Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry

One-pot synthesis of pillar[*n*]arenes catalyzed by minimum amount of TfOH and solution-phase mechanistic study **

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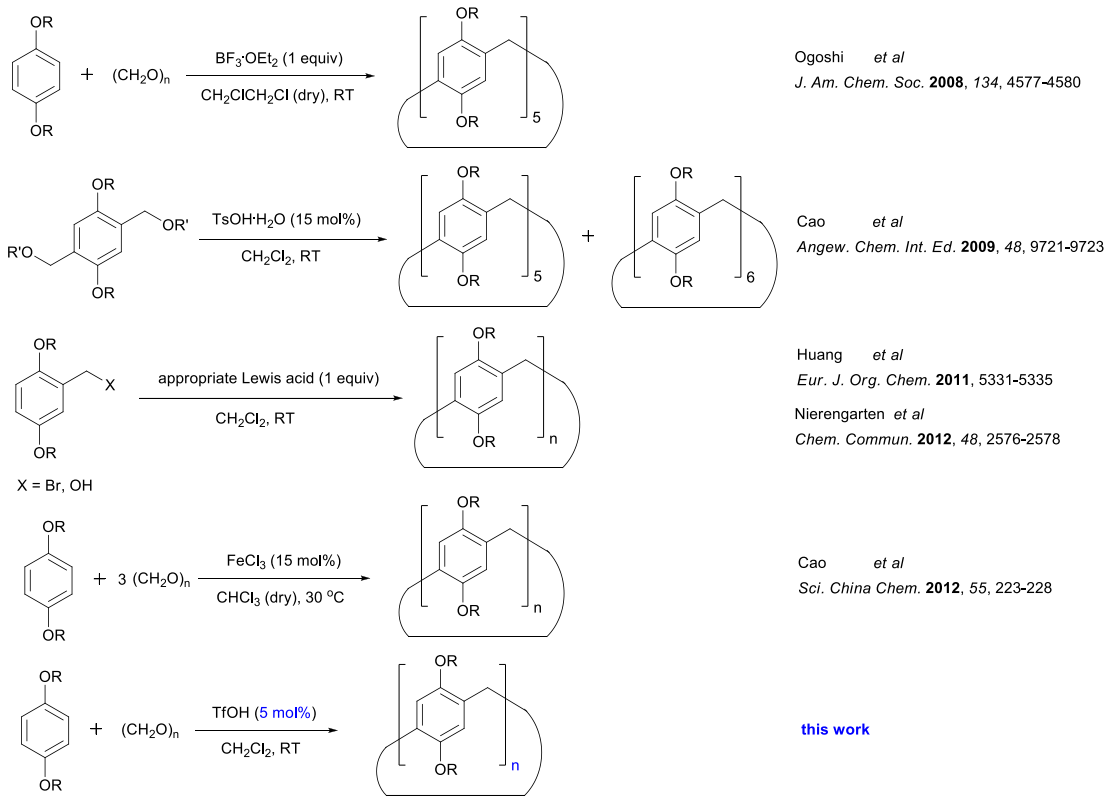
Materials and Methods.

Starting materials and reagents were purchased from Aldrich, Aladdin and Gibco, and used as received. All reagents were purchased from commercial sources and used without further purification, unless otherwise noted. The products were purified by column chromatography over silica gel. ^{1}H-NMR and ^{13}C-NMR spectra were recorded at 25 ºC on a Varian 300 MHz and 125 MHz respectively, and TMS was used as internal standard. Mass spectra were recorded on Bruker Daltonics Autoflex Speed Series: High-Performance MALDI-TOF Systems. The electron spin resonance spectra were obtained on a JES-FA 200 EPR spectrometer. The details of the instrumental parameters are as follows: scanning frequency: 9.45 GHz, central field: 3360 G, scanning width: 8000G, scanning power: 0.998mW, and scanning temperature: 25 ºC. The stable radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) and manganese (Mn) marker were used as standards for calculation of the spin concentration.

General Procedure for the Synthesis of Pillar[*n*]arenes.



Scheme S1. Reported procedures and our procedures for the synthesis of pillararenes.

Our Procedure.

Paraformaldehyde (0.09 g, 3 mmol) was added to a solution of 1,4-dialkoxybenzene **1** (2 mmol) in dichloromethane (60 mL). Then, TfOH (9.2 μL, 5 mol%) was added to the solution and the mixture was stirred at room temperature (approximately 25 ºC). The color of the reaction mixture changed gradually from colorless to blue-green. When the starting material was consumed completely (as detected by TLC), the mixture was poured into aqueous NH_4Cl solution (60 mL). The organic layer was collected and aqueous layer was extracted with CH_2Cl_2 thrice. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and then the solvent was removed by rotary evaporation. The crude product was purified by flash column chromatography with an appropriate eluting solvent to get pure pillar[*n*]arene derivatives **2**.

Characterization data.

2a.[S1] White solid, **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.77 (s, 10H), 3.77 (s, 10H), 3.65 (s, 30H).

2b.[S2] White solid, **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.72 (s, 10H), 3.82 (q, *J* = 6.9 Hz, 20H), 3.76 (s, 10H), 1.26 (t, *J* = 6.9 Hz, 30H).

2c.[S3] White solid, **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.84 (s, 10H), 3.85 (t, *J* = 6.3 Hz, 20H), 3.76 (s, 10H), 1.85-1.76 (m, 20H), 1.54 (m, 20 H), 1.29- 1.32 (m, 40 H), 0.90 (t, *J* = 6.9 Hz, 30H).

2d. White solid, m.p. 106-107 ºC; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.87 (s, 10H), 3.85 (s, 20H), 3.76 (s, 10H), 1.82 (s, 20H), 1.52 (m, 20 H), 1.39-1.12 (m, 120 H), 0.85 (t, *J* = 6.9 Hz, 30H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 149.5, 127.9, 114.2, 67.9, 31.8, 29.9, 29.6(4), 29.6(1), 29.5, 29.3, 29.2, 26.3, 22.6, 14.1. MS (MALDI–TOF) calcd for $C_{135}H_{230}O_{10}$, *m/z* = 2013.277 $[M]^+$, found *m/z* = 2013.471.

2e.[S4] White solid, **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.65 (s, 10H), 4.25-4.17 (m, 10H), 3.71 (s, 10H), 1.08 (d, *J* = 6 Hz, 60H).

2f.[S5] White solid, **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.91 (s, 10H), 4.23 (t, *J* = 5.7 Hz, 20H), 3.84 (s, 10H), 3.63 (t, *J* = 5.7 Hz, 20H).

2g. White solid, m.p. 84-85 ºC; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.81 (s, 10H), 3.93 (t, *J* = 5.7 Hz, 20H), 3.75 (s, 10H), 3.44 (t, *J* = 5.7 Hz, 20H), 2.09-2.01 (m, 20H), 1.97-1.90 (m, 20H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 149.8, 128.3, 114.9, 67.6, 33.8, 29.8, 29.5, 28.5. MS (MALDI–TOF) calcd for $C_{75}H_{100}O_{10}Br_{10}$, *m/z* = 1960.628 $[M]^+$, found *m/z* = 1960.346.

2g′. White solid, m.p. 80-81 ºC; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.67 (s, 12H), 3.83-3.79 (m, 36H), 3.39 (t, *J* = 6.3 Hz, 24H), 1.98-1.91 (m, 24H), 1.88-1.81 (m, 24H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 150.0, 128.5, 115.1, 67.8, 34.0, 30.0, 29.7, 28.7. MS (MALDI–TOF) calcd for $C_{90}H_{120}O_{12}Br_{12,}$ *m/z* = 2352.754 $[M]^+$, found *m/z* = 2352.476.

Catalytic synthesis of copillar[5]arenes 2i – 2n by TfOH.

2i.[S6] White solid, m.p. 120-121 ºC; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.80−6.76 (m, 9H), 6.70 (s, 1H), 4.04 (t, *J* = 6 Hz, 2H), 3.80−3.76 (m, 10H), 3.70−3.64 (m, 27H), 3.44 (t, *J* = 6 Hz, 2H).

2j.[S7] White solid, m.p. 178-179 ºC; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.81−6.75 (m, 9H), 6.69 (s, 1H), 3.77 (s, 10H), 3.67−3.61 (m, 29H), 3.01 (s, 2H), 1.62 (s, 4H).

2k.[S8] White solid, m.p. 157-158 ºC; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.80−6.77 (m, 9H), 6.73 (s, 1H), 4.06 (t, *J* = 6 Hz, 2H), 3.77 (s, 10H), 3.69 (s, 18H), 3.65 (s, 6H), 3.46 (t, *J* = 6 Hz, 2H).

2l. White solid, m.p. 195-196 ºC; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.81−6.75 (m, 9H), 6.71 (s, 1H), 3.77 (s, 10H), 3.75 (s, 4H), 3.72−3.63 (m, 24H), 3.03 (s, 4H), 1.62 (s, 8H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 150.8(6), 150.8(1), 150.7, 150.6, 149.9, 128.5, 128.3, 128.2, 128.1, 114.9, 114.2, 113.9, 113.7, 67.4, 55.9, 55.8, 55.7, 33.3, 29.8, 29.5, 29.2, 28.3. MS (MALDI–TOF) calcd for $C_{51}H_{60}O_{10}Br_2$, *m/z* = 992.446 $[M]^+$, found *m/z* = 992.246.

2m. Paraformaldehyde (0.15 g, 5 mmol) was added to a solution of 1,4-dimethoxybenzene **1a** (0.138 g, 1 mmol) and 1,4-dihexyloxybenzene **1c** (1.112g, 4 mmol) in dichloromethane (100 mL). Then, TfOH (23 uL, 5 mol%) was added to the solution and the mixture was stirred at room temperature (approximately 25 °C) for 24h. The mixture was poured into aqueous NH_4Cl solution (100 mL), the organic layer was collected and aqueous layer was extracted with CH_2Cl_2 three times. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and then the solvent was removed by rotary evaporation. The crude product was purified by flash column chromatography with an appropriate eluting solvent (petroleum ether / ethyl acetate 100:1) to get the desired copillar[5]arene **2m** as a white solid. Y = 15%, m.p. 114-115 ºC; ^{1}H NMR (300 MHz, 298 K, $CDCl_3$) δ = 6.85-6.81 (m, 10H), 3.87-3.83 (m, ,16H), 3.77 (s, 10H), 3.71 (s, 6H), 1.83-1.76 (m, 16H), 1.52 (s, 16H), 1.29 (s, 32H), 0.92-0.87 (m, 24H). ^{13}C NMR (125 MHz, 298 K, $CDCl_3$) δ = 150.6, 150.0, 149.9, 128.4, 128.3, 128.2, 128.1, 128.0, 114.9, 114.8, 114.0, 68.5(5), 68.5(2), 68.4(8),

68.4(4), 55.7, 31.8, 31.7, 29.9, 29.5(8), 29.5(2), 29.3, 26.1, 22.6, 22.5, 14.0(8), 14.0(5). MS (MALDI–TOF) calcd for $C_{85}H_{130}O_{10}$, *m/z* = 1311.939 $[M]^+$, found *m/z* = 1311.946.

2n. Paraformaldehyde (0.15 g, 5 mmol) was added to a solution of 1,4-dimethoxybenzene **1a** (0.138 g, 1 mmol) and 1,4-bis(4-bromobutoxy)benzene **1g** (1.512g, 4 mmol) in dichloromethane (100 mL). Then, TfOH (23 μL, 5 mol%) was added to the solution and the mixture was stirred at room temperature (approximately 25 °C) for 24h. The mixture was poured into aqueous NH_4Cl solution (100 mL), the organic layer was collected and aqueous layer was extracted with CH_2Cl_2 three times. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and then the solvent was removed by rotary evaporation. The crude product was purified by flash column chromatography with an appropriate eluting solvent (petroleum ether / dichloromethane 1:2) to get the desired copillar[5]arene **2n** as a white solid. Y = 8%, m.p. 115-116 ºC; ^{1}H NMR (300 MHz, 298 K, $CDCl_3$) δ = 6.84-6.78 (m, 10H), 3.91-3.89 (m, ,16H), 3.76(d, 10H), 3.43-3.34 (m, 16H), 2.07-1.87 (m, 32H). ^{13}C NMR (125 MHz, 298 K, $CDCl_3$) δ = 150.6, 149.9, 149.8, 128.4, 128.3, 128.2, 128.1, 115.2, 115.1, 114.9, 114.0, 67.6, 67.5, 67.4, 56.0, 33.8, 33.7, 33.6, 29.8, 29.7, 29.5, 28.5, 28.4. MS (MALDI–TOF) calcd for $C_{69}H_{90}O_{10}Br_8$, *m/z* = 1718.677 $[M]^+$, found *m/z* = 1718.204.

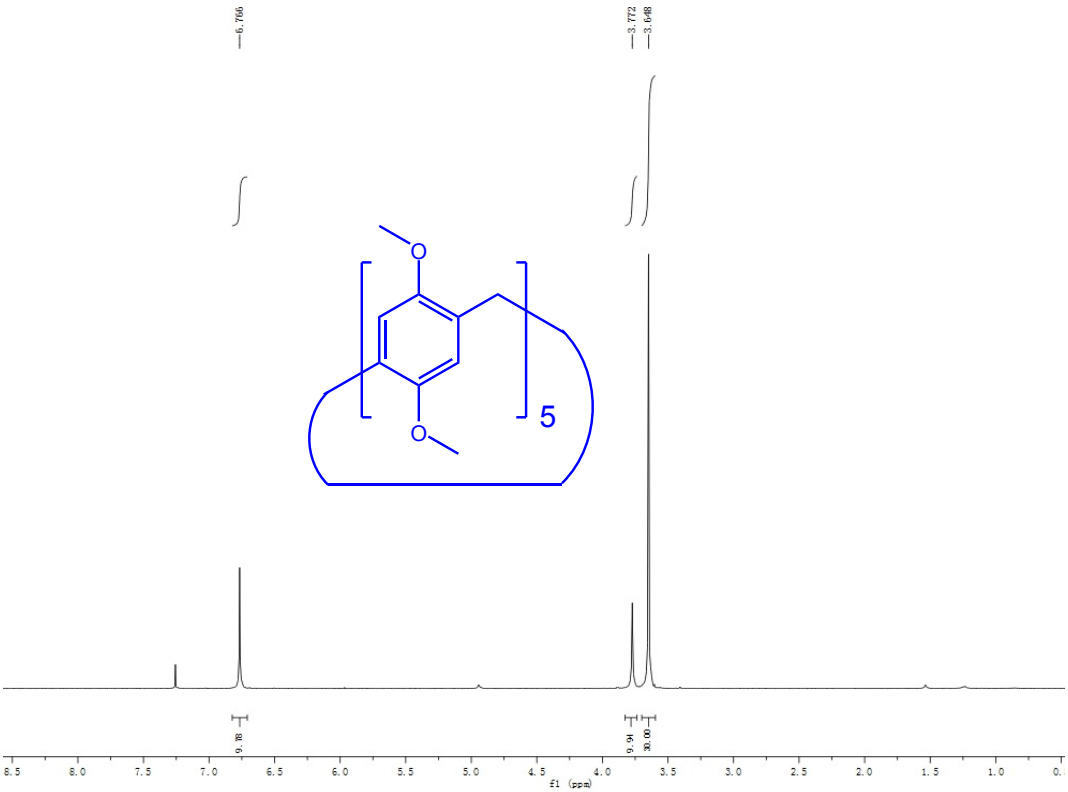


Fig. S1 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2a**.

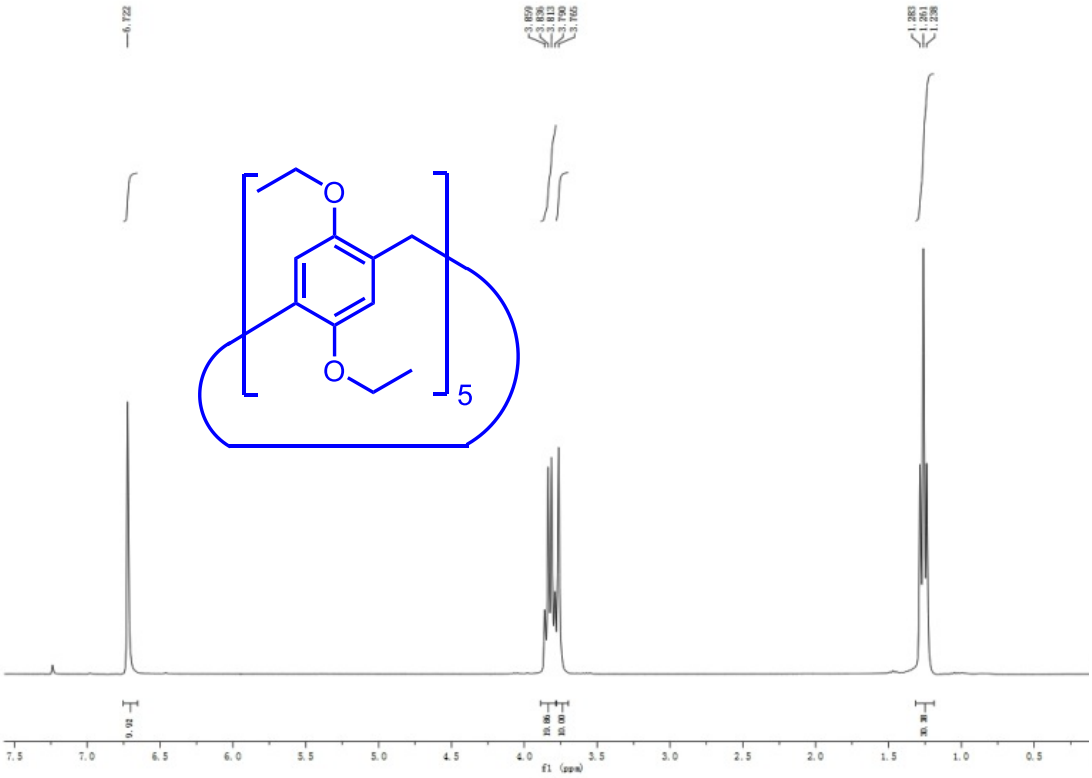


Fig. S2 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2b**.

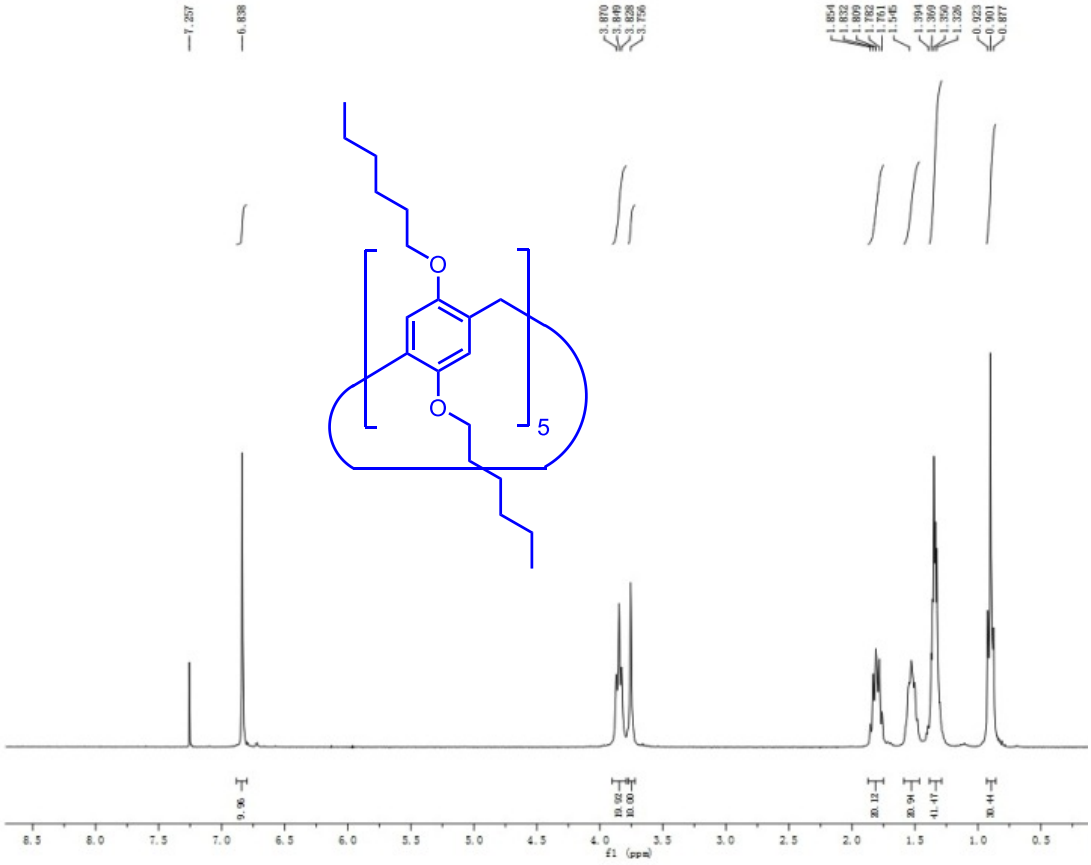


Fig. S3 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2c**.

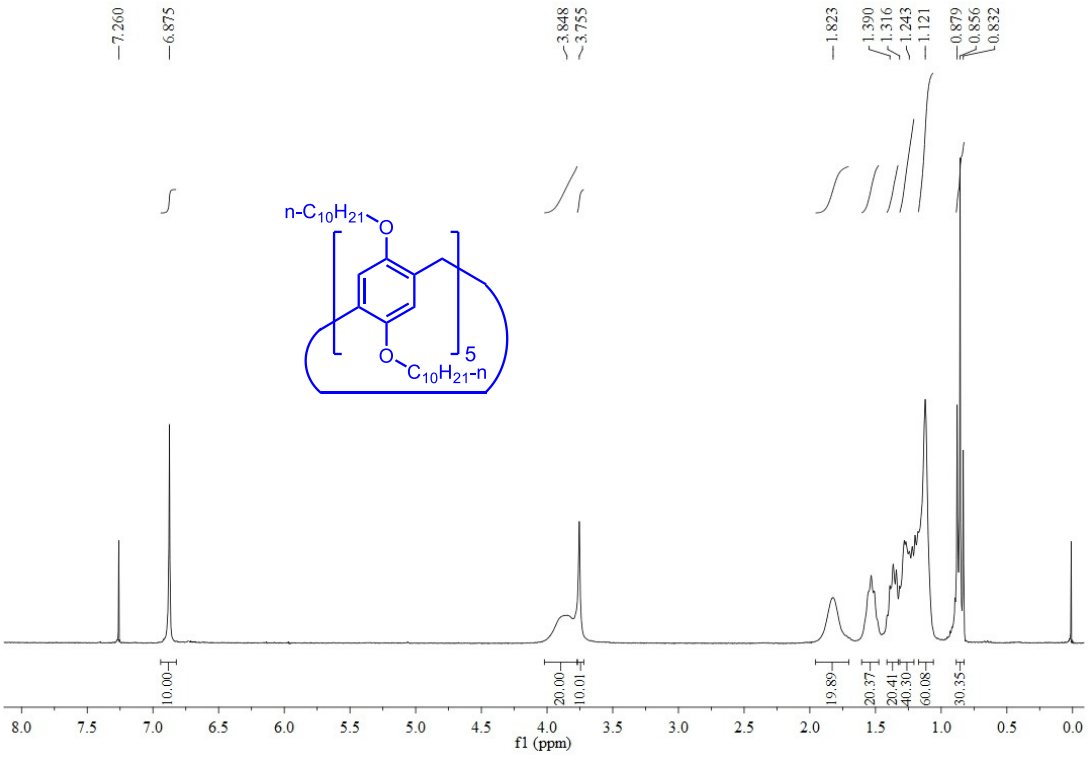


Fig. S4 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2d**.

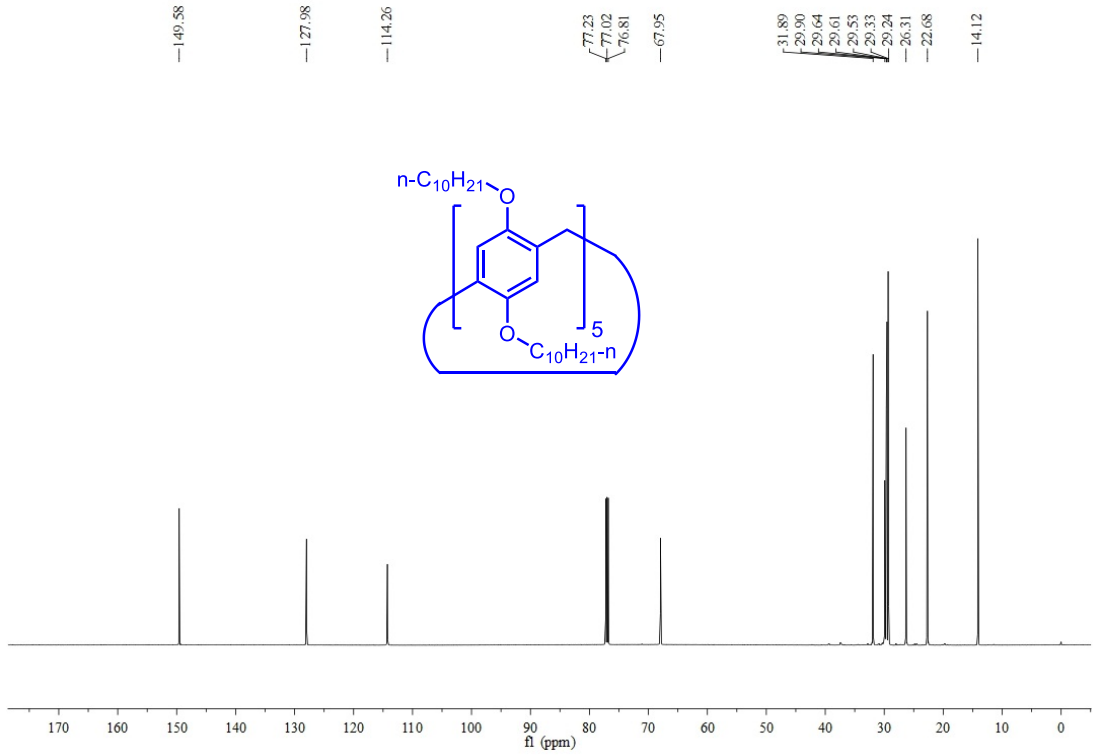


Fig. S5 ^{13}C NMR spectrum ($CDCl_3$, 298 K, 125 MHz) of **2d**.

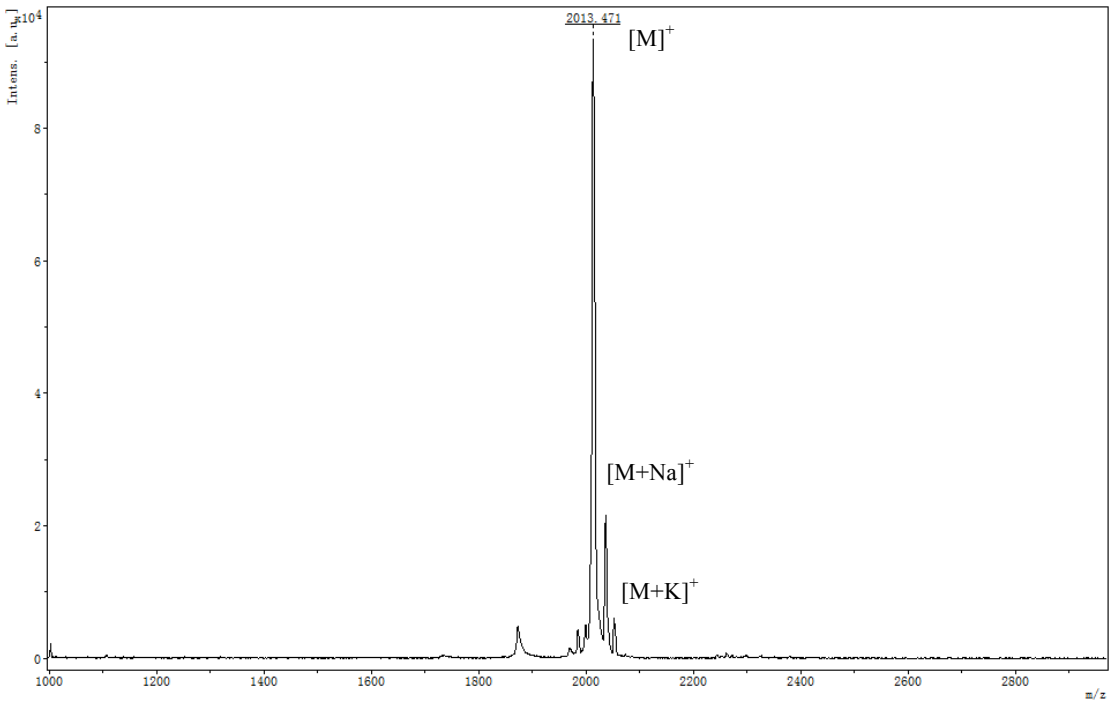


Fig. S6 MS (MALDI-TOF) of **2d**.

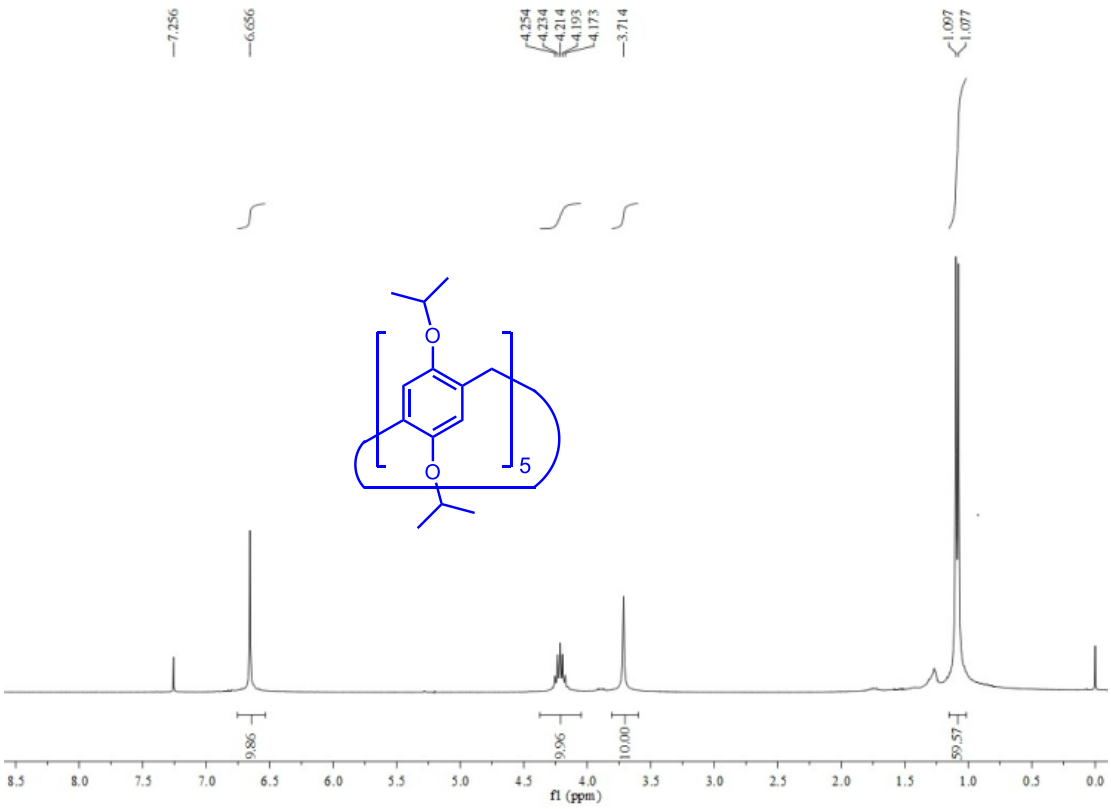


Fig. S7 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2e**.

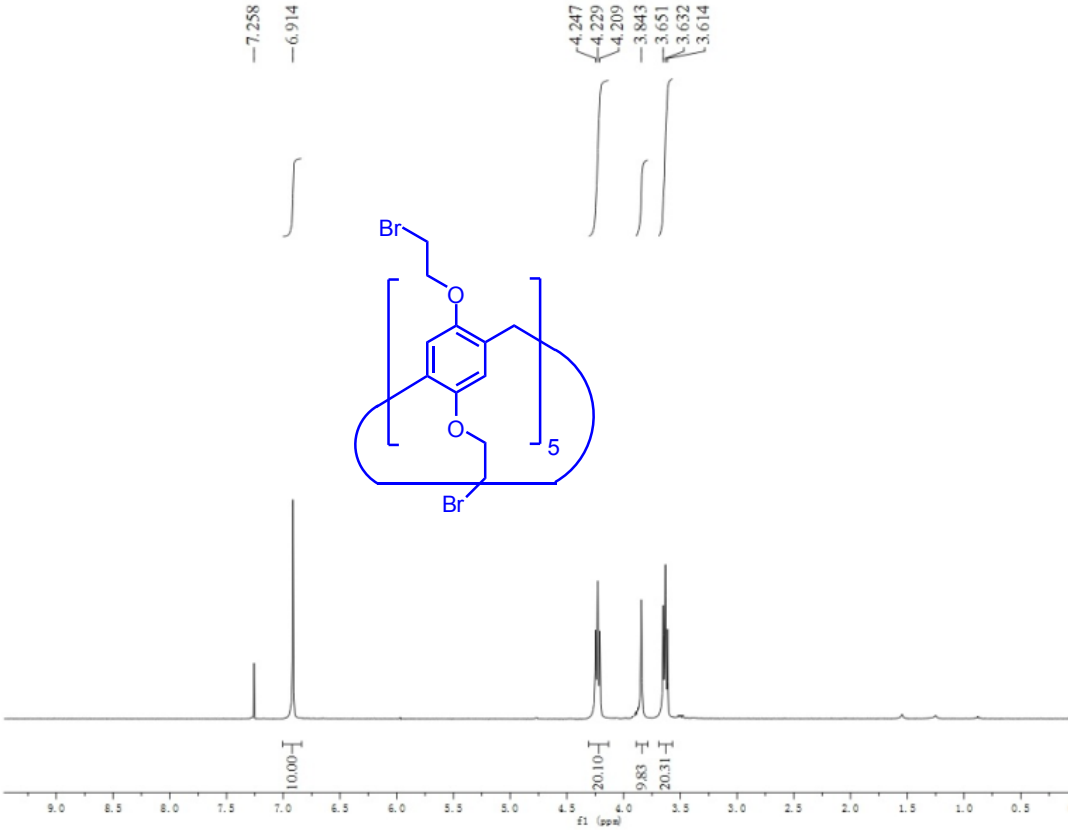


Fig. S8 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2f**.

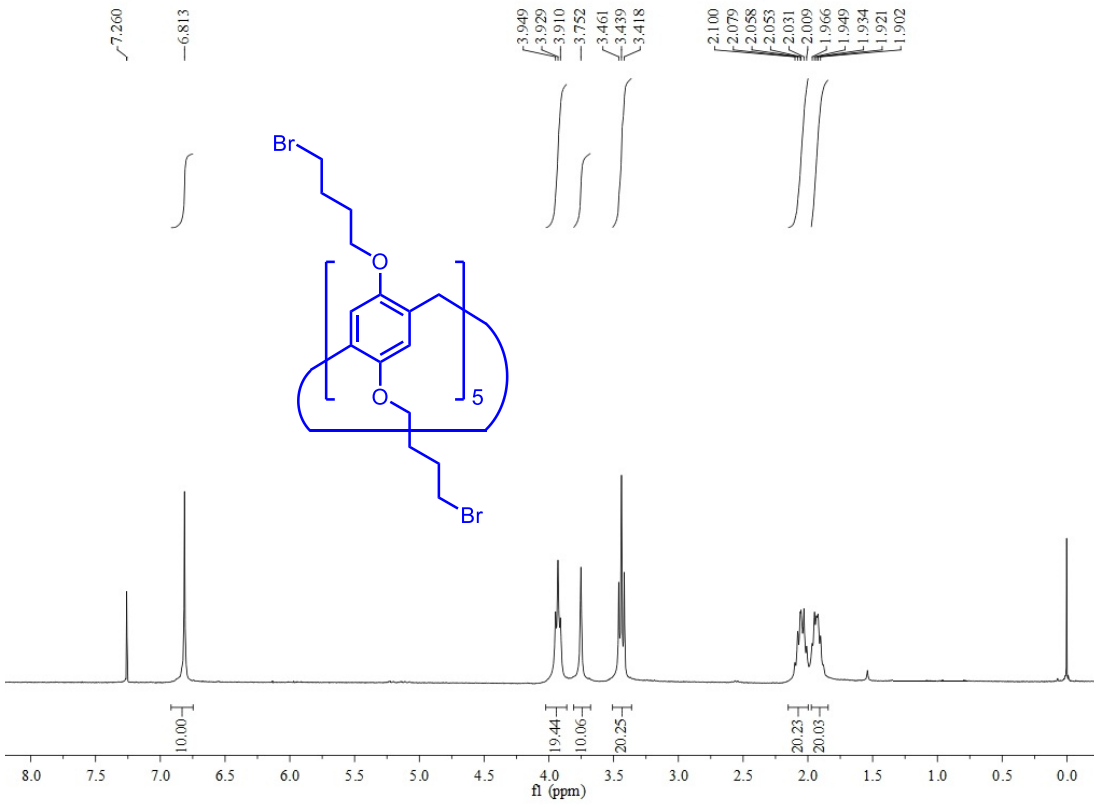


Fig. S9 ^{1}H NMR of spectrum ($CDCl_3$, 298 K, 300 MHz) **2g**.

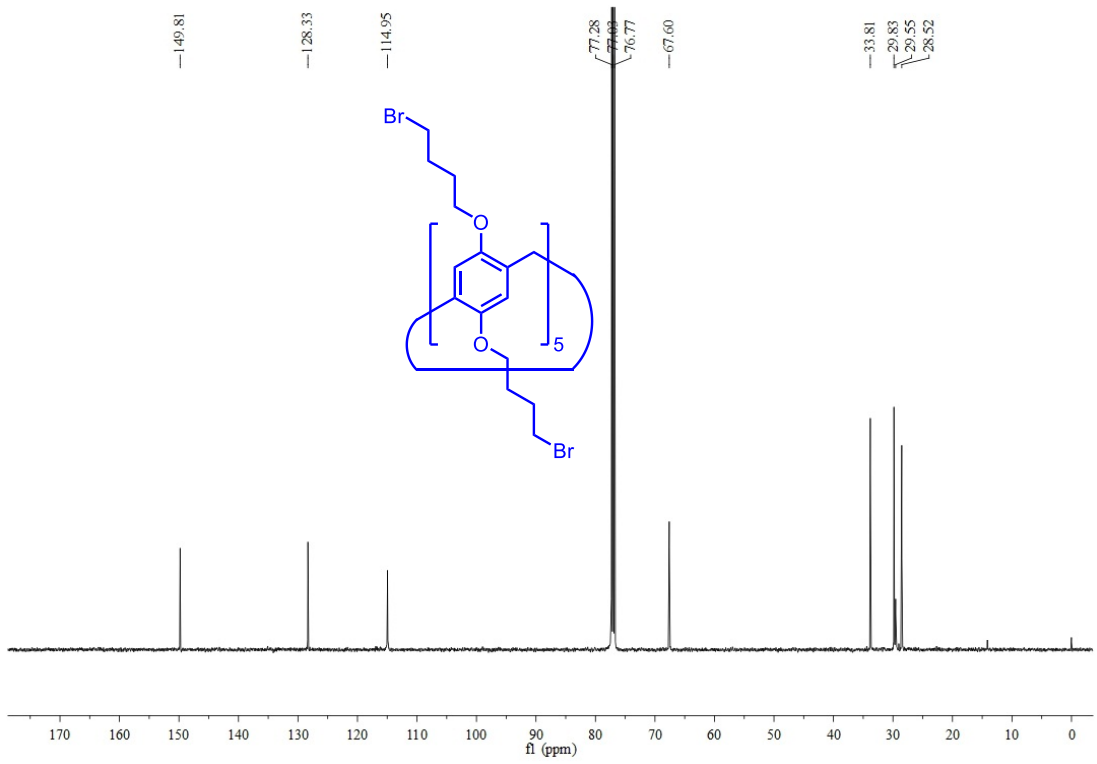


Fig. S10 ^{13}C NMR spectrum ($CDCl_3$, 298 K, 125 MHz) of **2g**.

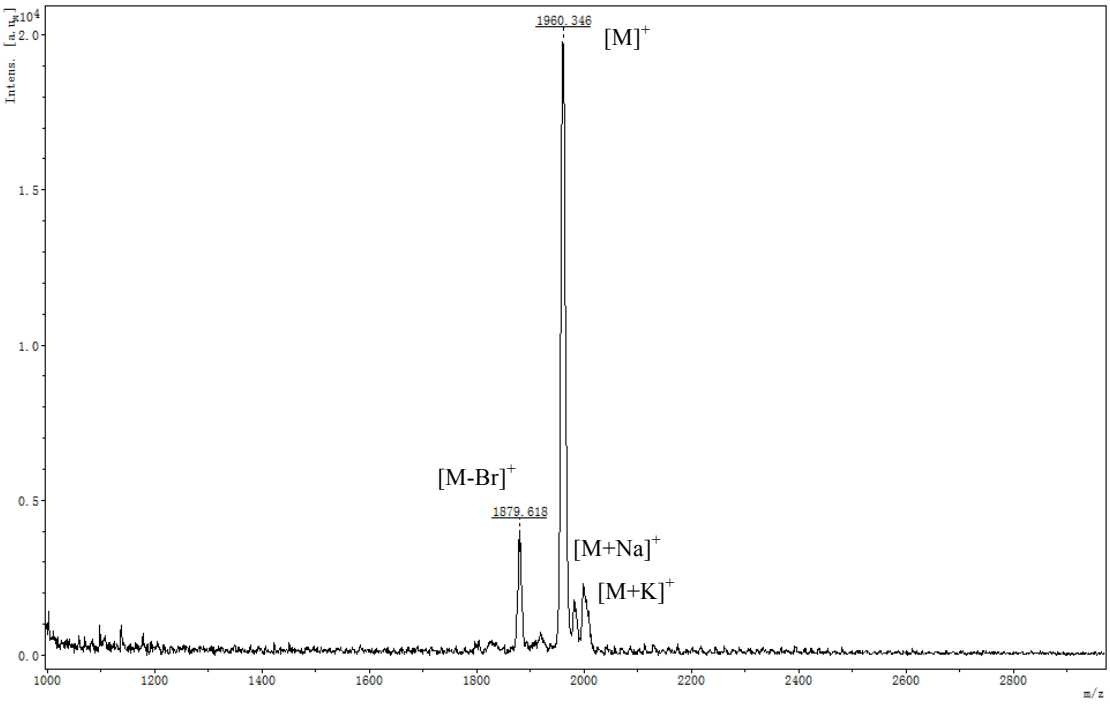


Fig. S11 MS (MALDI-TOF) of **2g**.

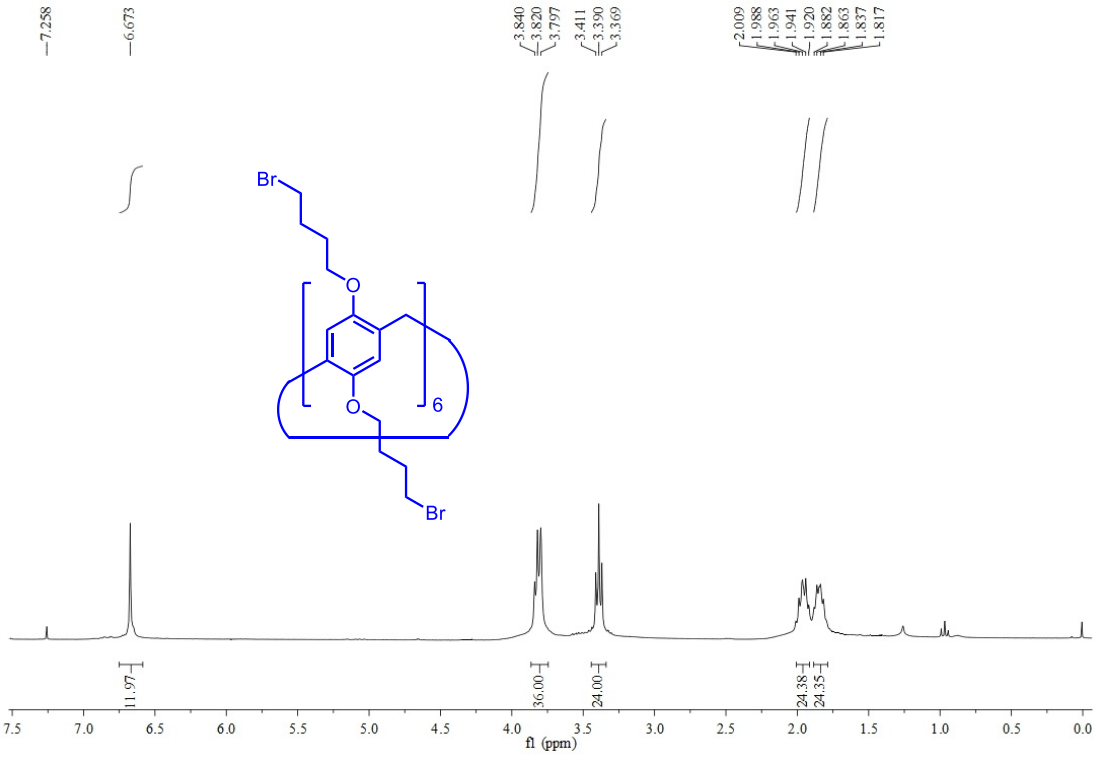


Fig. S12 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2g′**.

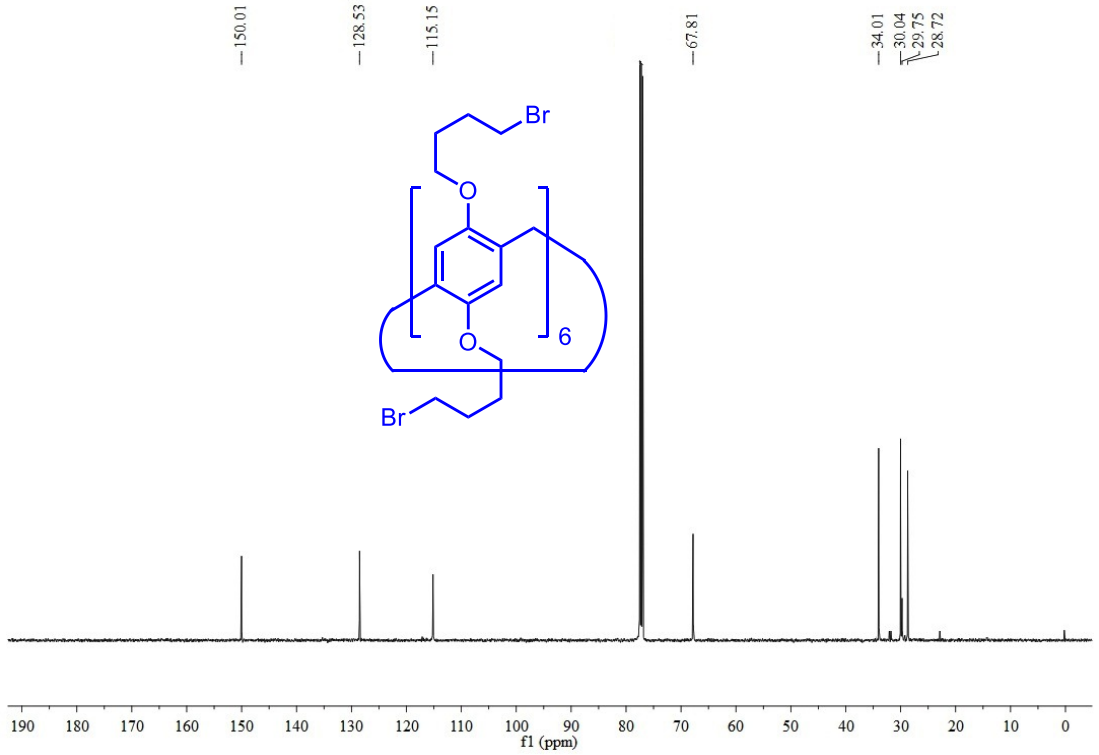


Fig. S13 ^{13}C NMR spectrum ($CDCl_3$, 298 K, 125 MHz) of **2g′**.

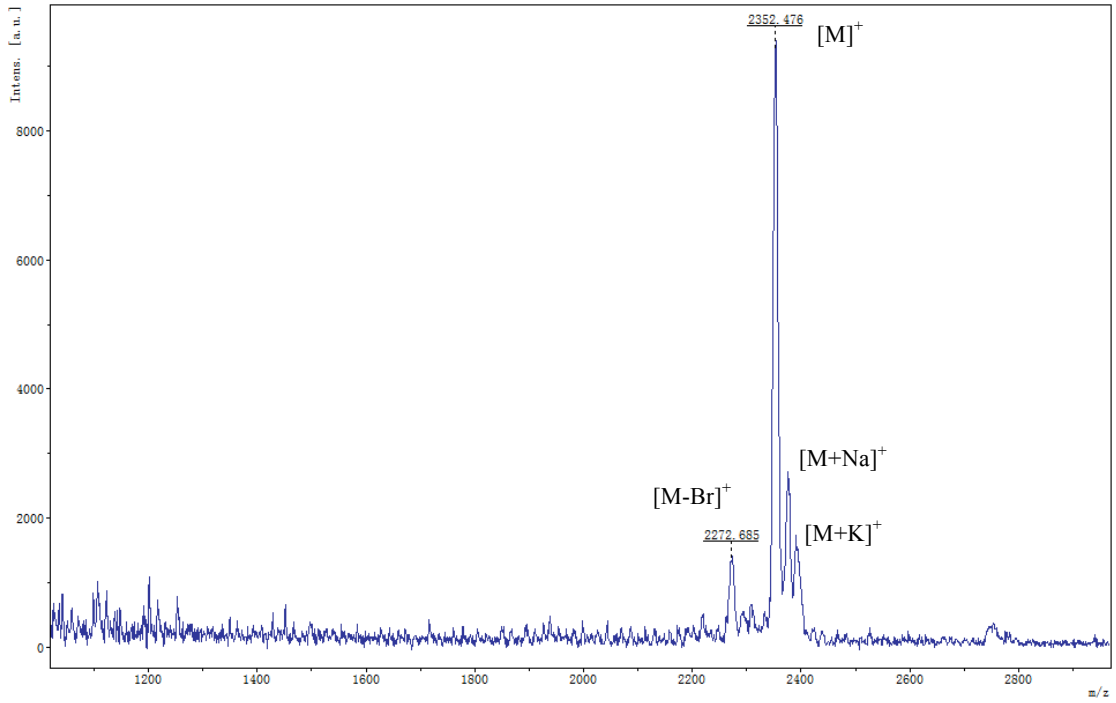


Fig. S14 MS (MALDI-TOF) of **2g'**.

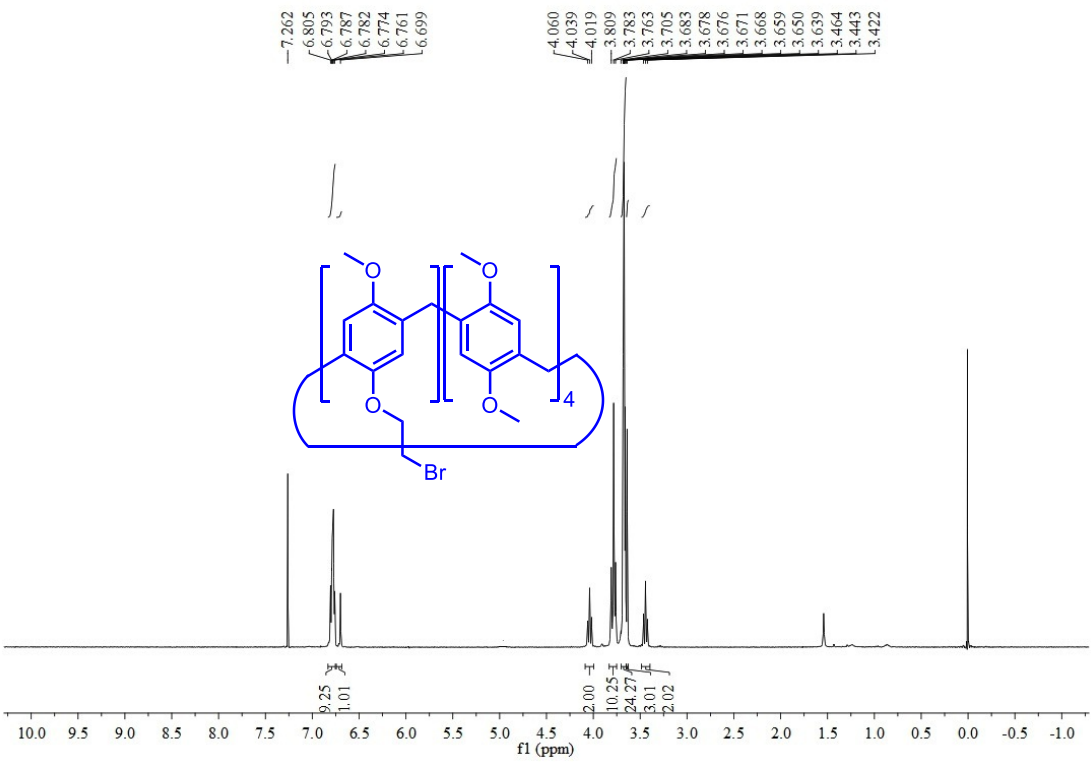


Fig. S15 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2i**.

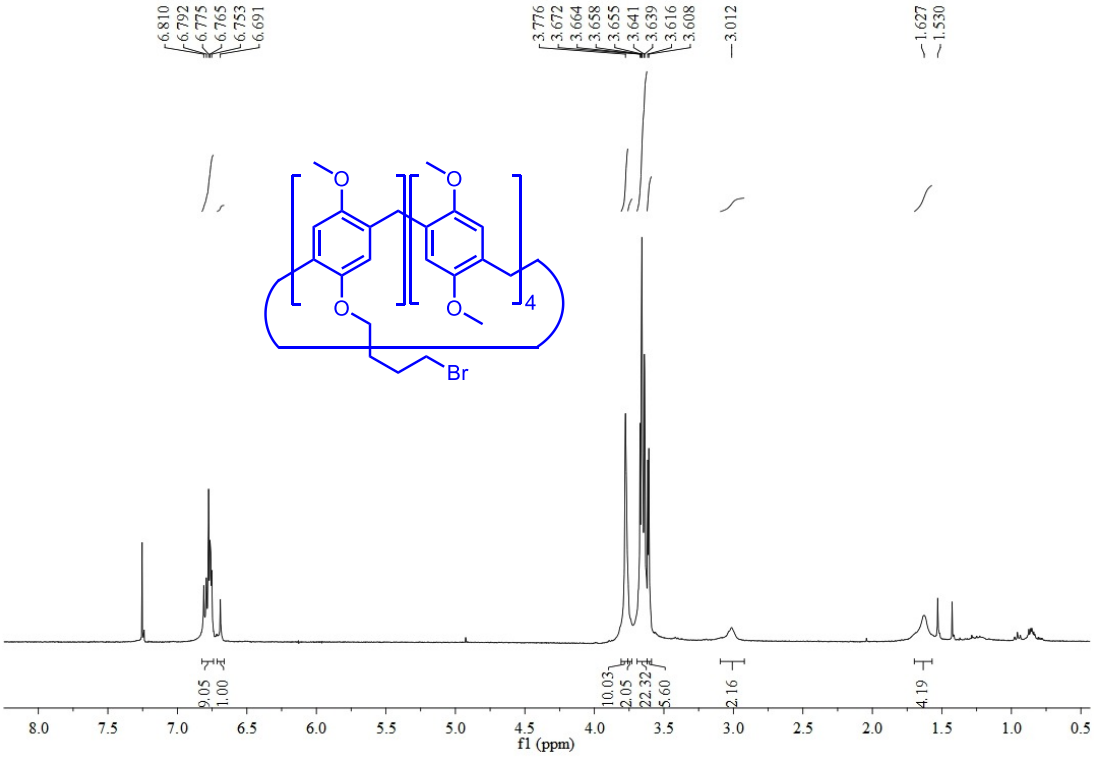


Fig. S16 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2j**.

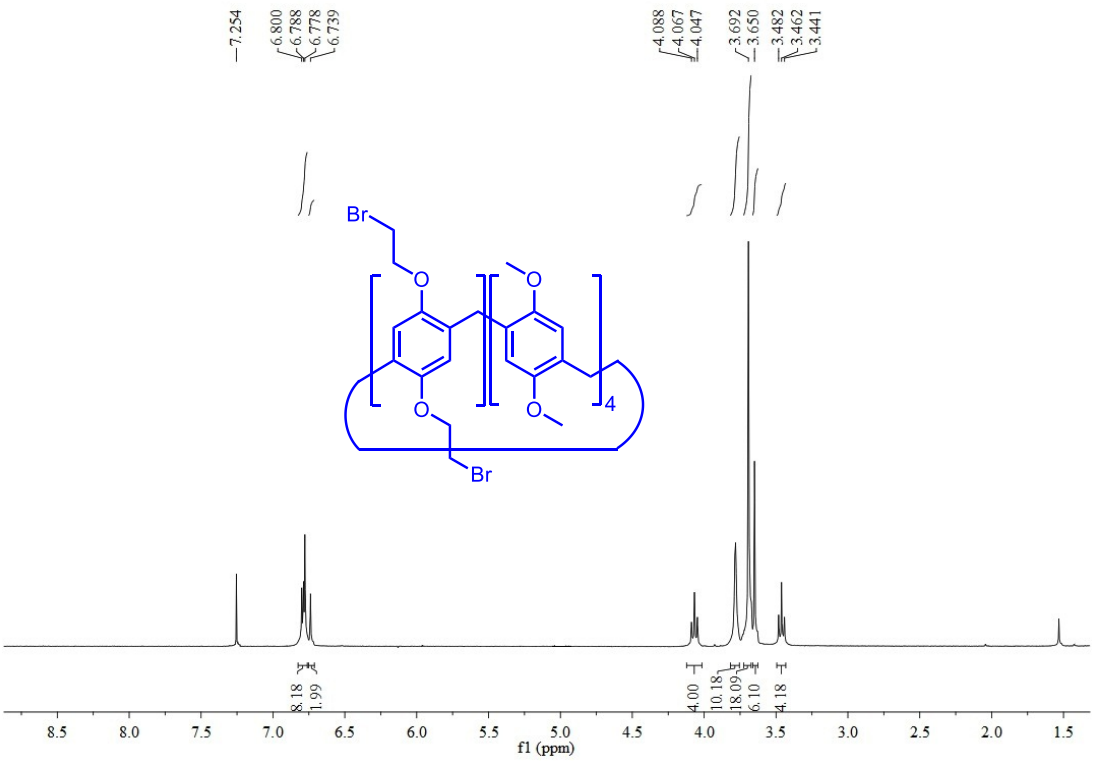


Fig. S17 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2k**.

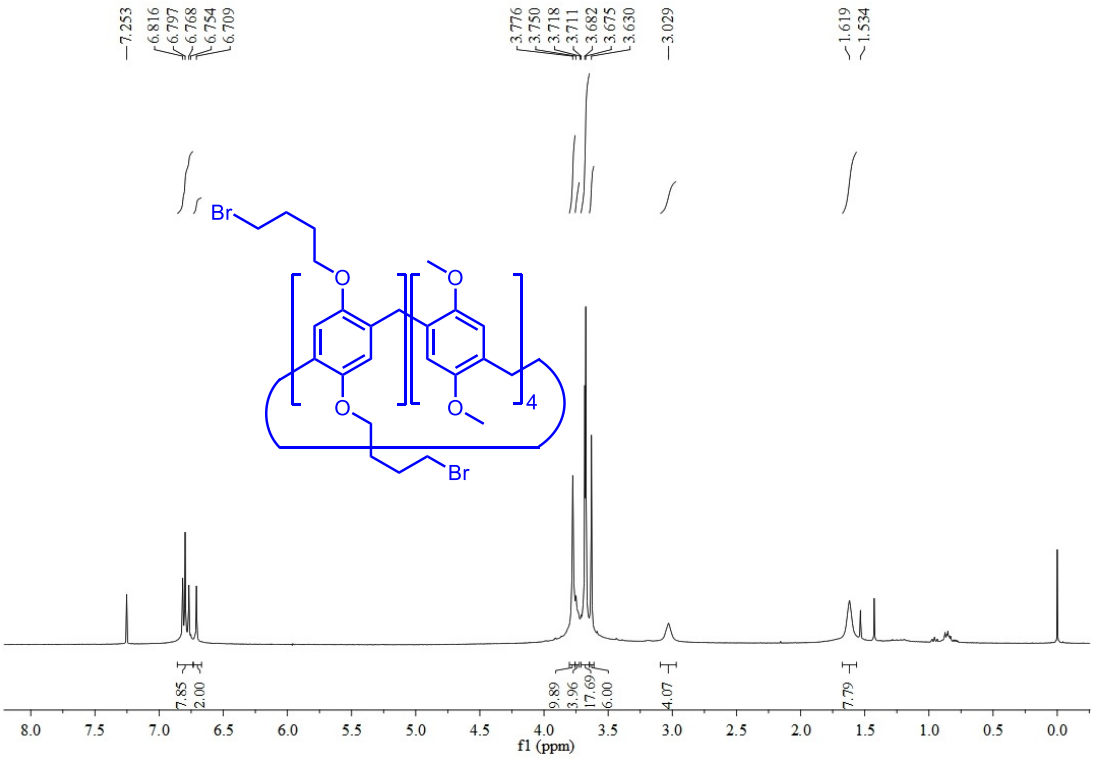


Fig. S18 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2l**.

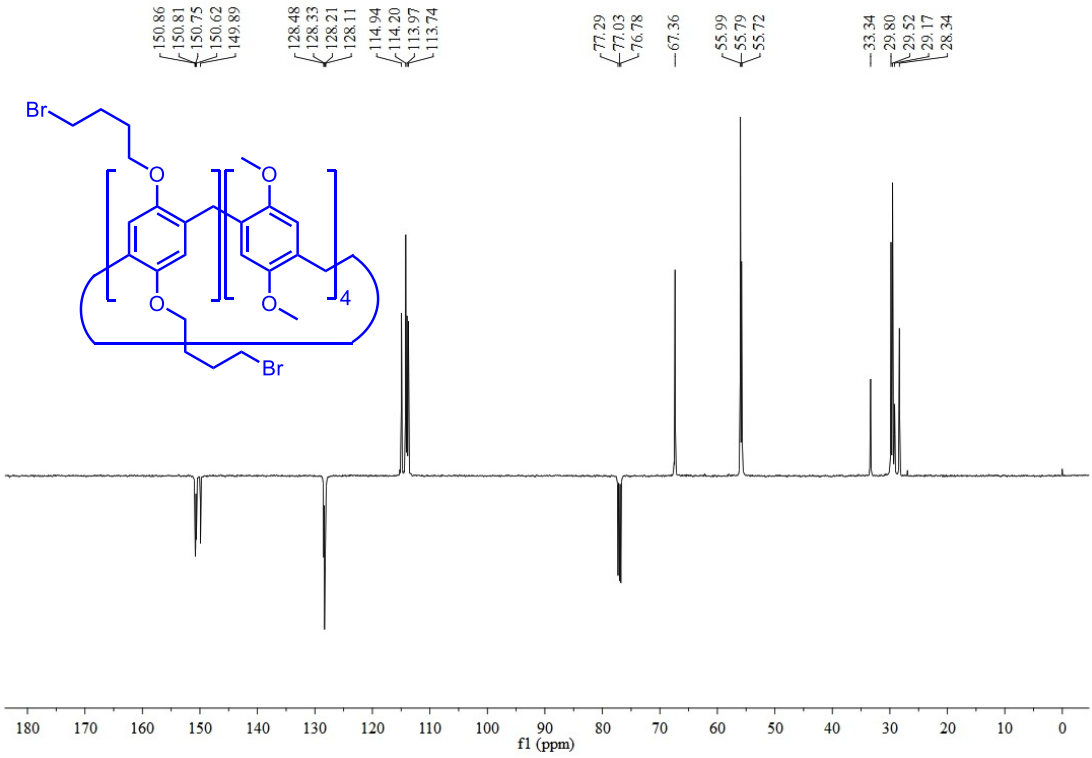


Fig. S19 ^{13}C NMR spectrum ($CDCl_3$, 298 K, 125 MHz) of **2l**.

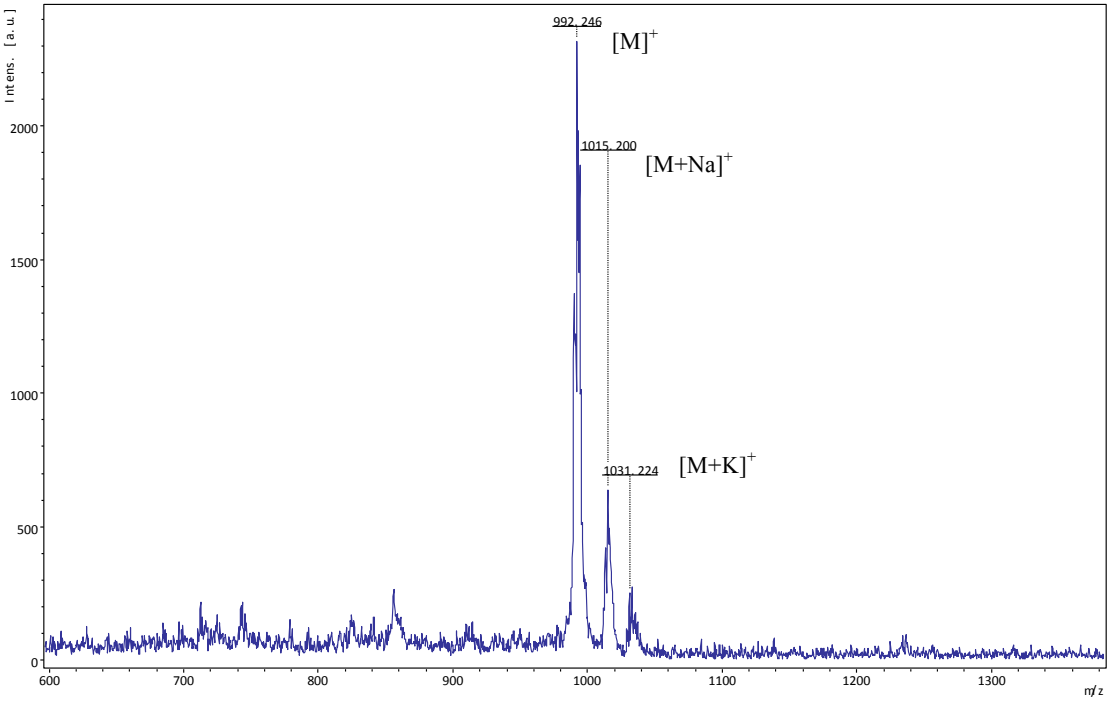


Fig. S20 MS (MALDI-TOF) of **2l**.

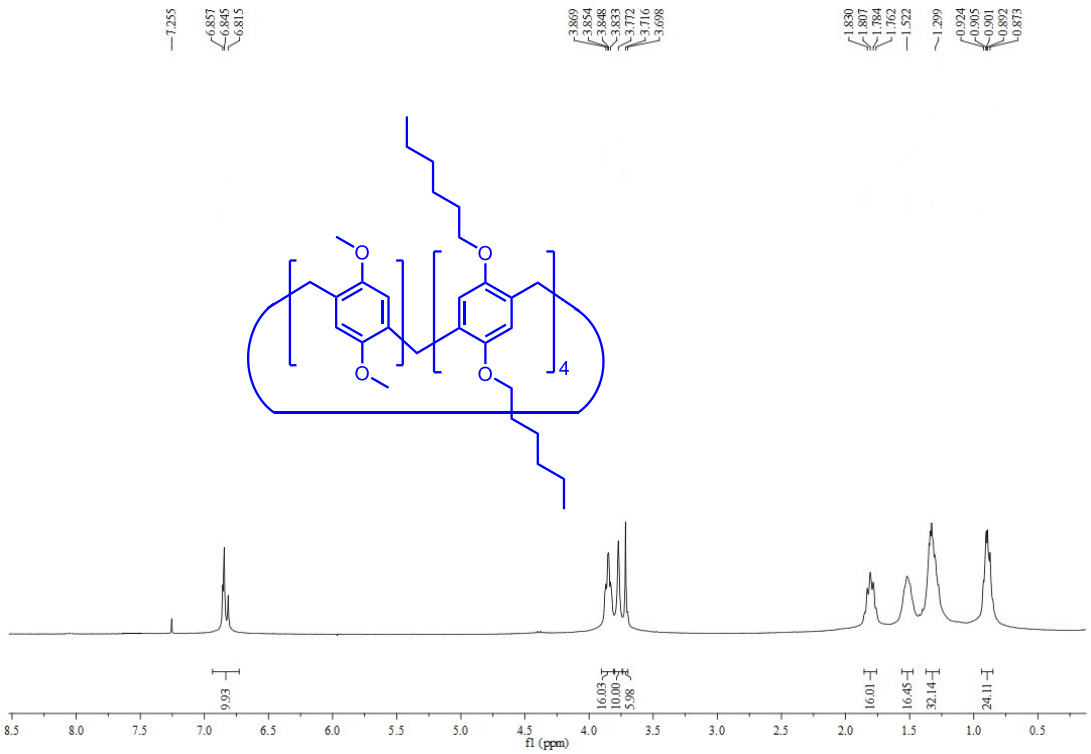


Fig. S21 ^{1}H NMR of spectrum ($CDCl_3$, 298 K, 300 MHz) **2m**.

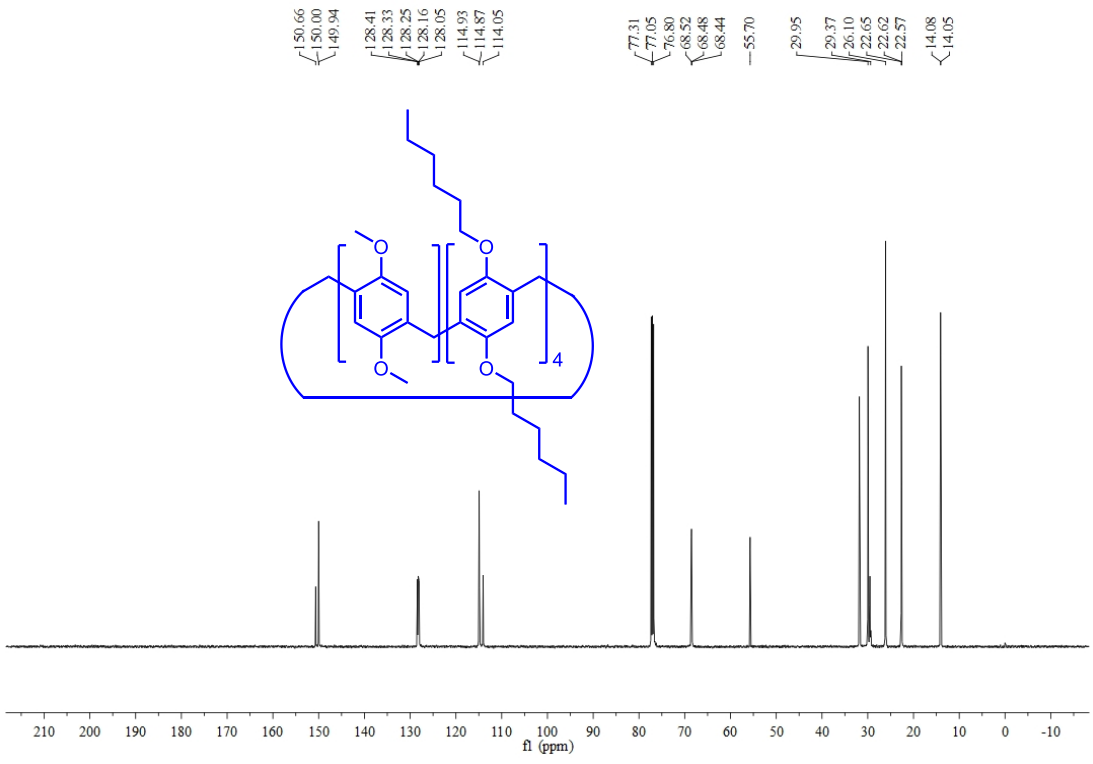


Fig. S22 ^{13}C NMR spectrum ($CDCl_3$, 298 K, 125 MHz) of **2m**.

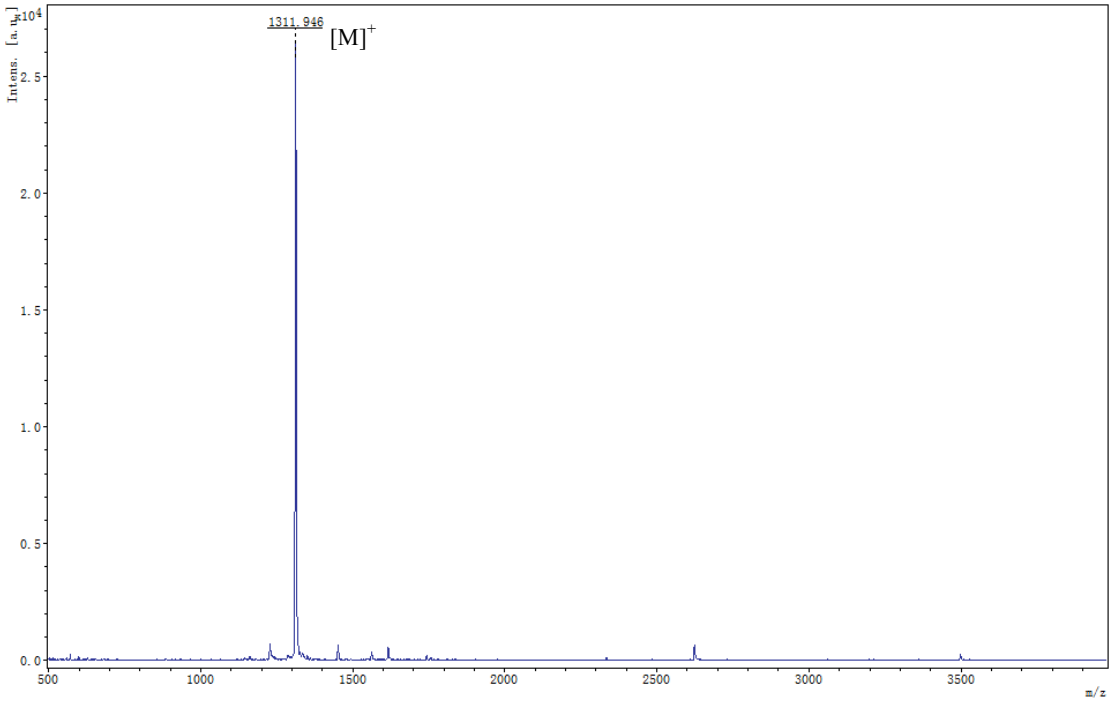


Fig. S23 MS (MALDI-TOF) of **2m**.

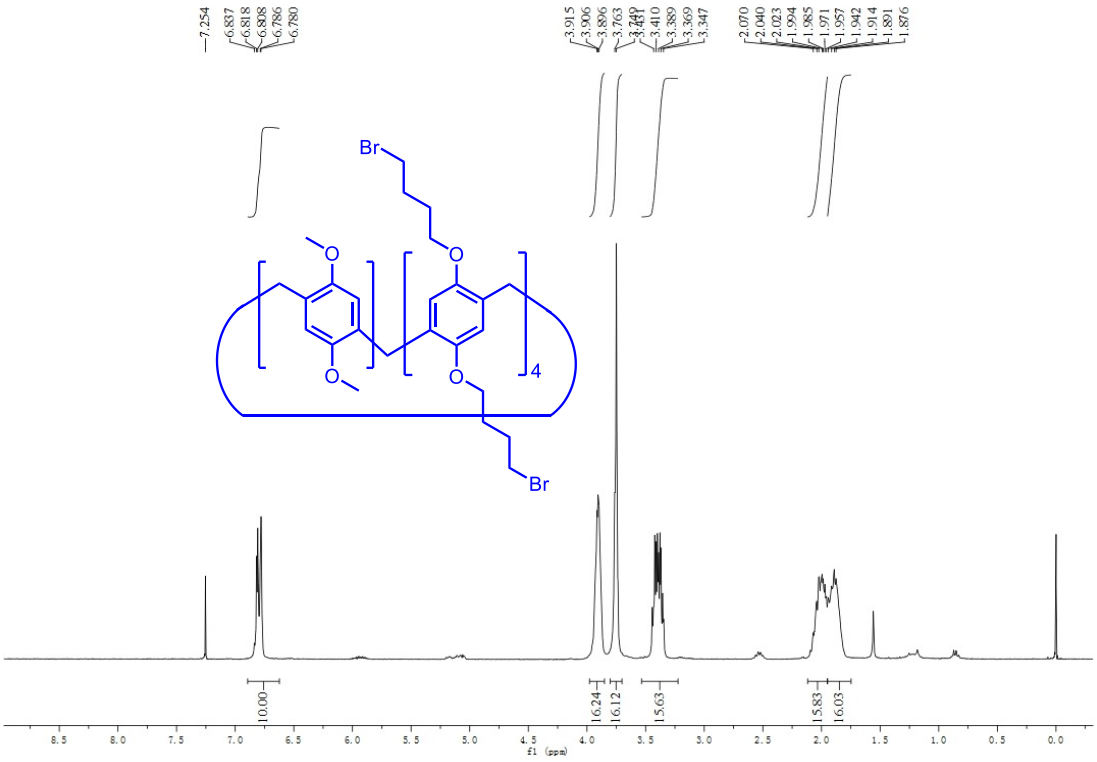


Fig. S24 ^{1}H NMR spectrum ($CDCl_3$, 298 K, 300 MHz) of **2n**.

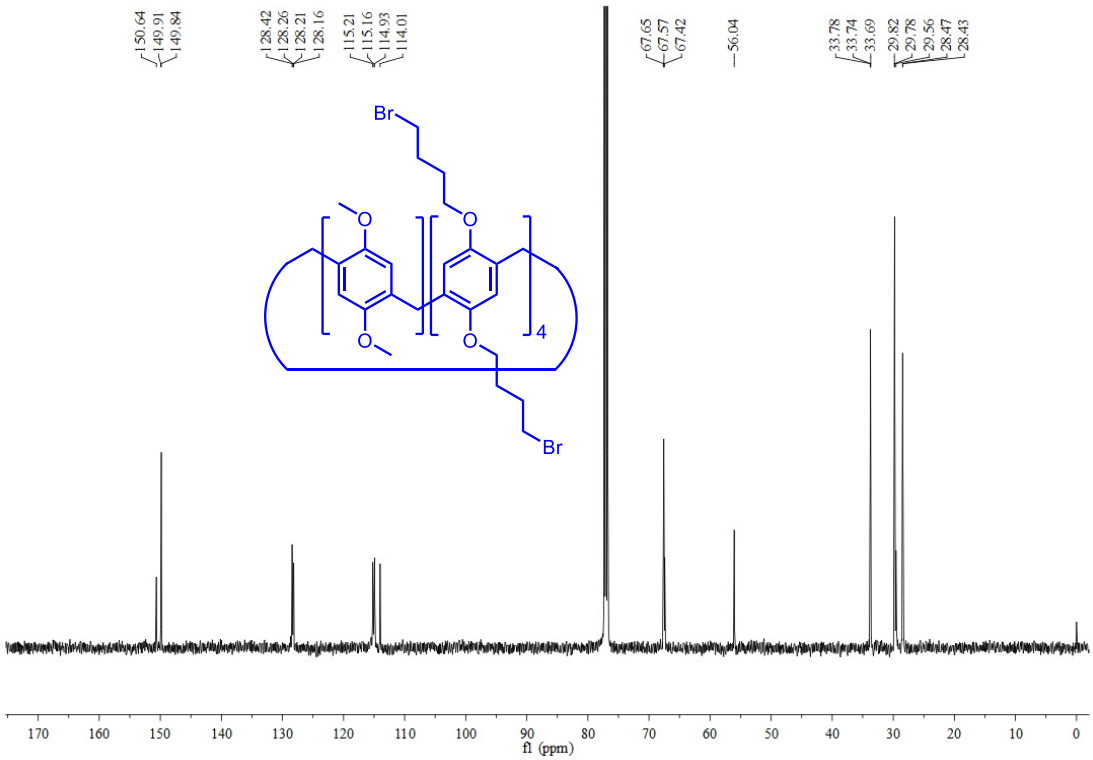


Fig. S25 ^{13}C NMR spectrum ($CDCl_3$, 298 K, 125 MHz) of **2n**.

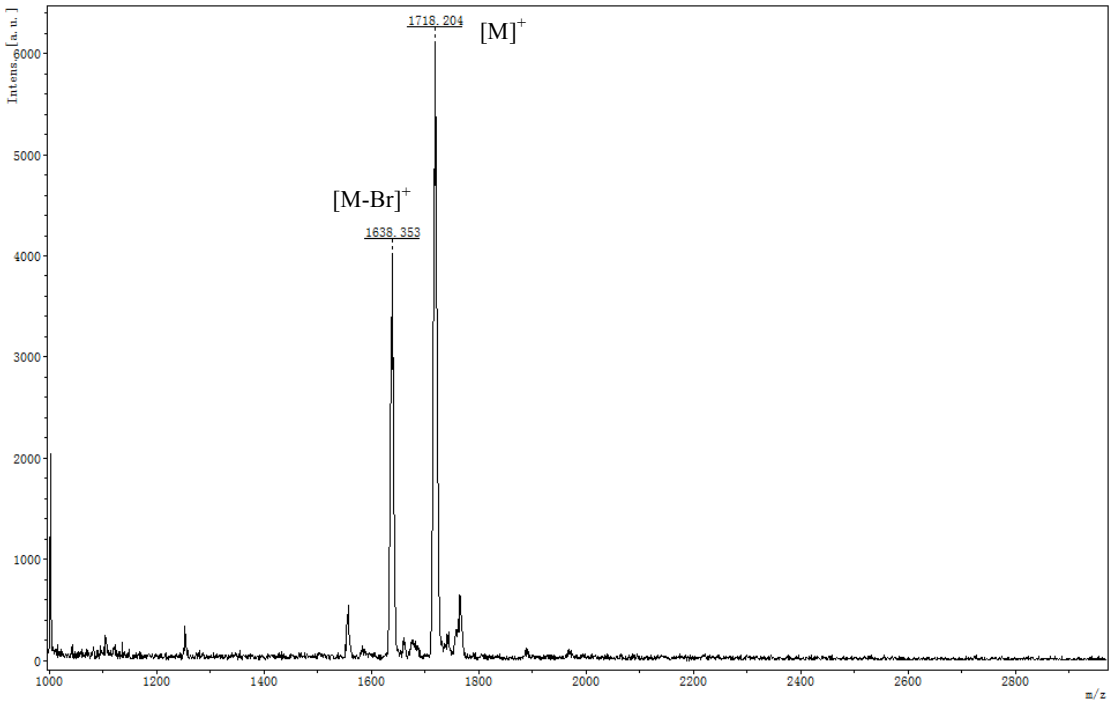


Fig. S26 MS (MALDI-TOF) of **2n**.

Investigation on the Reaction Mechanism.

ESR Spectra.

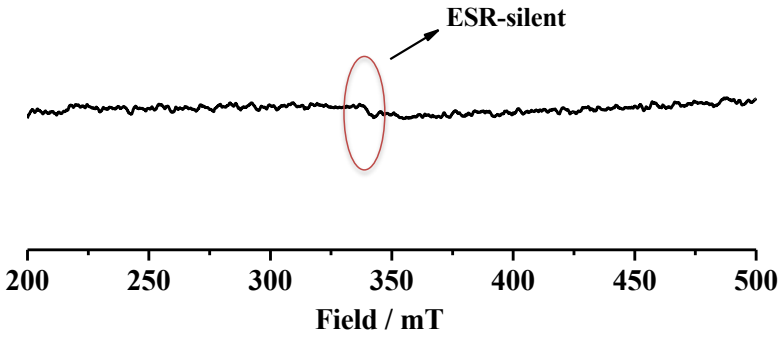
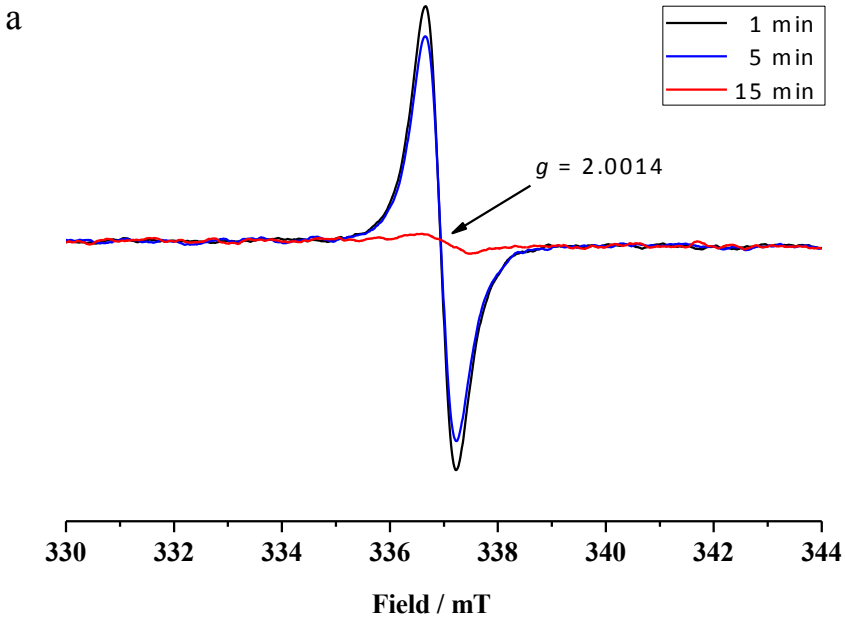
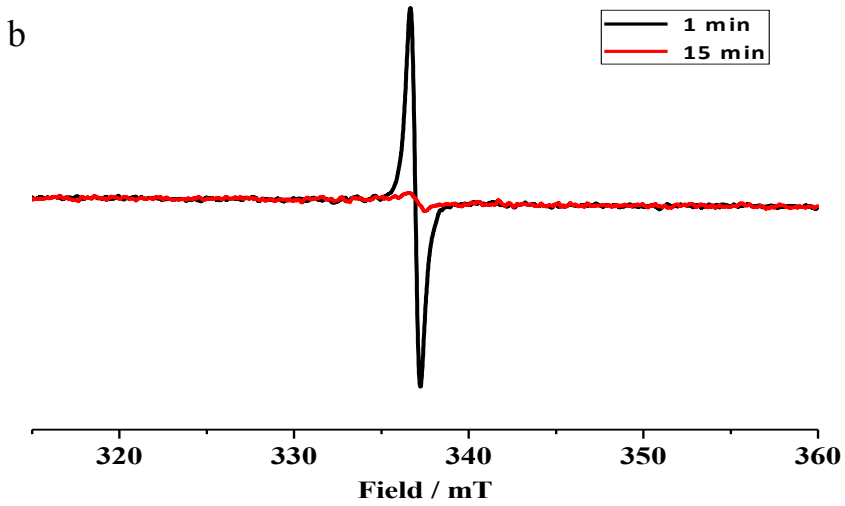


Fig. S27 Analysis of room-temperature X-band ESR spectrum before the addition of TfOH as a catalyst.





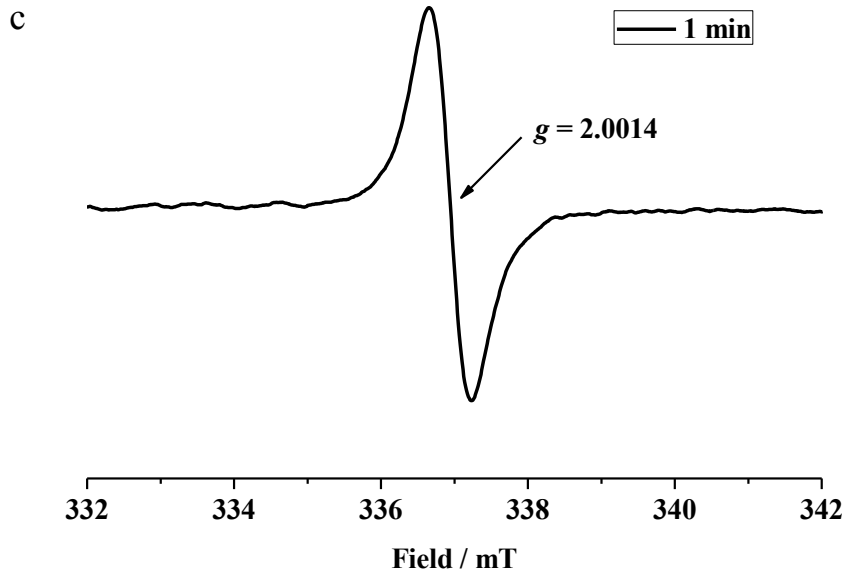


Fig. S28 a) and b) Room temperature X-band ESR spectra after the reaction proceeded for 1 min, 5 min, and 15 min; c) a close view of X-band ESR signal after the reaction proceeded for 1 min (g = 2.0014)

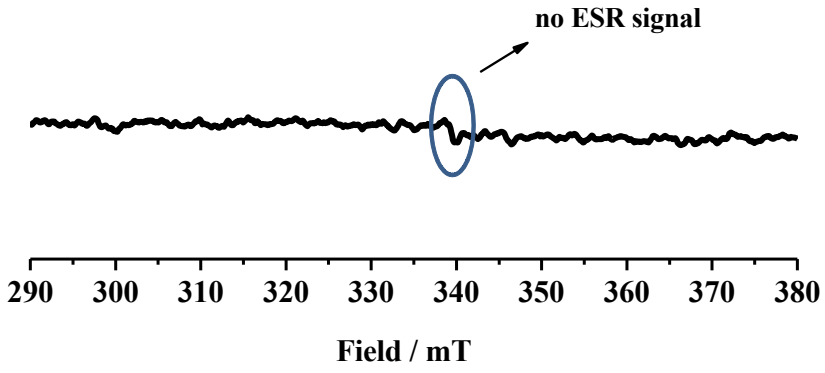
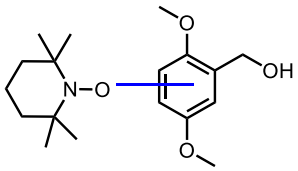


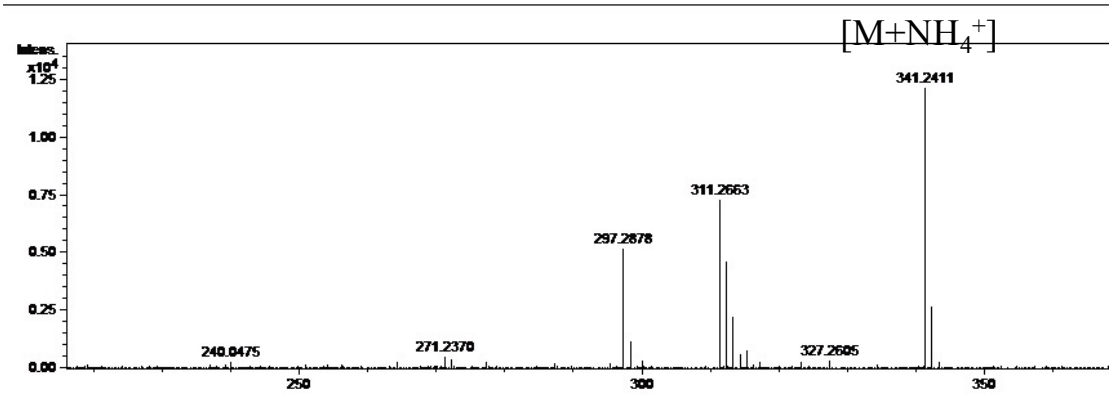
Fig. S29 Room temperature X-band ESR spectrum after the reaction proceeded for 20 min.

Mass Spectra.

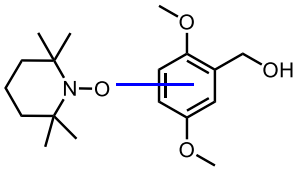
a



Exact Mass: 323.2175



b



Exact Mass: 323.2175

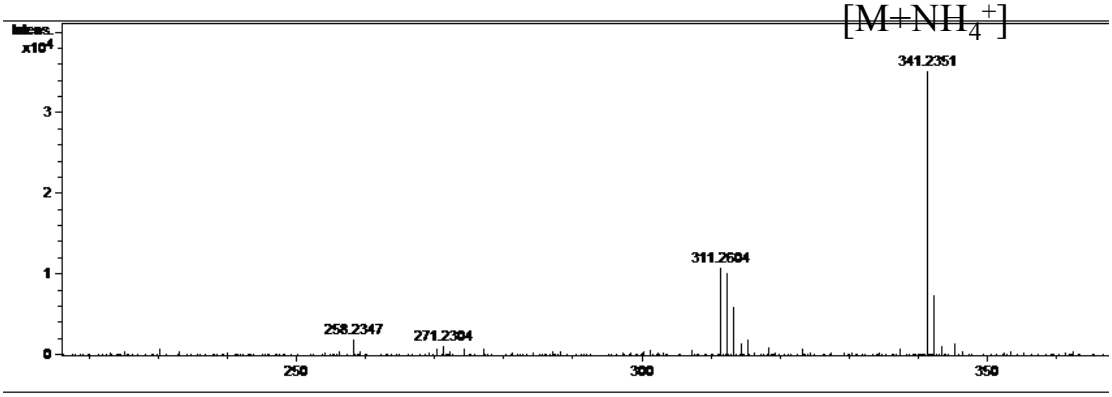
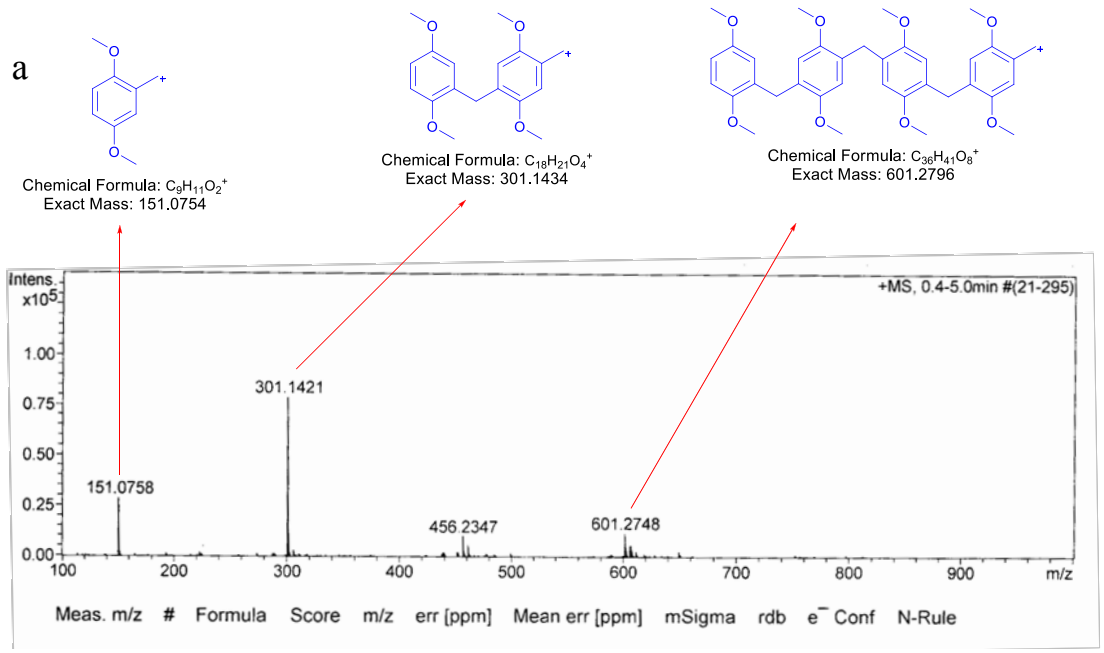


Fig. S30 Detection of radical cation intermediate by ESI-HRMS (collision energy 2 eV) upon addition of 1 equiv. of TEMPO: **a**) addition of TEMPO after the reaction proceeded for 1 min; **b**) addition of TEMPO after the reaction proceeded for 5 min.



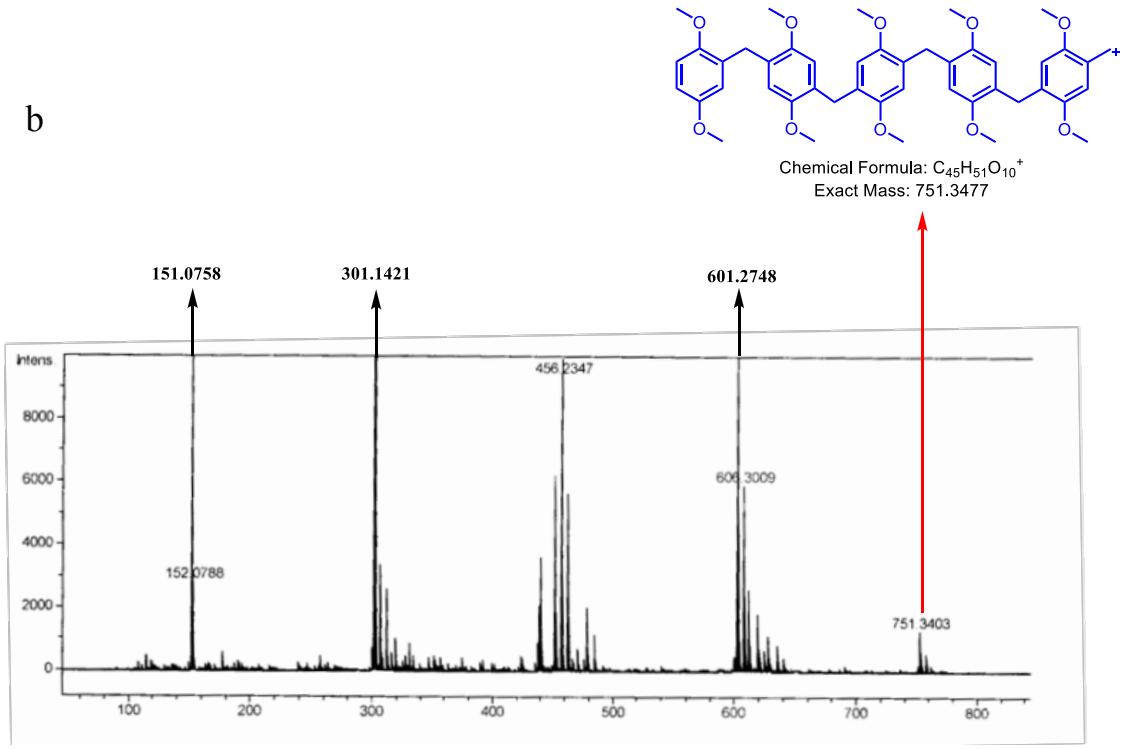
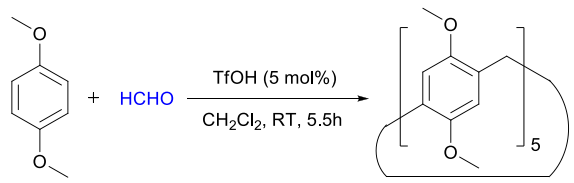


Fig. S31 ESI-HRMS (collision energy 2 eV) analysis after the reaction proceeded for 15 min.

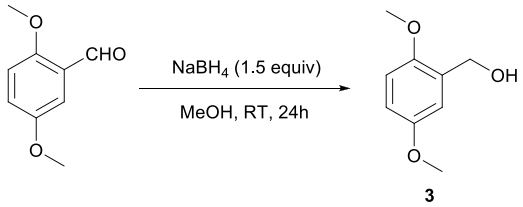
Synthesis of DMPillar[5]arene using HCHO gas instead of $(HCHO)_n$.



Scheme S2

1,4-dimethoxy benzene (0.138 g, 1 mmol) was added in anhydrous dichloromethane (30 mL), and the reaction flask was capped and gas formaldehyde (depolymerization of paraformaldehyde employing H_2SO_4 (98%) as catalyst at 100 °C) bubbled through the solution for 15 minutes. Then, TfOH (4.6 *u*L, 5 mol%) was added to the solution and the mixture was stirred at room temperature (approximately 25 °C). When the starting material was consumed completely (detected by TLC), the mixture was poured into aqueous NH_4Cl solution (30 mL). The organic layer was collected and aqueous layer was extracted with CH_2Cl_2 three times. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and then the solvent was removed by rotary evaporation. The crude product was purified by flash column chromatography with an appropriate eluting solvent (petroleum ether/ethyl acetate 6:1) to get pure DMpillar[5]arene (93 mg, 62%) as a white solid.

Synthesis of DMPillar[5]arene via another step-wise route.



Synthesis of compound 3[S6]**.** To a solution of 2,5-dimethoxybenzaldehyde (1.66g, 10 mmol) in MeOH, $NaBH_4$ (0.56g, 15 mmol) was added at 0 °C. The mixture was stirred overnight at room temperature. The solvent was removed by evaporation. Then CH_2Cl_2/H_2O was added to the residue, aqueous layer was extracted with CH_2Cl_2 thrice.

The organic layer was dried with andydrous Na_2SO_4. After filtration, solvents were evaporated to give **3** as a colorless oil (1.6g, 95%). **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 6.88 (d, *J* = 2.4Hz, 1H), 6.80 (d, 2H), 4.66 (s, 2H), 3.82 (s, 3H), 3.77 (s, 3H), 2.31 (br, 1H).

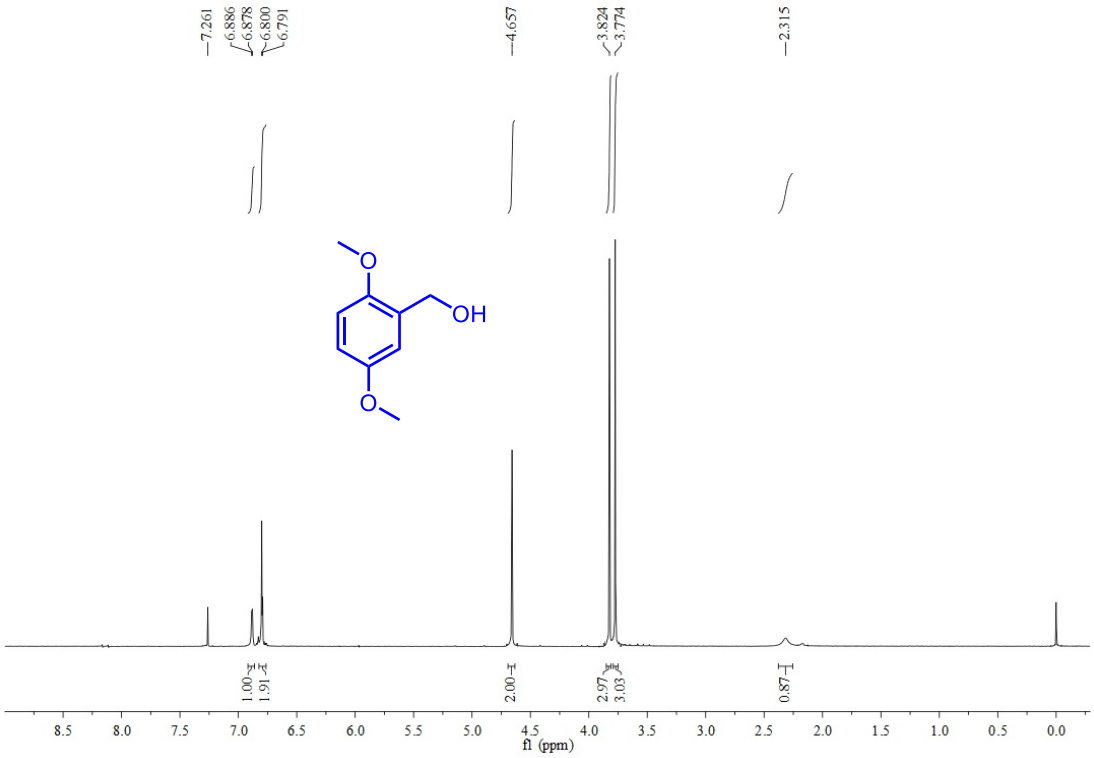
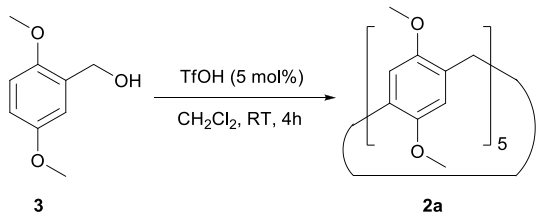


Fig. S32



Scheme S3

Synthesis of DMpillar[5]arene 2a from 3. To a solution of **3** (0.168g, 1 mmol) in anhydrous dichloromethane (20 mL), TfOH (4.6 μL, 5 mol%) was added to the solution and the mixture was stirred at room temperature (approximately 25 °C). Solution color changed gradually from colorless to green. When the starting material was completely consumed (as detected by TLC), the mixture was poured into aqueous

NH_4Cl solution (30 mL). The organic layer was collected and aqueous layer was extracted with CH_2Cl_2 thrice. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and then the solvent was removed by rotary evaporation. The crude product was purified by flash column chromatography with an appropriate eluting solvent (petroleum ether/ethyl acetate 6:1) to get pure DMpillar[5]arene **2a** (99mg, 66%).

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