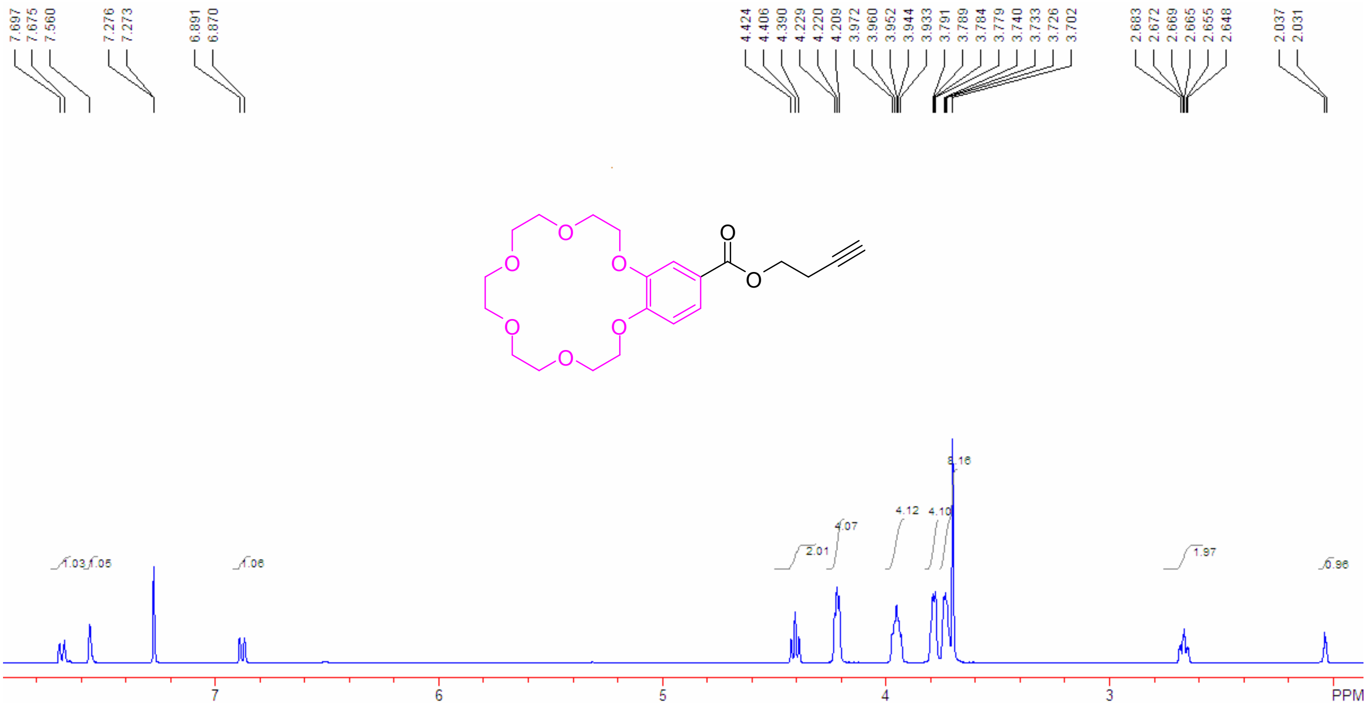


Figure S7. ^{1}H NMR spectrum (400 MHz, chloroform-*d*, room temperature) of **7**.

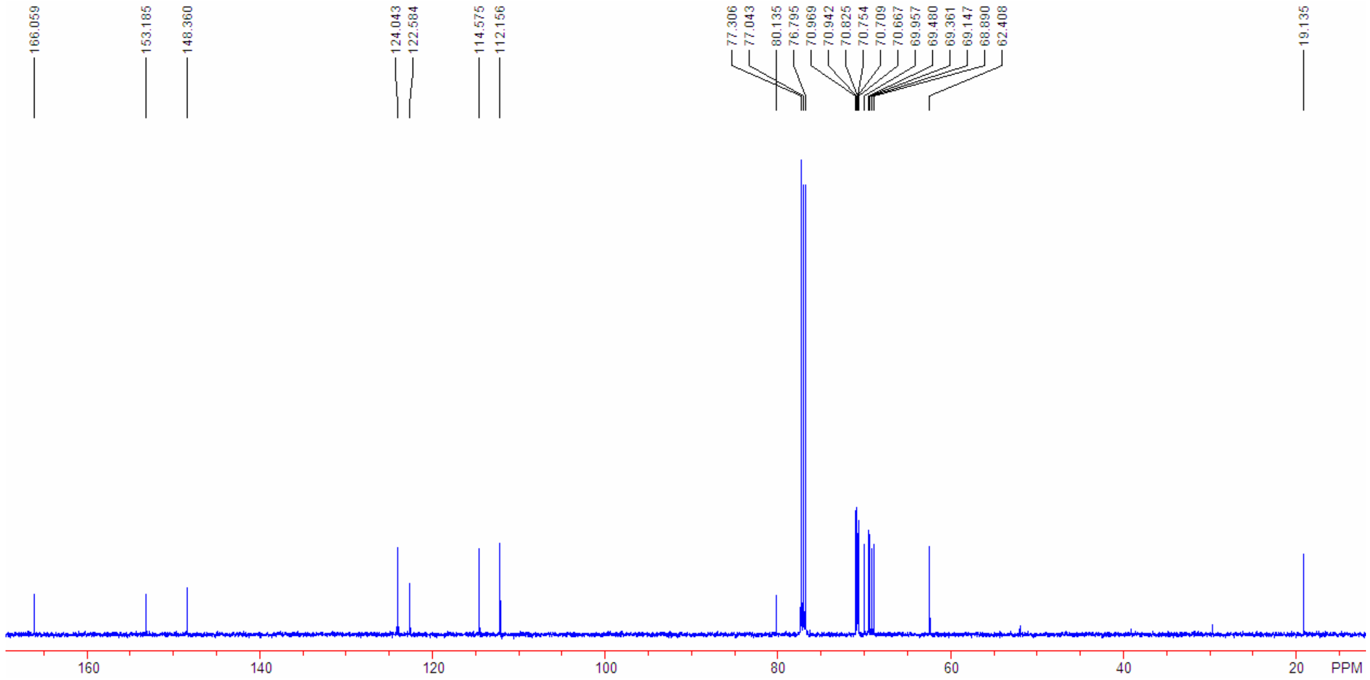


Figure S8. ^{13}C NMR spectrum (125 MHz, chloroform-*d*, room temperature) of **7**.

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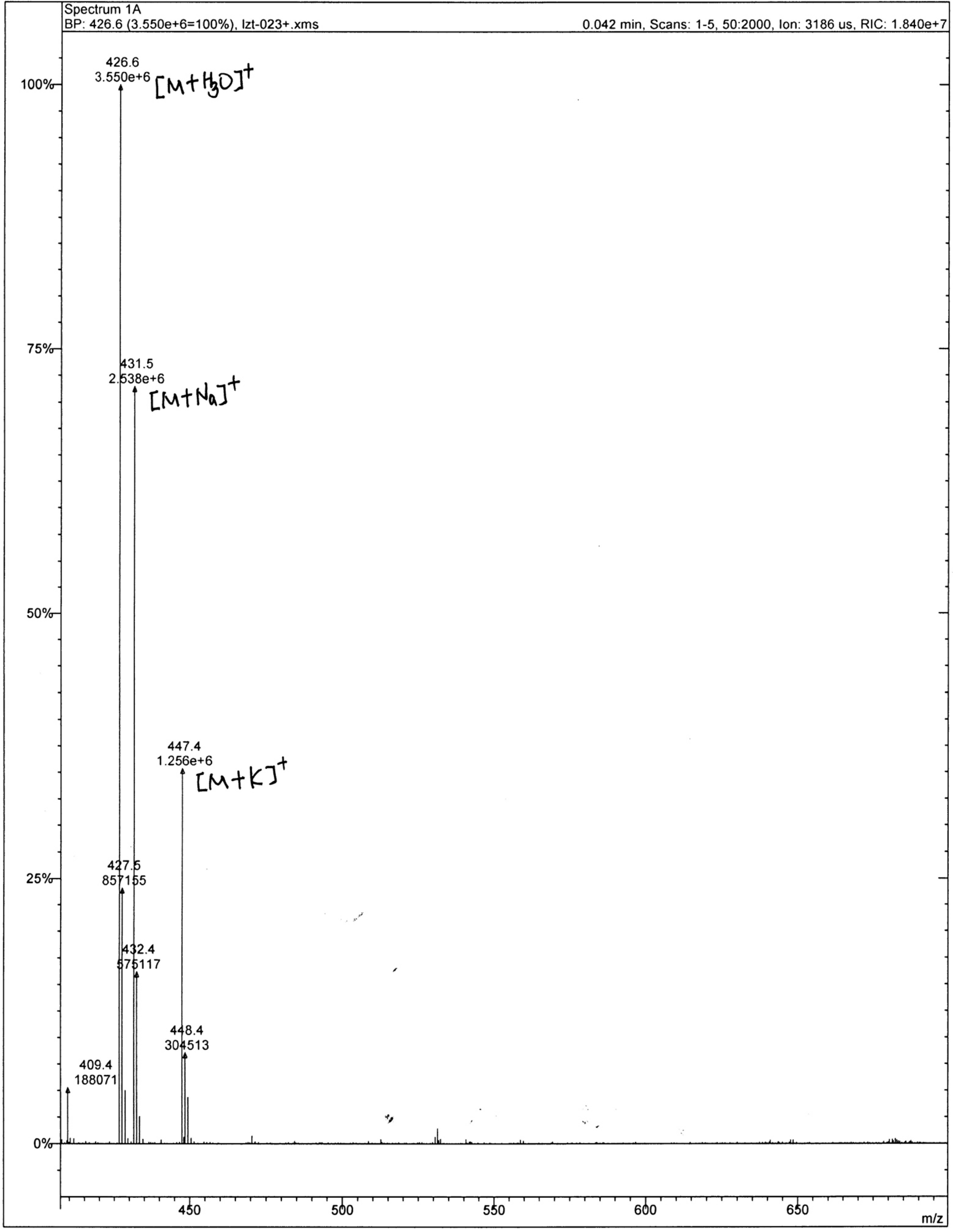
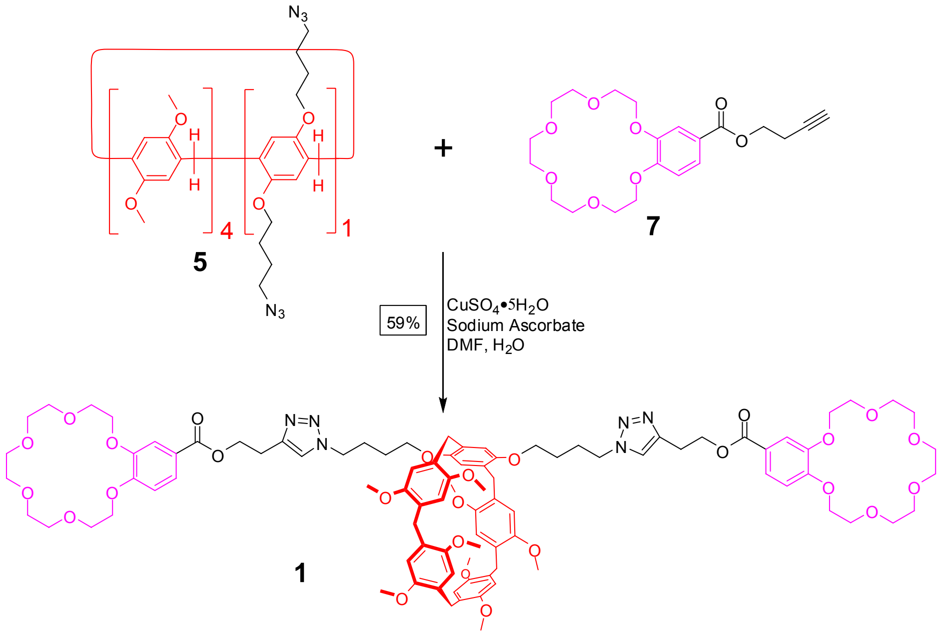


Figure S9. Electrospray ionization mass spectrum of **7**.

*2.4. Synthesis of compound **1***



A mixture of **5** (1.45 g, 1.58 mmol) and **7** (1.30 g, 3.18 mmol) in a mixture of DMF and H_2O (4:1, 100 mL) in the presence of $CuSO_4$•$5H_2O$ (120 mg, 0.480 mmol) with sodium ascorbate (313 mg, 1.58 mmol) was stirred at 50 ºC for 24 h. The reaction mixture was poured into saturated brine (100 mL) and the resultant solution was extracted with chloroform (100 mL × 3). The combined organic phase was concentrated and purified by flash column chromatography (MeOH/CH_2Cl_2, 1:50 *v*/*v*) to afford compound **1** as a pale yellow solid (1.62 g, 59%). Mp 56.9–58.0 °C. The ^{1}H NMR spectrum of **1** is shown in Figure S10. ^{1}H NMR (400 MHz, chloroform-*d*, room temperature) δ (ppm): 7.57 (d, J = 8.4 Hz, 2H) 7.47 (s, 2H), 7.10 (s, 2H), 6.77 (d, J = 8.4 Hz, 2H), 6.74 (s, 2H), 6.72 (s, 2H), 6.66 (s, 4H), 6.54 (s, 2H), 4.47 (t, J = 6.6 Hz, 4H), 4.08–4.19 (m, 8H), 3.96 (t, J = 6.6 Hz, 4H), 3.82–3.91 (m, 8H), 3.77 (t, J = 6.6 Hz, 4H), 3.57–3.75 (m, 46H), 3.54 (s, 6H), 3.48 (s, 6H), 3.13 (t, J = 6.6 Hz, 4H), 1.62–1.80 (m, 4H), 1.44–1.60 (m, 4H). The ^{13}C NMR spectrum of **1** is shown in Figure S11. ^{13}C NMR (125 MHz, chloroform-*d*, room temperature) δ (ppm): 25.7, 26.6, 27.1, 29.5, 29.7, 29.8, 31.3, 36.1, 49.8, 55.7, 55.8, 55.9, 63.6, 67.3, 68.6, 68.7, 69.2, 69.3, 70.5, 70.6, 70.6, 70.7, 111.7, 113.9, 114.2, 114.3, 115.1, 121.3, 122.6, 123.7, 128.0, 128.1, 128.3, 128.5, 144.2, 148.2, 149.9, 150.7, 150.8, 150.9, 152.9, 162.6, and 166.2. LRESIMS is shown in Figure S12: *m*/*z* 1772.7 $[M + K]^+$, 1756.8 $[M + Na]^+$, 1734.8 $[M + H]^+$. Anal. Calcd for $C_{93}H_{116}N_6O_{26}$: C, 64.42; H, 6.74; N, 4.85; found: C, 64.51; H, 6.77; N, 4.90.

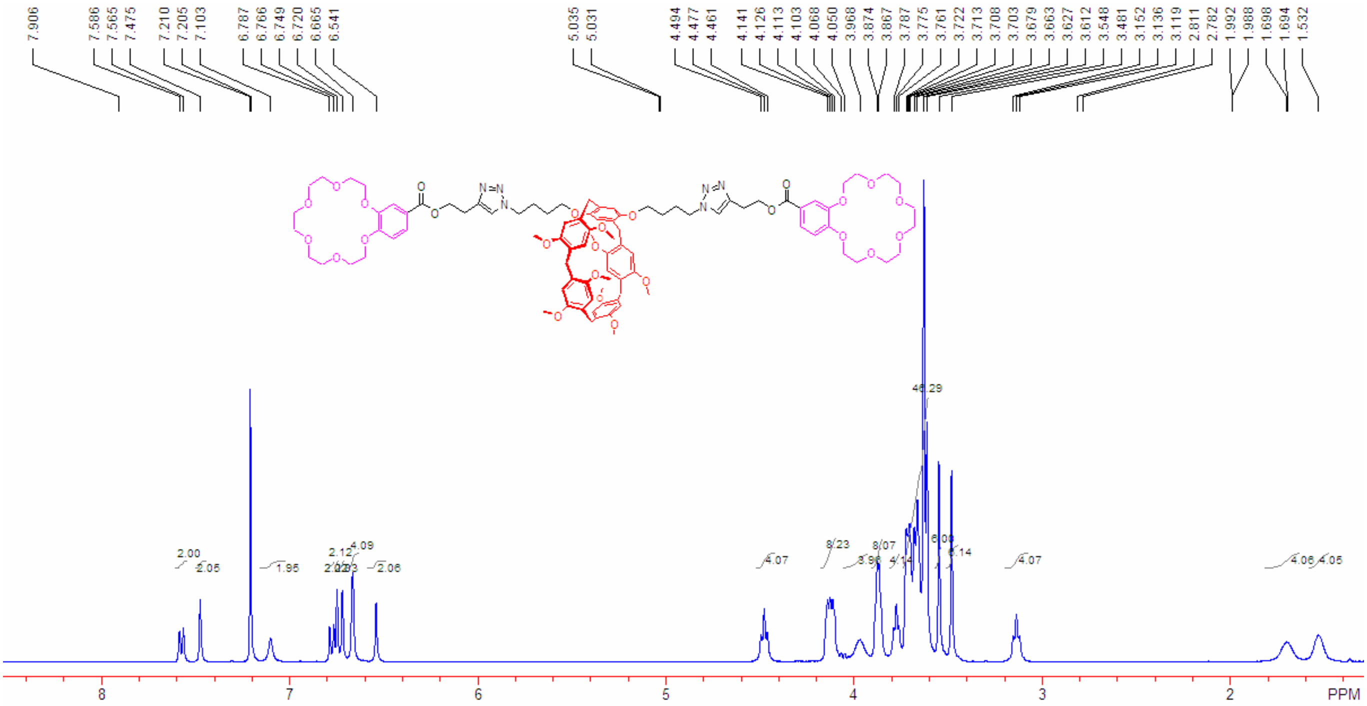


Figure S10. ^{1}H NMR spectrum (400 MHz, chloroform-*d*, room temperature) of **1**.

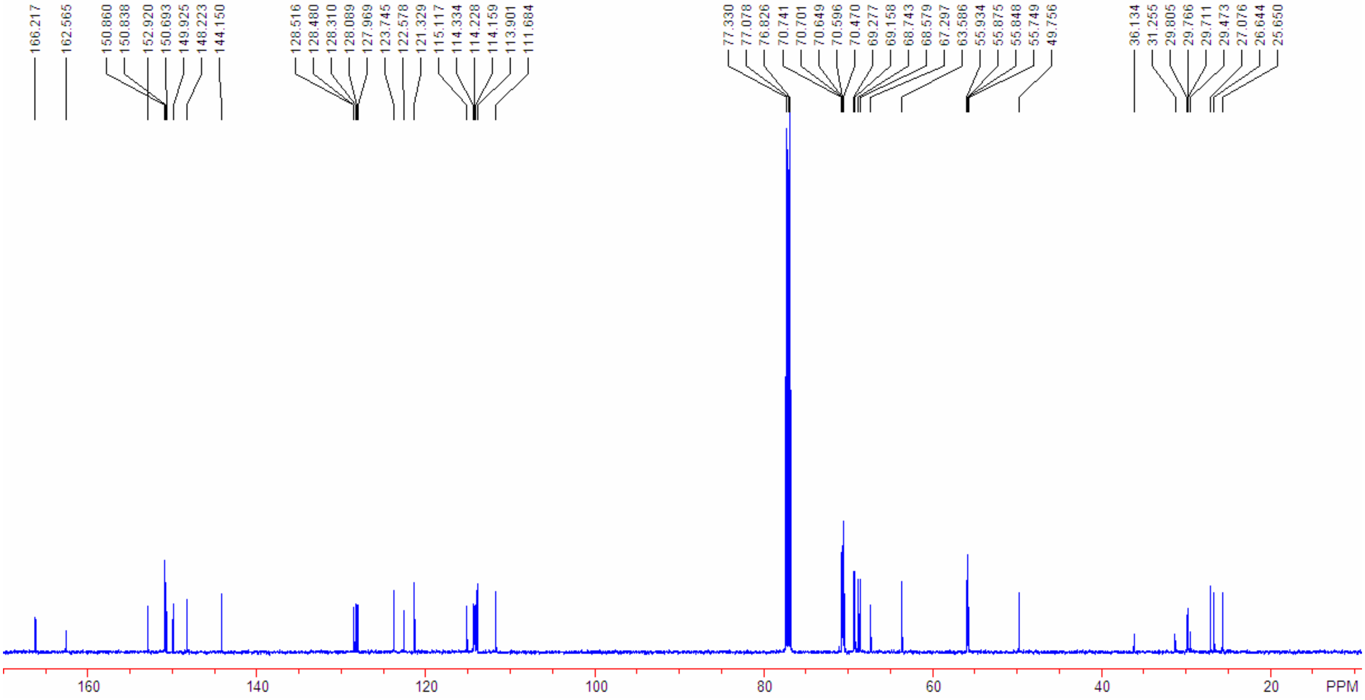


Figure S11. ^{13}C NMR spectrum (125 MHz, chloroform-*d*, room temperature) of **1**.

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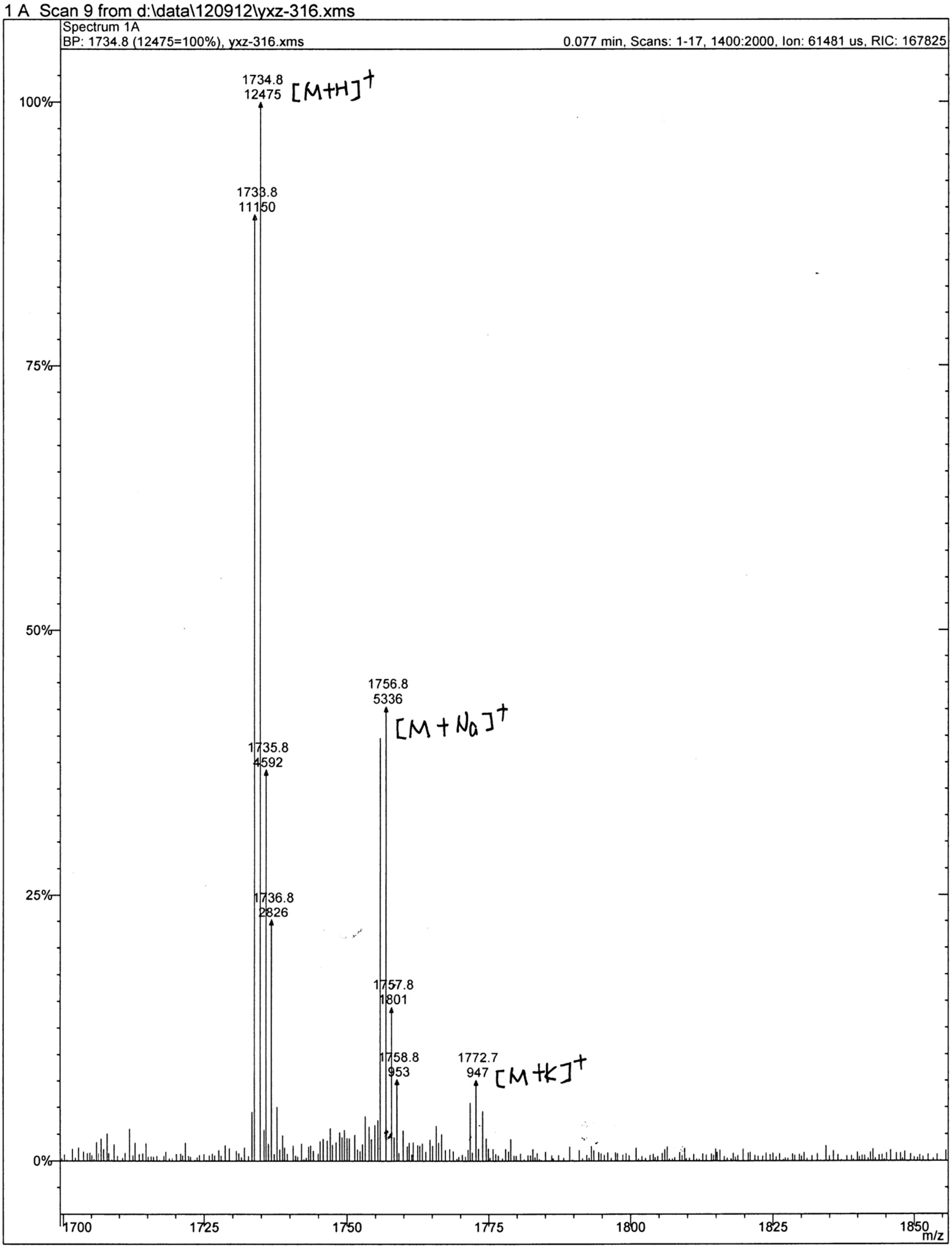

Figure S12. Electrospray ionization mass spectrum of **1**.

*3. COSY NMR spectrum of **1***

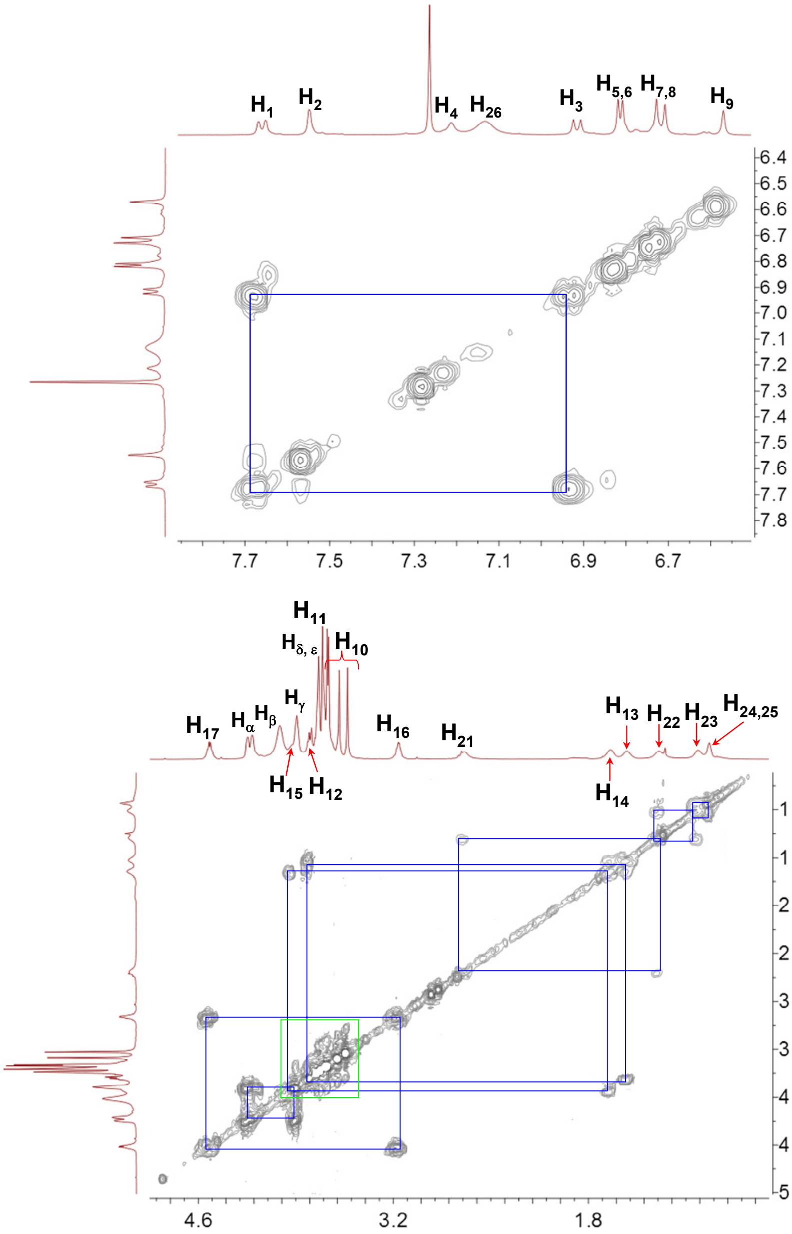

Figure S13. COSY NMR (500 MHz, chloroform-*d*, 293 K) spectrum of **1**.

4. Partial ^{1}H NMR of the dynamic pH-responsive [1]catenane

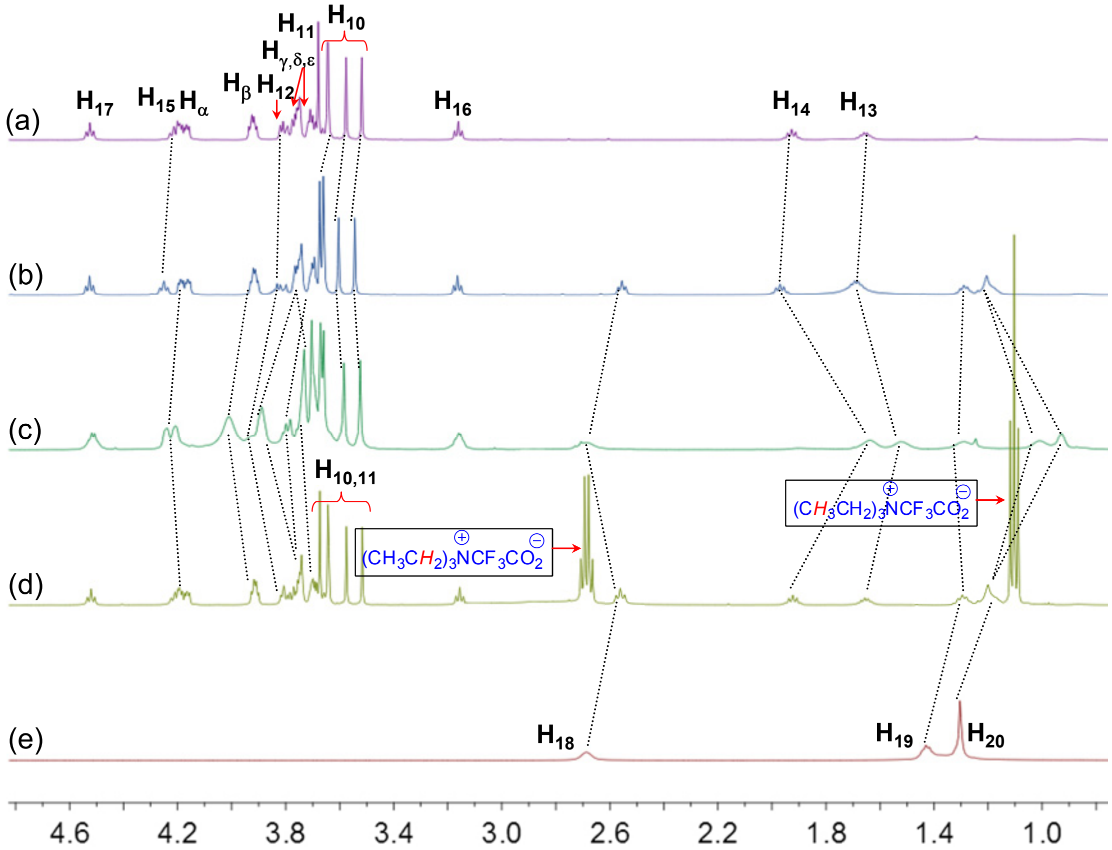

Figure S14. Partial ^{1}H NMR spectra (chloroform-*d*, 293 K, 400 MHz): (a) 10.0 mM **1**; (b) 10.0 mM **1** and **2**; (c) after addition of 2.00 equiv of TFA to b; (d) after addition of 2.00 equiv of TEA to c; (e) 10.0 mM **2**.

5. Partial ^{1}H NMR showing the formation of the dynamic [1]catenane

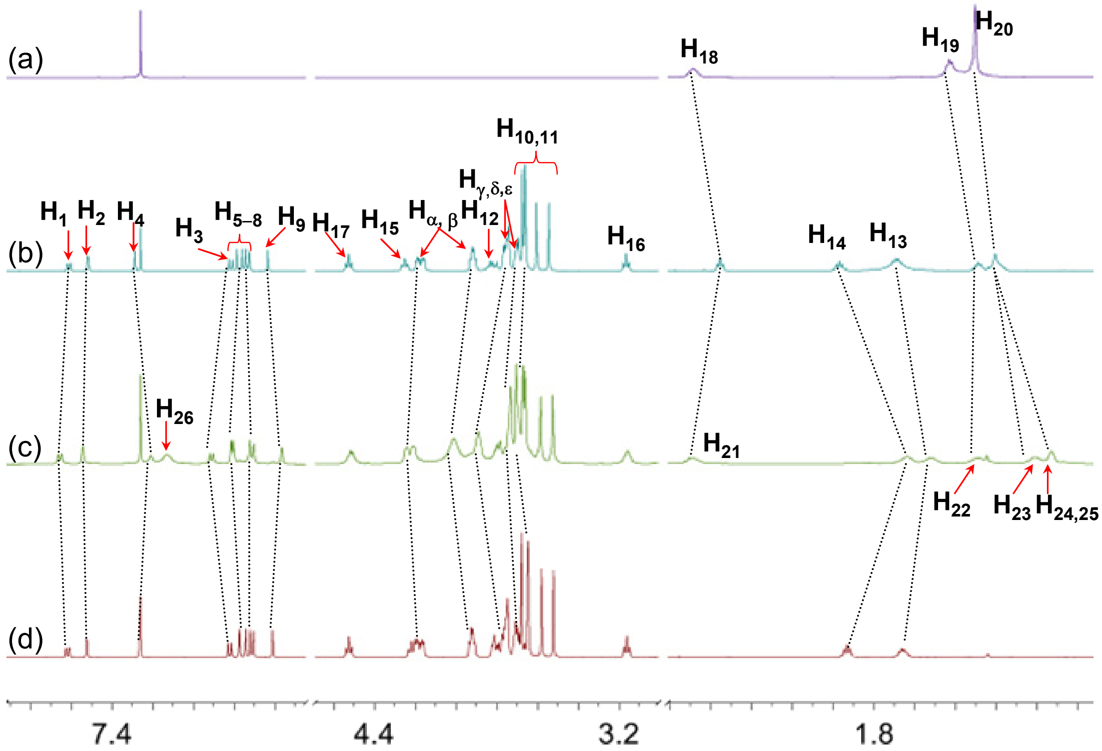

Figure S15 Partial ^{1}H NMR spectra (chloroform-*d*, 293 K, 400 MHz): (a) 10.0 mM **2**; (b) 10.0 mM **1** and **2**; (c) after addition of 2.00 equiv of TFA to b; (d) 10.0 mM **1**.

6. ESI-MS of the dynamic [1]catenane

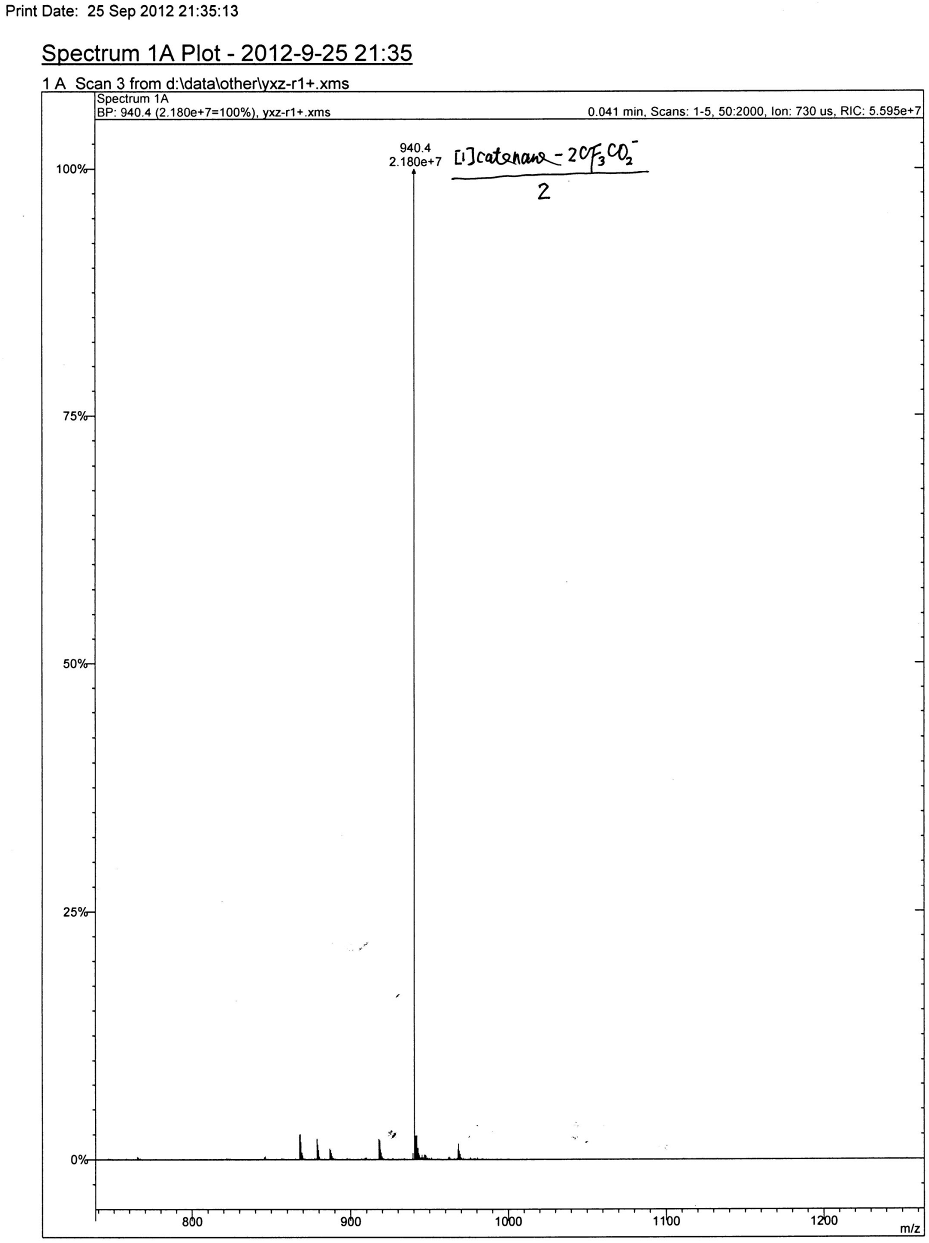

Figure S16 ESI-MS of the dynamic [1]catenane formed by orthogonal host-guest molecular recognitions.

References:

S1. D.-J. Feng, X.-Q. Li, X.-Z. Wang, X.-K. Jiang and Z.-T. Li, *Tetrahedron*, 2004, **60**, 6137.

S2. P. Wei, X. Yan, J. Li, Y. Ma and F. Huang, *Chem. Commun.*, 2013, **49**, 1070–1072.