Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Enhanced Molecular Binding Affinity toward Aromatic Dications by Anthracene-Derived Crown Ethers in Water

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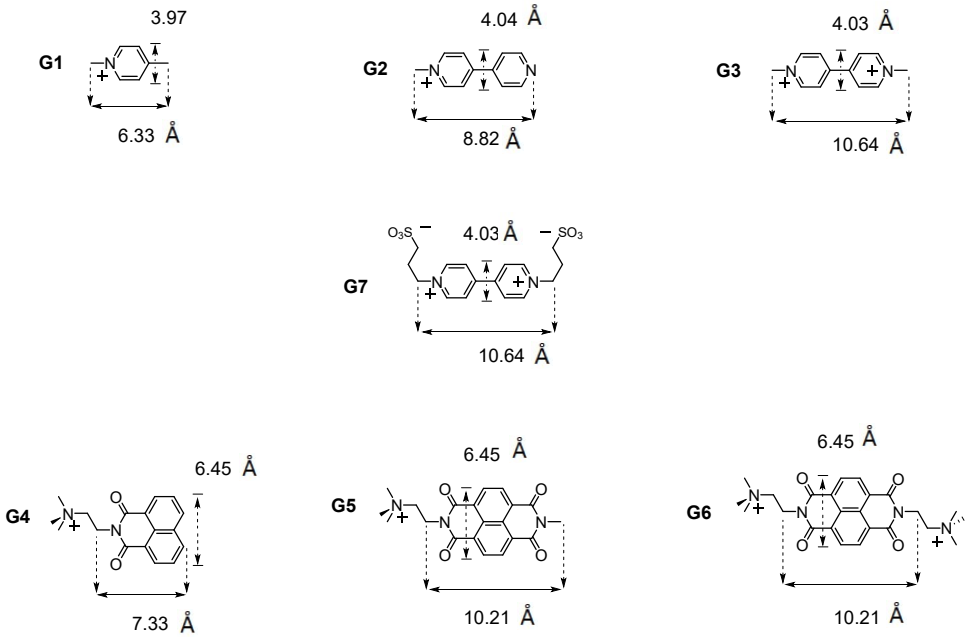
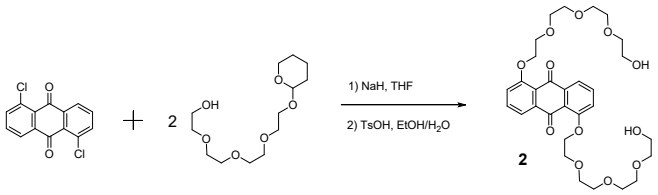


Figure S1. Molecular size of **G1** – **G7**

Preparation of 2.



To a vigorously stirred solution of 2-[2-[2-[2-[(tetrahydro-2*H*-pyran-2-yl)oxy]ethoxy]ethoxy]ethoxy]-ethanol (24.0 g, 86.3 mmol) in anhydrous THF (650 mL), was slowly added NaH (60% oil dispersion, 3.1 g, 77.5 mmol) and then stirred for 0.5 h. Then 1,5-dichloroanthraquinone (8.0 g, 28.9 mmol) was added and stirring continued at reflux overnight. The mixture was then cooled down and filtered. The filtrate was concentrated in reduced pressure to obtained a brownish red oil. The oil was dissolved in EtOH (95%, 300 mL) and TsOH was added until pH = 3. The mixture was refluxed overnight to complete the deprotection of THP group. After cooling down to room temperature and removing the solvent under reduced pressure,

crude product **2** was obtained as brown oil (12.8 g, 75.1%), which was used in subsequent reduction step without further purification. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (d, J = 7.7 Hz, 2H), 7.66 (t, J = 8.1 Hz, 2H), 7.29 (d, J = 8.4 Hz, 2H), 4.30 (t, J = 4.5 Hz, 4H), 4.00 (t, J = 4.4 Hz, 4H), 3.89 – 3.84 (m, 4H), 3.69 (dd, J = 13.3, 8.8 Hz, 16H), 3.61 – 3.57 (m, 4H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 182.14, 158.89 , 137.19 , 134.84 , 121.11 , 119.80 , 118.50 , 98.80 , 72.58, 70.91, 70.46, 70.17, 69.91, 69.32, 66.54, 62.07, 61.43, 30.45, 25.32, 19.35. HRMS (ESI): m/z: $[M + H]^+$ cacld for $C_{30}H_{41}O_{12}$: 593.2598; found: 593.2605.

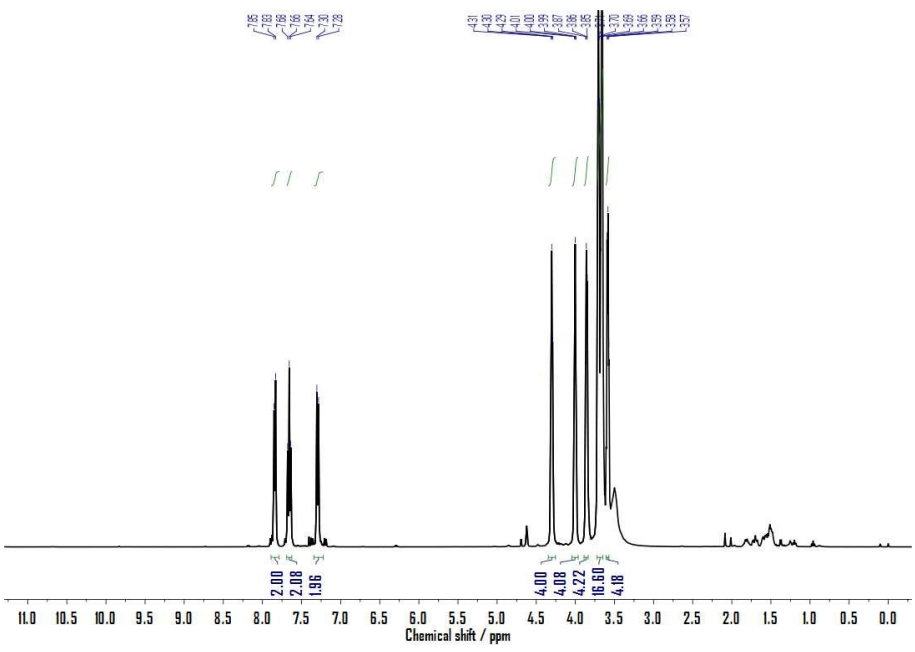


Figure S2. ^{1}H NMR spectrum of **2** ($CDCl_3$, 400 MHz, 25 °C).

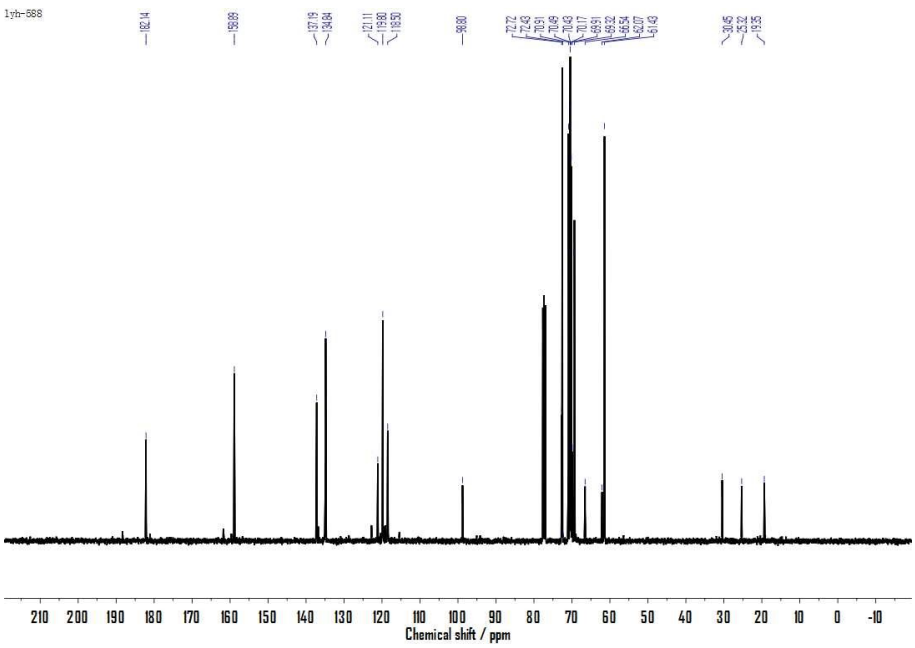
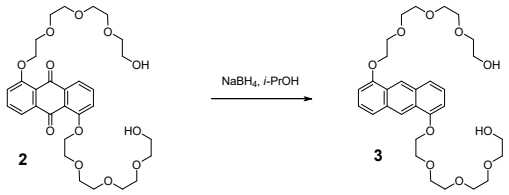


Figure S3. ^{13}C NMR spectrum of **2** ($CDCl_3$, 100 MHz, 25 °C).

Preparation of 3.



A solution of **2** (12 g, 20.3 mmol) in *i*-PrOH (650 mL) was added $NaBH_4$ (15.4 g, 406.0 mmol), then the mixture was stirred at reflux overnight under nitrogen. The reaction was cooled down and neutralized by 0.1 N HCl slowly. The mixture was extracted with CH_2Cl_2 (200 mL × 3) and the combined organic extracts was concentrated under reduced pressure. After dried in vacuum the product **3** was obtained as brownish red oil without further purification (95.5%, 10.9 g). ^1H NMR (400 MHz, $CDCl_3$) δ 8.78 (s, 2H), 7.63 (d, J = 8.5 Hz, 2H), 7.36 – 7.29 (m, 2H), 6.73 (d, J = 7.4 Hz, 2H), 4.41 – 4.32 (m, 4H), 4.08 – 4.03 (m, 4H), 3.88 – 3.79 (m, 4H), 3.74 – 3.71 (m, 4H), 3.69 – 3.62 (m, 12H), 3.58 – 3.52 (m, 4H). ^{13}C NMR (100 MHz,

$CDCl_3$) δ 154.39, 132.18, 125.33, 124.99, 121.29, 120.57, 103.08, 72.5, 70.96, 70.64, 70.30, 69.80, 67.75, 64.29, 61.66, 25.30. HRMS (ESI): *m*/*z*: $[M + H]^+$ cacld for $C_{30}H_{43}O_{10}$: 563.2856; found: 563.2854.

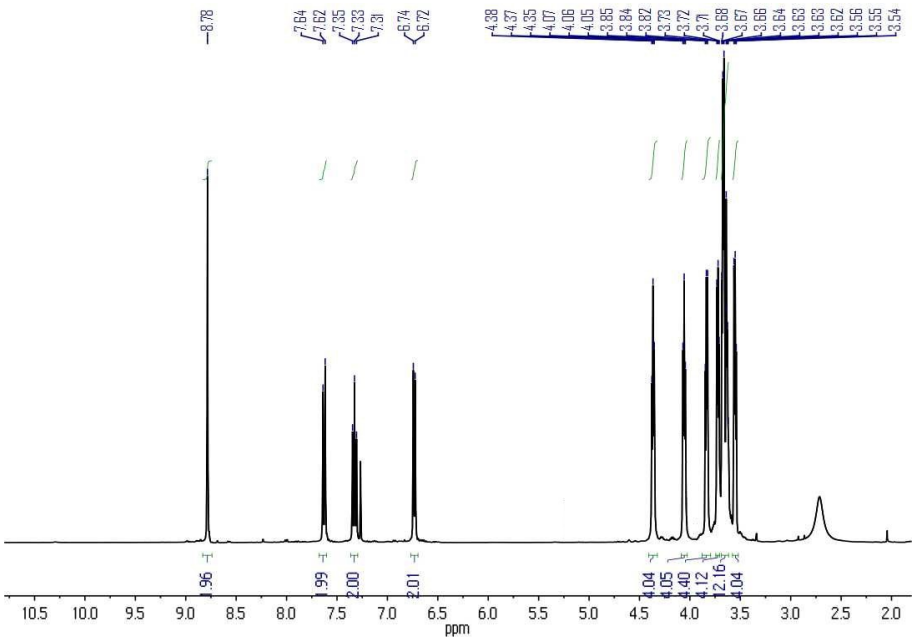


Figure S4. ^{1}H NMR spectrum of **3** ($CDCl_3$, 400 MHz, 25 °C).

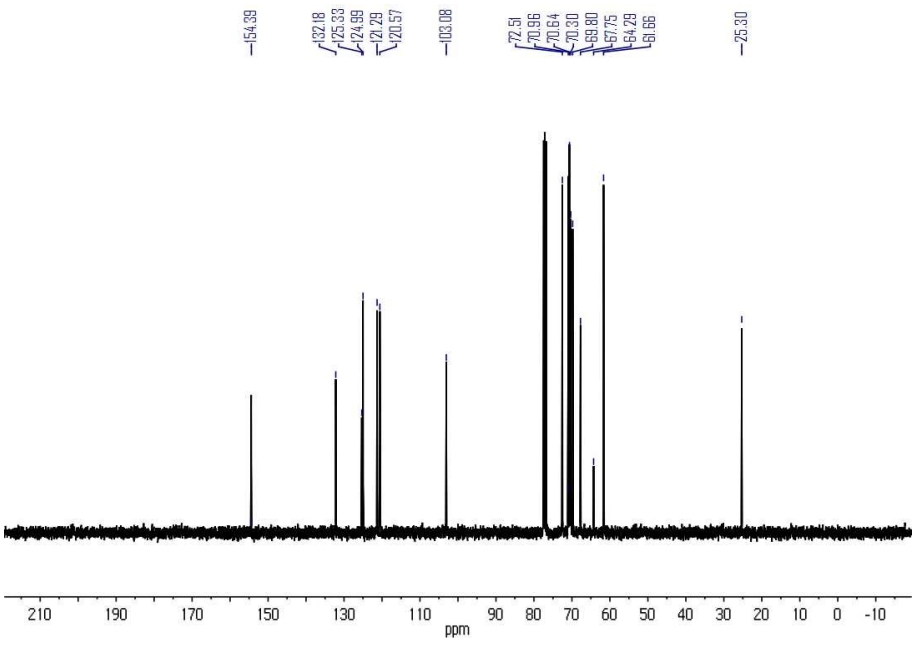
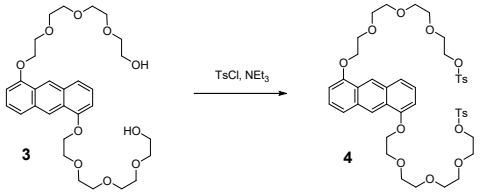


Figure S5. ^{13}C NMR spectrum of **3** ($CDCl_3$, 100 MHz, 25 °C).

Preparation of 4



3 (8.00 g, 14.2 mmol), NEt_3 (8.60 g, 85.2 mmol), and DMAP (20 mg, 0.16 mmol) were dissolved in CH_2Cl_2 (150 mL). A solution of TsCl (8.12 g, 42.6 mmol) in CH_2Cl_2 (100 mL) was added dropwise to this mixture at room temperature. After the addition was complete, the reaction mixture was stirring overlight. It was then washed with HCl solution and brine. The organic phase was dried (Na_2SO_4) and evaporated under reduced pressure. And the reside was subjected to column chromatography (CH_2Cl_2 → EtOAc) to isolate the ditosylate of **4** as red oil (10.70 g, 86.5%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.78 (s, 2H), 7.76 (d, J = 8.2 Hz, 4H), 7.62 (d, J = 8.5 Hz, 2H), 7.34 (d, J = 7.8 Hz, 2H), 7.30 (t, J = 5.8 Hz, 4H), 6.74 (d, J = 7.4 Hz, 2H), 4.38 (t, J = 4.8 Hz, 4H), 4.11 (t, J = 4.8 Hz, 4H), 4.10 – 4.04 (m, 4H), 3.86 – 3.80 (m, 4H), 3.72 – 3.68 (m, 4H), 3.67 – 3.59 (m, 8H), 3.59 – 3.52 (m, 4H), 2.40 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.45, 144.78, 132.99, 132.16, 129.81, 127.94, 125.33, 125.04, 121.26, 120.57, 103.08, 70.94, 70.74, 70.58, 69.81, 69.25, 68.64, 67.79, 21.59. HRMS (ESI): m/z: $[M + Na]^+$ cacld for $C_{44}H_{54}NaO_{14}S_2$: 893.2852; found: 893.2855.

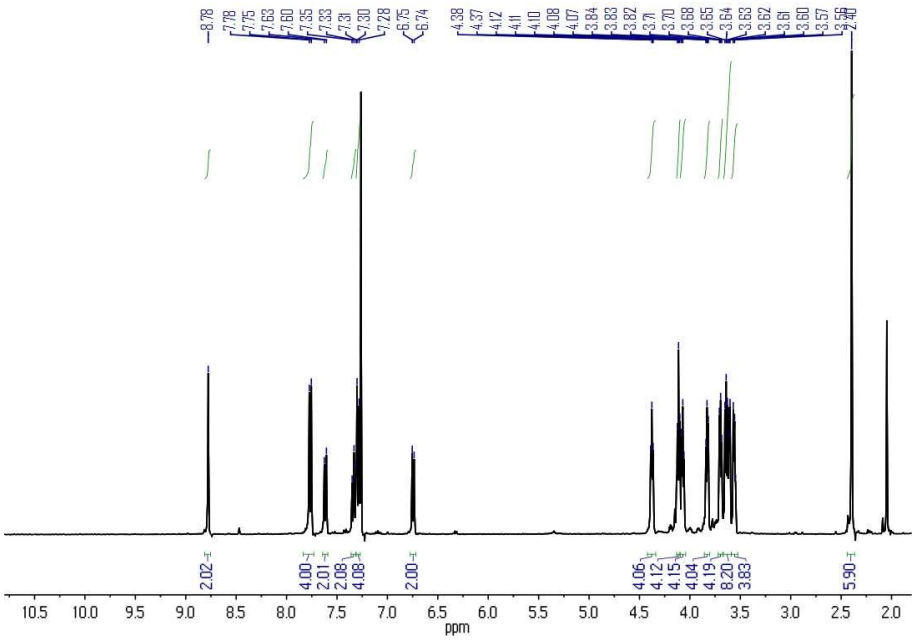


Figure S6. ^{1}H NMR spectrum of **4** ($CDCl_3$, 400 MHz, 25 °C).

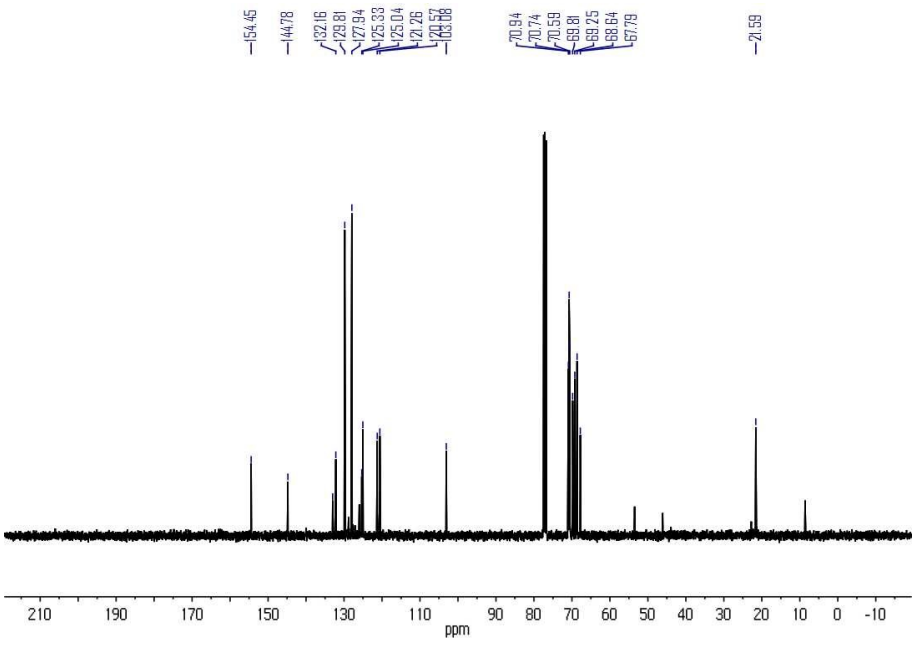
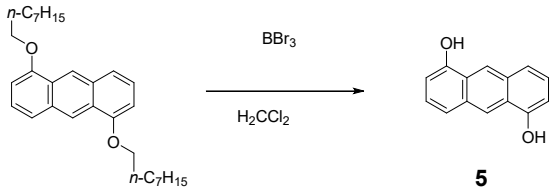


Figure S7. ^{13}C NMR spectrum of **4** ($CDCl_3$, 100 MHz, 25 °C).

Preparation of 5



To a solution of 1,5-di-*n*-octyloxyanthracene[5] (20.00 g, 43.1 mmol) in dry dichloromethane (800 mL) in an ice bath was added boron bromide (16.30 mL, 86.2 mmol). After stirring at room temperature overnight, the reaction mixture was poured into ice and vigorously stirred for another 1 h, then the mixture was filtrated, washed with water and dichloromethane. The filter residue was dried in vacuum to yield a green solid product (7.48 g, 82.6%). ^{1}H NMR (400 MHz, [d6]-DMSO) δ 8.67 (s, 2H), 7.56 (d, J = 8.5 Hz, 2H), 7.28 (t, J = 7.9 Hz, 2H), 6.82 (d, J = 7.2 Hz, 2H). ^{13}C NMR (100 MHz, [d6]-DMSO) δ 153.45, 132.24, 126.07, 125.0, 120.66, 119.58, 106.20. HRMS (ESI): m/z: $[M + H]^+$ cacld for $C_{14}H_{11}O_2$: 211.0759; found: 211.0763

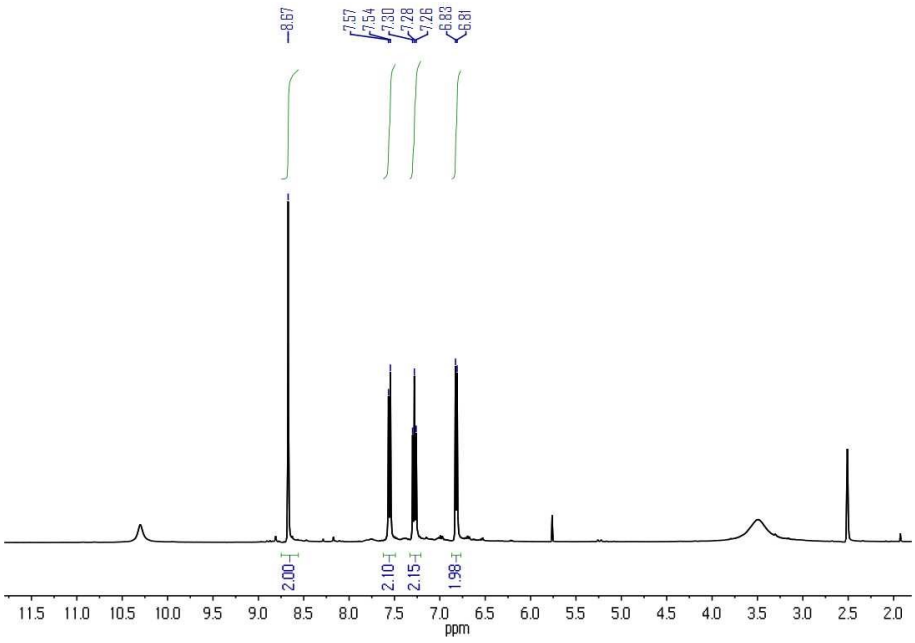


Figure S8. ^{1}H NMR spectrum of **5** ([D_6]-DMSO, 400 MHz, 25 °C).

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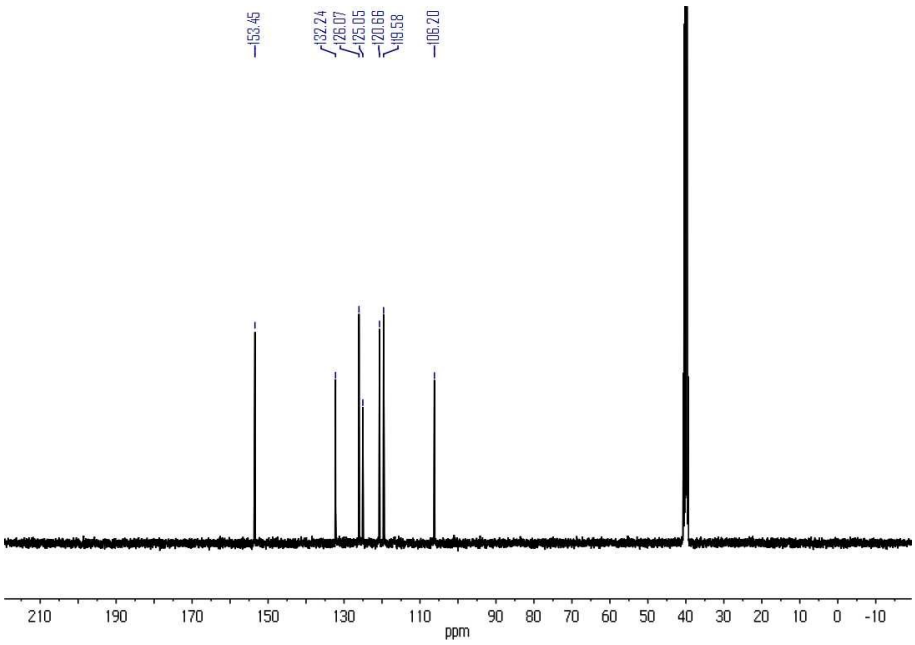
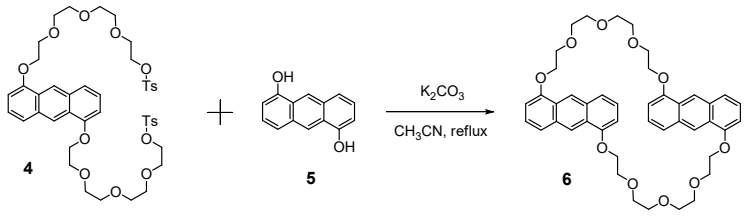


Figure S9. ^{13}C NMR spectrum of **5** ([D_6]-DMSO, 100 MHz, 25 °C).

Preparation of 6:



A mixture of **4** (10.00 g, 11.5 mmol) and **5** (2.41 g, 11.5 mmol) in DMF/MeCN (V/V = 1/3, 250 mL) was added simutaneously under nitrogen atmosphere over a period of 6 h to a stirred suspension of K_2CO_3 (6.35 g, 46.0 mol) and NaI (0.3 g, 2 mmol) in MeCN (100 mL) heated at reflux. The mixture was refluxed for additional 2 days and then cooled to room temperature. Then the mixture was filtered and washed with CHCl3. The filtrate was combined and evaporated under reduced pressure. The dark brown residue was subjected to column chromatographed over flash silica gel using

EtOAc and a brown solid was obtained. After recrystallizing from $CHCl_3$/MeOH (V/V = 1/4) the product **6** was afforded as a yellow powder (1.88 g, 22.2 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (s, 4H), 7.34 (d, J = 8.5 Hz, 4H), 7.03 – 6.98 (m, 4H), 6.24 (d, J = 7.4 Hz, 4H), 3.94 – 3.89 (m, 9H), 3.85 – 3.79 (m, 8H), 3.68 (dd, J = 6.5, 1.8 Hz, 16H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.15, 131.93, 125.05, 124.67, 121.03, 120.29, 102.65, 70.94, 69.70, 67.45. HRMS (ESI): m/z: $[M + NH_4]^+$ cacld for $C_{44}H_{51}NO_{10}$: 754.3591; found: 754.3583.

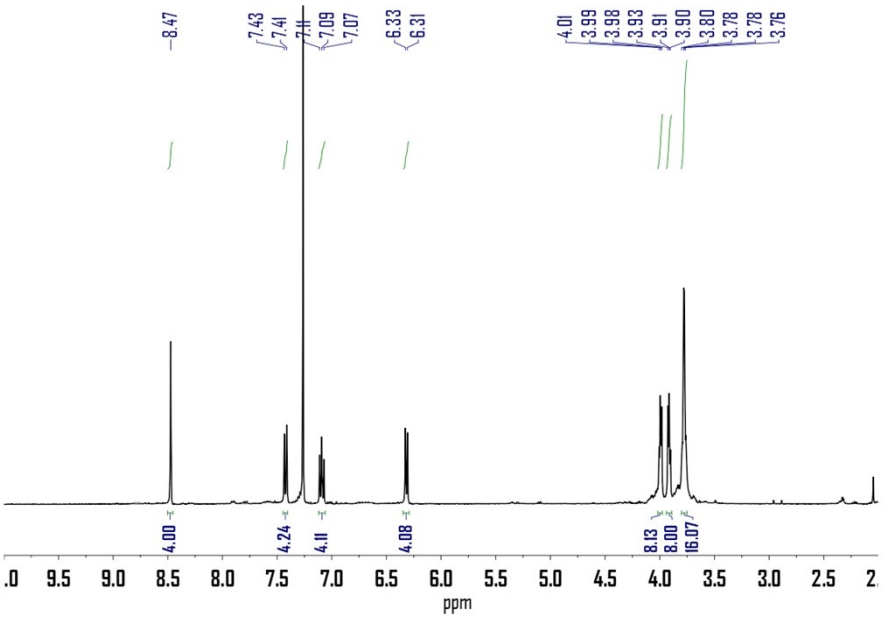


Figure S10. ^{1}H NMR spectrum of **6** ($CDCl_3$, 400 MHz, 25 °C).

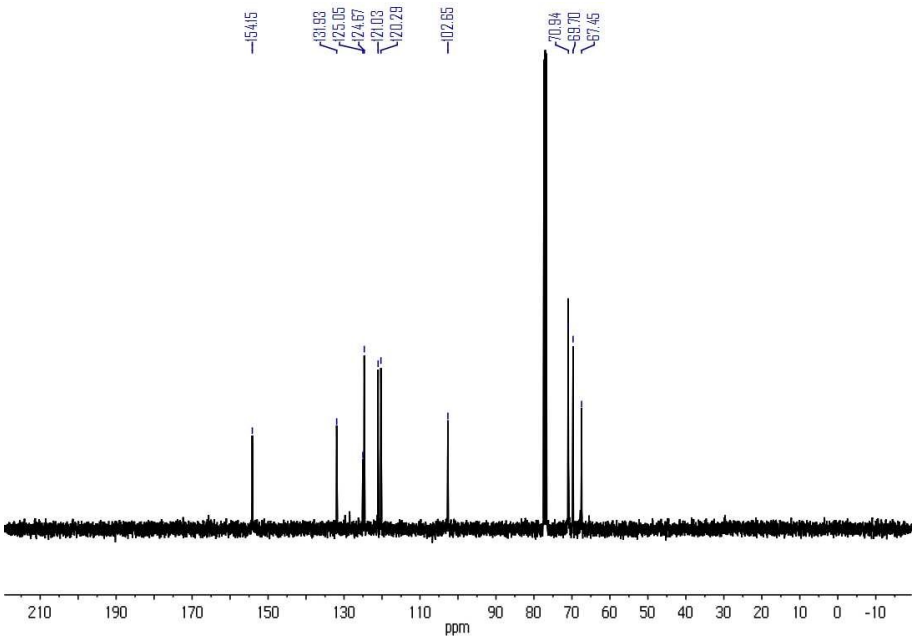
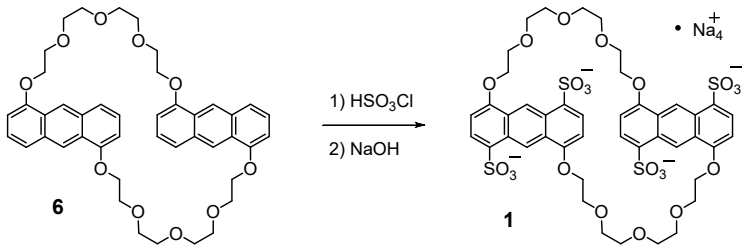


Figure S11. ^{13}C NMR spectrum of **6** ($CDCl_3$, 100 MHz, 25 °C).

Preparation of 1:



A solution of chlorosulfonic acid (0.65 g, 5.58 mmol) in dry CH_2Cl_2 (50 mL) was added dropwise over a period of 0.5 h to a stirred solution of **6** (1.0 g, 1.36 mmol) in dry CH_2Cl_2 (100 mL) at 0 °C. Then the mixture was stirred at 0 °C for an additional 1 h to give a green precipitate. The precipitate was carefully collected by filtration and washed with dry CH_2Cl_2 (30 mL). The reside was taken up into H_2O (100 mL), and NaOH solution was added until pH = 7. The solvate was evaporated and dried by vacuum. After recrystallizing from alcohol−water for several times and drying by vacuum, **1** was afforded as white solid that absorbs moisture in the air (1.36 g, 87.4%):

^{1}H NMR (400 MHz, D_2O) δ 9.46 (s, 4H), 8.04 (d, J = 8.0 Hz, 4H), 6.60 (d, J = 8.1 Hz, 4H), 3.85 (s, 8H), 3.60 (s, 8H), 3.38 (dd, J = 17.6, 4.5 Hz, 16H). ^{13}C NMR (100 MHz, D_2O) δ 156.54, 130.76, 128.93, 127.71, 123.70, 101.39, 69.85, 69.43, 68.55, 67.71. HRMS (ESI): m/z: [M - Na]$^-$ cacld for $C_{44}H_{44}Na\ O_{22}S_4$: 1121.0900; found: 1121.0896. Elemental analysis: calcd (%) for $(C_{44}H_{44}O_{22}S_4Na_4)\cdot(H_2O)_6$: C 42.17, H 4.50; found C 41.86, H 4.41.

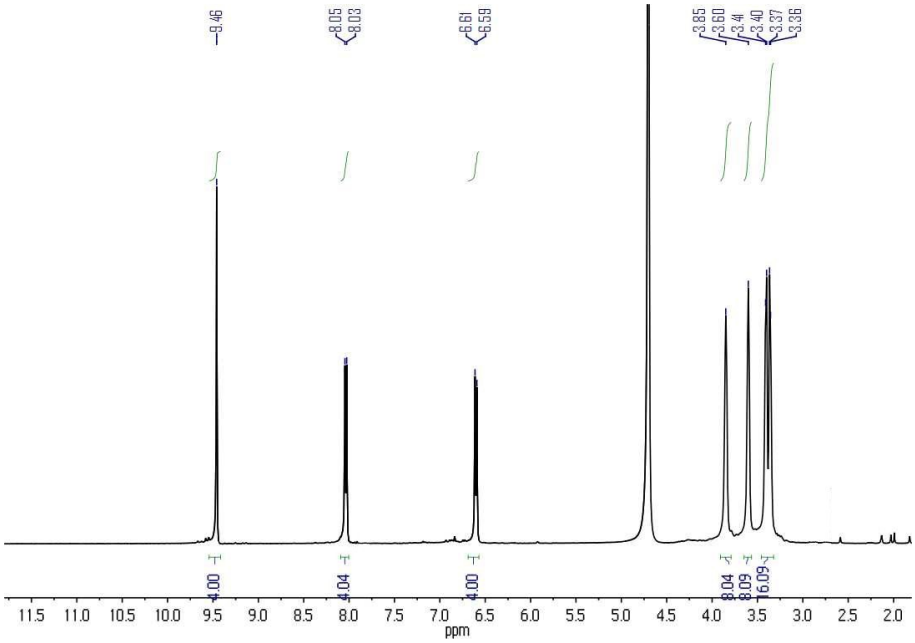


Figure S12. ^{1}H NMR spectrum of **1** (D_2O, 400 MHz, 25 °C).

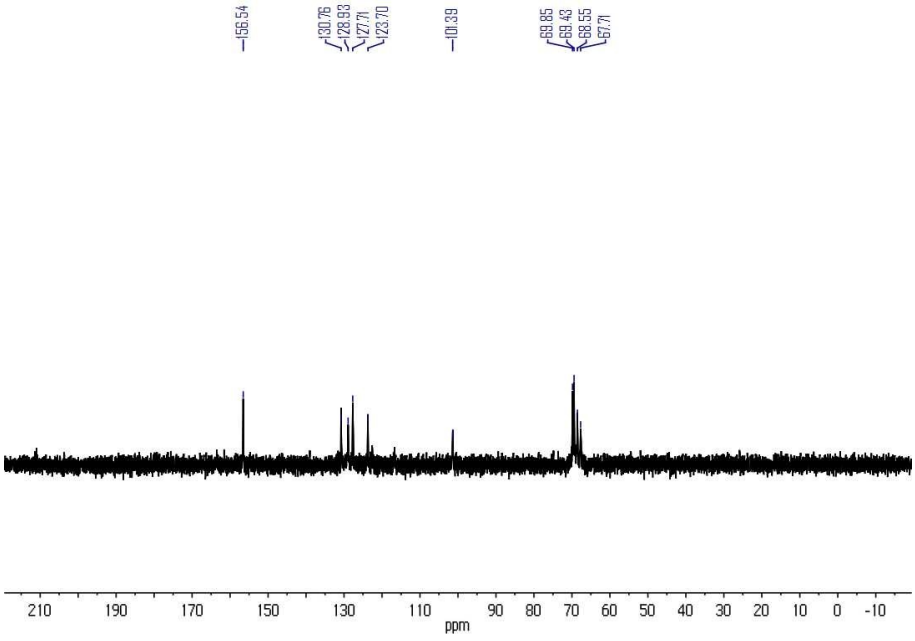
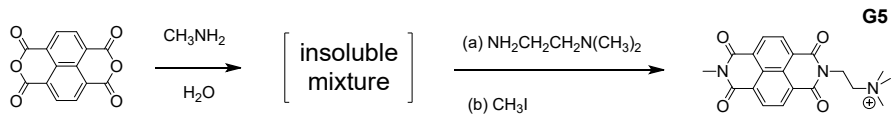


Figure S13. ^{13}C NMR spectrum of **1** (D_2O, 100 MHz, 25 °C).

Preparation of G5·Cl



1,4,5,8-naphthalenetetracarboxylic acid dianhydride (4.00 g, 14.90 mmol) was suspended in water (600 mL) followed by slowly adding aqueous KOH solution (1 M, 70 mL) until all the solid dissolved (pH = 11 – 12). The solution was carefully acidified to 6.4 by adding H_3PO_4 (1 M). To this solution, methylamine (1 M) was slowly added and then 1 M H_3PO_4 was added to reajust pH to 6.4. The mixture was heated to reflux for 48 h. After cooling to room temperature, the solution was filtered. Acetic acid (30 mL) was added and white precipitate formed at once. After filtration and drying under vacuum, white solid was obtained (3.25 g) which speculated to be a mixture containing about 40 percentage of N-methyl-1,8-naphthalene imide-4,5-dicarboxylic acid anhydride.

The white solid was suspended in a solution of N,N-dimethylethylamine (0.36 g, 11.56 mmol) in DMF (300 mL). The reaction mixture was refluxed for 6 h, and iodomethane (7.1 g, 50 mmol) was added and refluxed for another 2 h. After cooling to room temperature, the mixture was concentrated to 80 mL. NH_4PF_6 solution (1 M, 100 mL) and water (900 mL) was added to precipitate **G5·PF$_6$** as gray solid. An anion exchanging process was implemented to **G5**·PF_6 as following. That is, the gray solid was filtrated and dissolved in MeCN (50 mL), tetrabutylammonium chloride (2.8 g, 10.00 mmol) was added to give a precipitate which was filtered and washed with CH_3CN. After filtration and dried under vacumm, **G5·Cl** was obtained as pale brown solid (1.26 g, 21% yield). ^{1}H NMR (400 MHz, D_2O) δ 8.48 (d, *J* = 7.6 Hz, 2H), 8.36 (d, *J* = 7.6 Hz, 2H), 4.64 – 4.53 (t, 2H), 3.71 – 3.60 (t, 2H), 3.32 (d, 12H). ^{13}C NMR (100 MHz, D_2O) δ 162.9, 131.27, 130.94, 125.15, 61.91, 53.54, 34.44, 27.05. HRMS (ESI): *m*/*z*: $[M - Cl]^+$ cacld for $C_{20}H_{20}N_3O_4$: 366.1453; found: 366.1449.

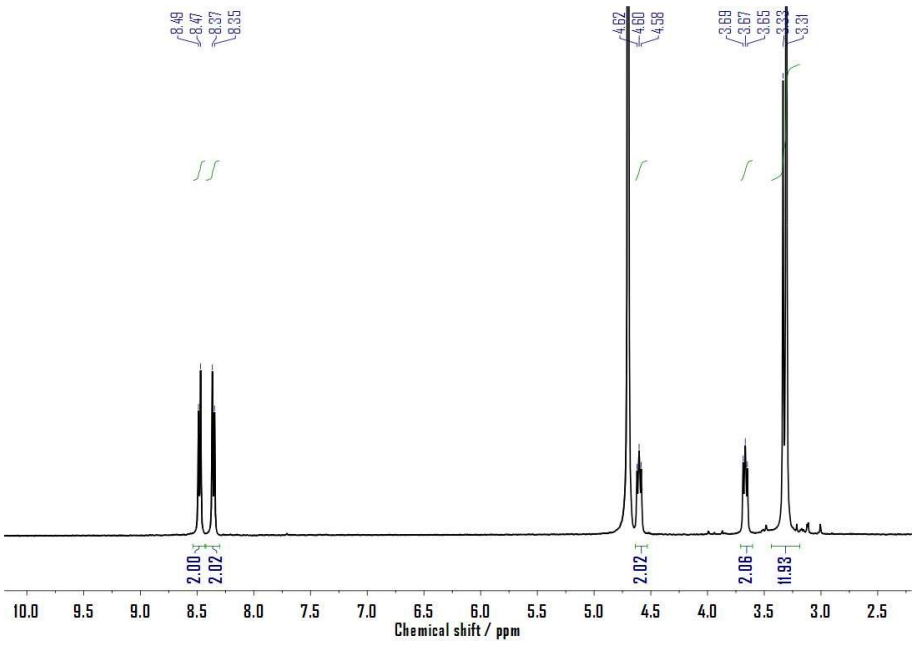


Figure S14. ^{1}H NMR spectrum of **G5·Cl** (D_2O, 400 MHz, 25 °C).

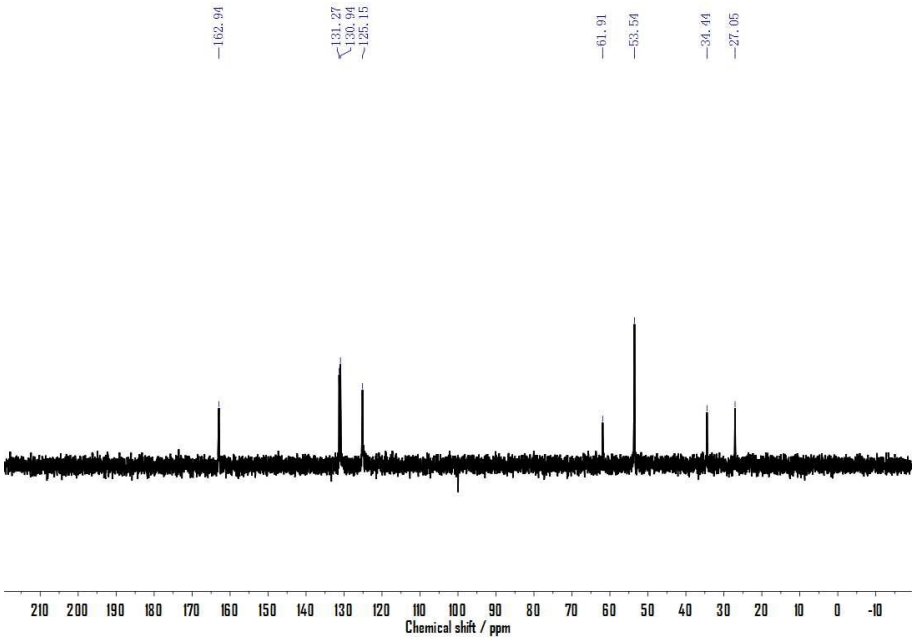


Figure S15. ^{13}C NMR spectrum of **G5·Cl** (D_2O, 100 MHz, 25 °C).

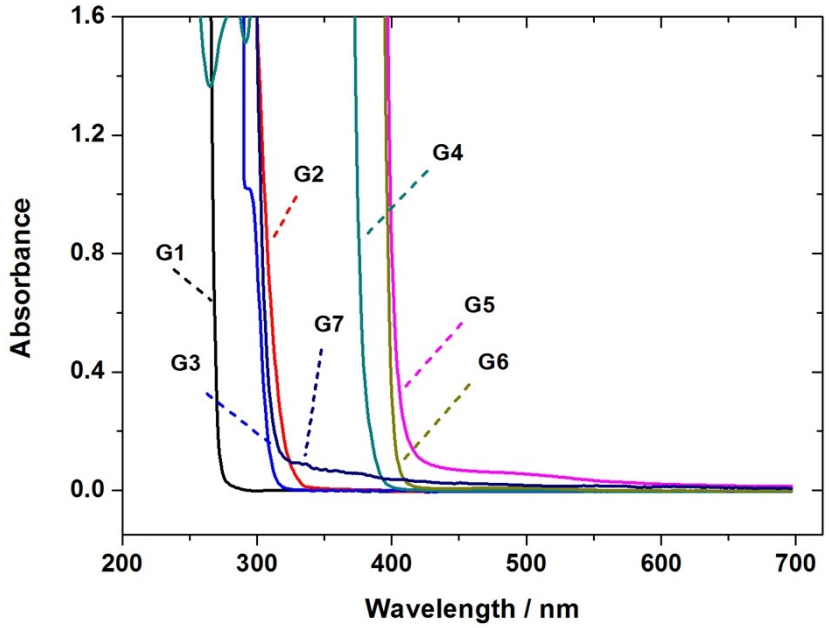


Figure S16. UV–vis spectra of **G1** – **G7** (1 mM) in aqueous solution.

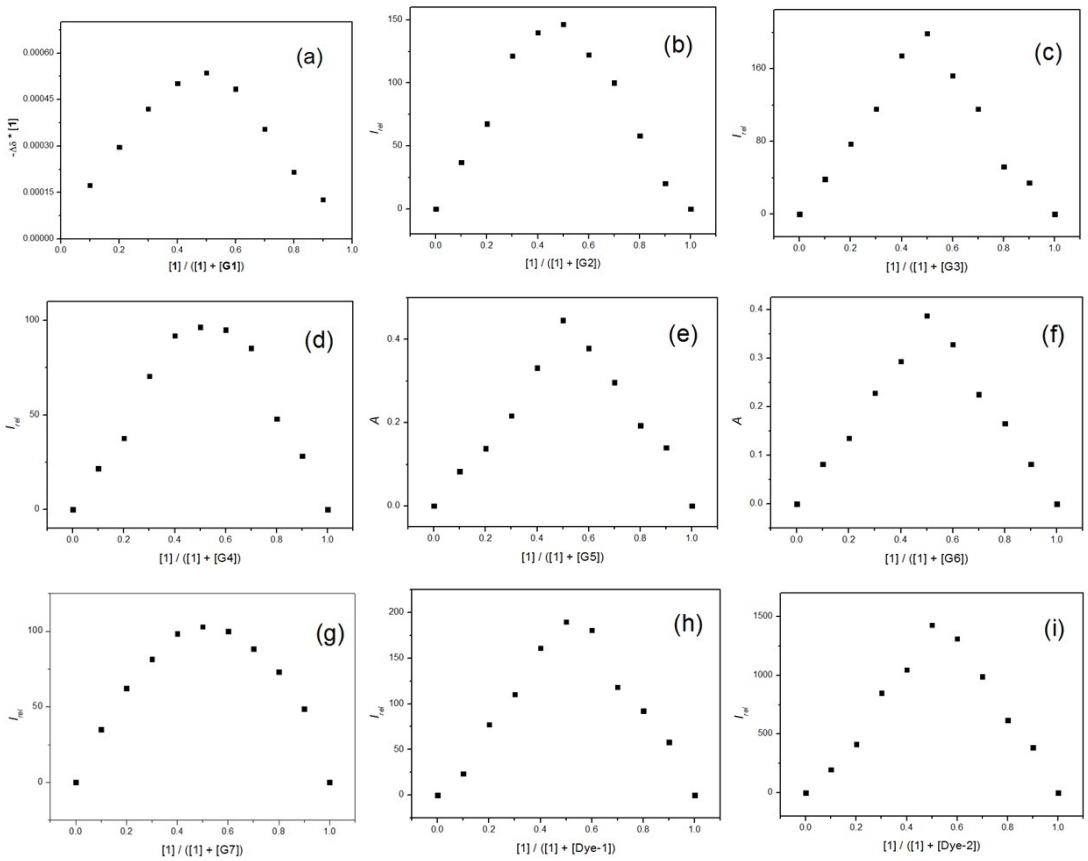
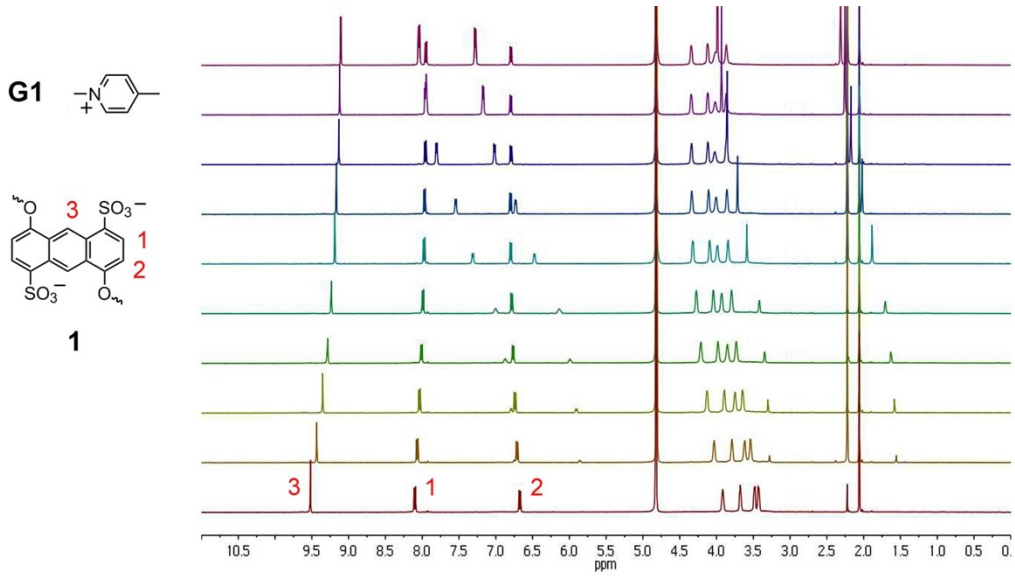


Figure S17. Job plot analyses for the host **1** with guest **G1**–**G7** (a–g), **Dye-1** (h) and **Dye-2** (i).



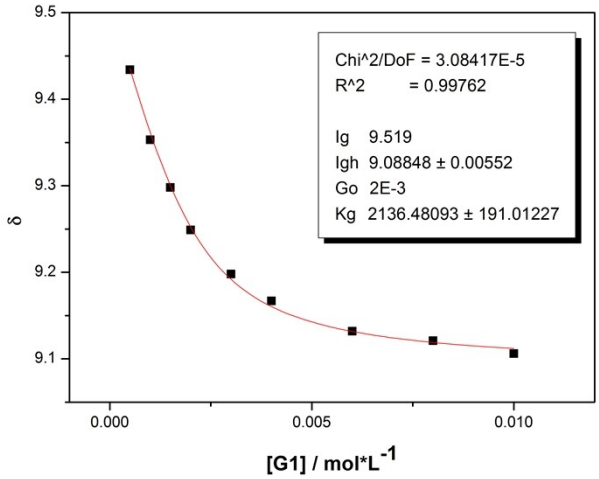


Figure S18. ^{1}H NMR titration of **G1⊂1** in D_2O. Top: The ^{1}H NMR spectral changes of **1** (2.0 mM) upon addition of **G1** (0 – 10.0 mM); bottom: nonlinear curve-fitting of δ_{H3}.

Fluorescence titration spectra of two dyes (Dye-1, Dye-2) with hosts 1

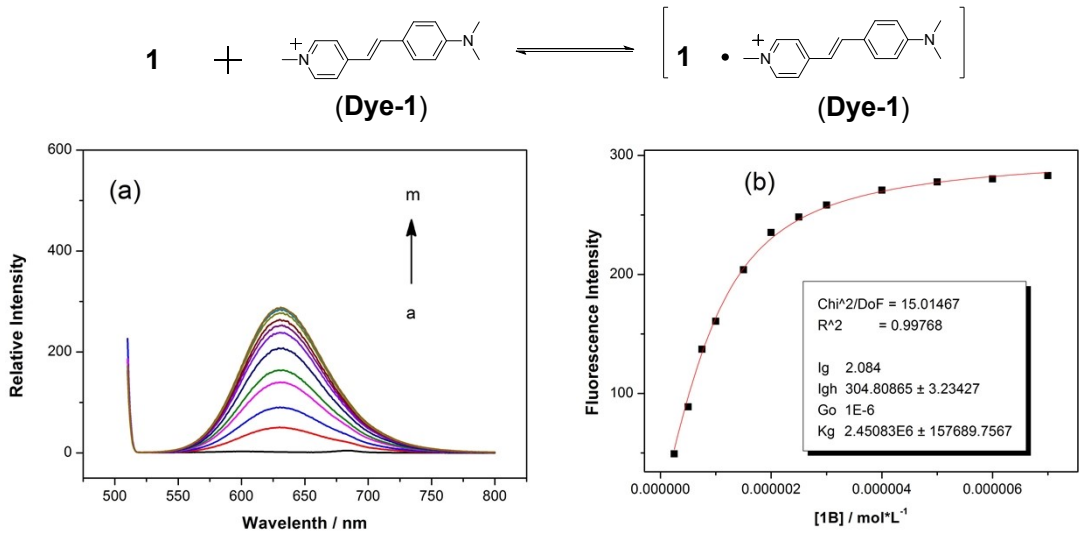


Figure S19. (a) Fluorescence titration spectra for **Dye-1** upon sequential addition of **1** ([**Dye-1**] = 0.001 mM, [**1**] = 0 – 0.007 mM); (b) nonlinear curve-fitting of fluorescence changes at 630 nm.

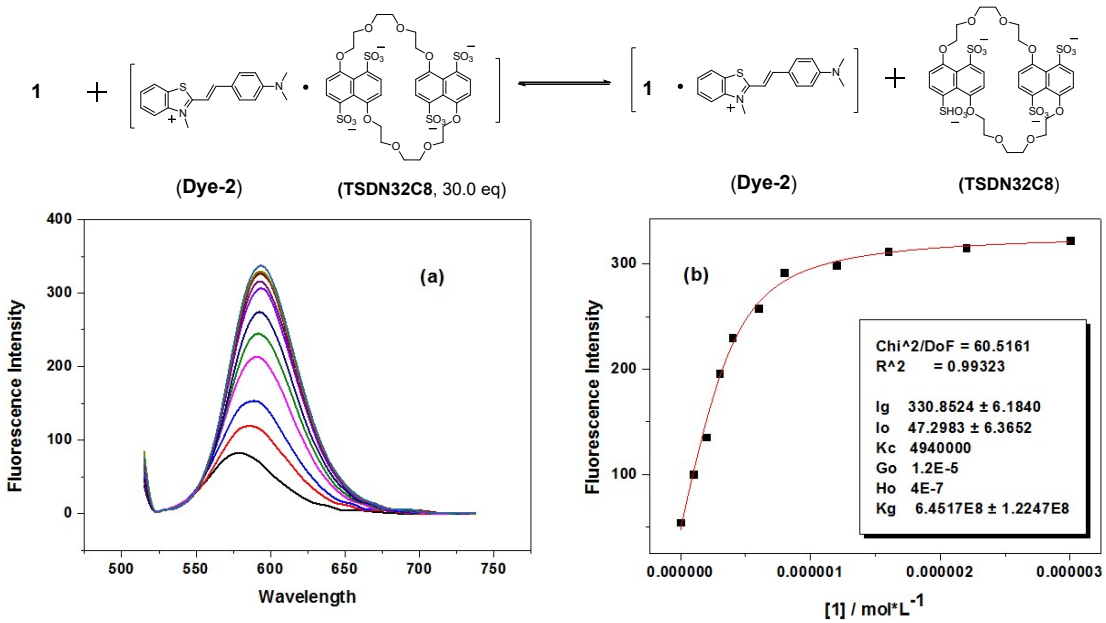


Figure S20. (a) Competitive fluorescence titration spectra of **Dye-2⊂TSDN32C8** upon sequential addition of **1** ([**Dye-2**] = 0.0004 mM, [**TSDN32C8**] = 0.012 mM, [**1**] = 0 – 0.003 mM); (b) nonlinear curve-fitting of fluorescence changes at 600 nm.

Fluorescence titration spectra of G2 – G7 with host 1

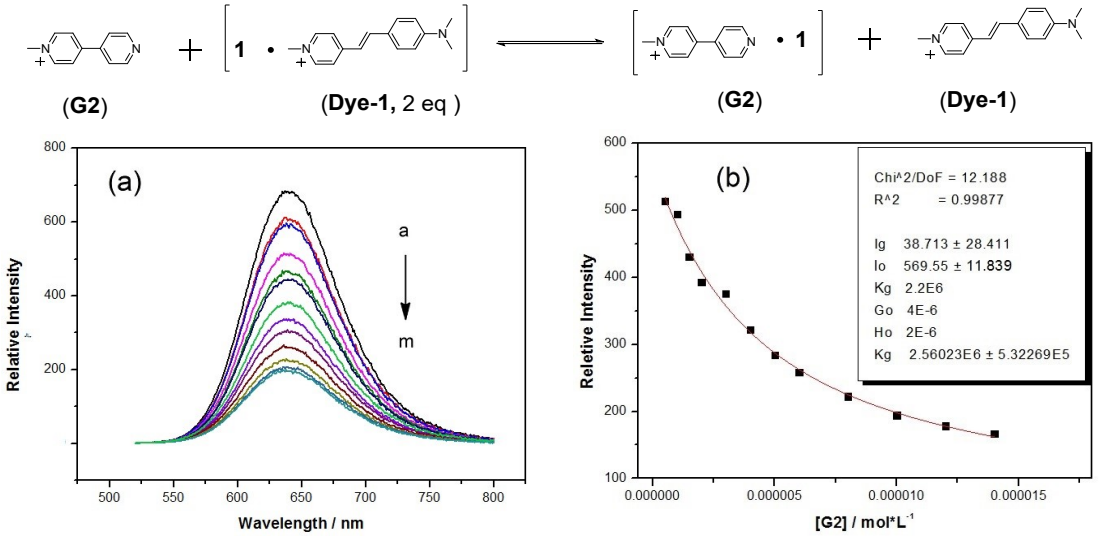


Figure S21. (a) Competitive fluorescence titration spectra for **Dye-1⊂1** upon sequential addition of **G2** ([**1**] = 0.002 mM, [**Dye-1**] = 0.004 mM, [**G2**] = 0 – 0.014 mM); (b) nonlinear curve-fitting of fluorescence changes at 630 nm.

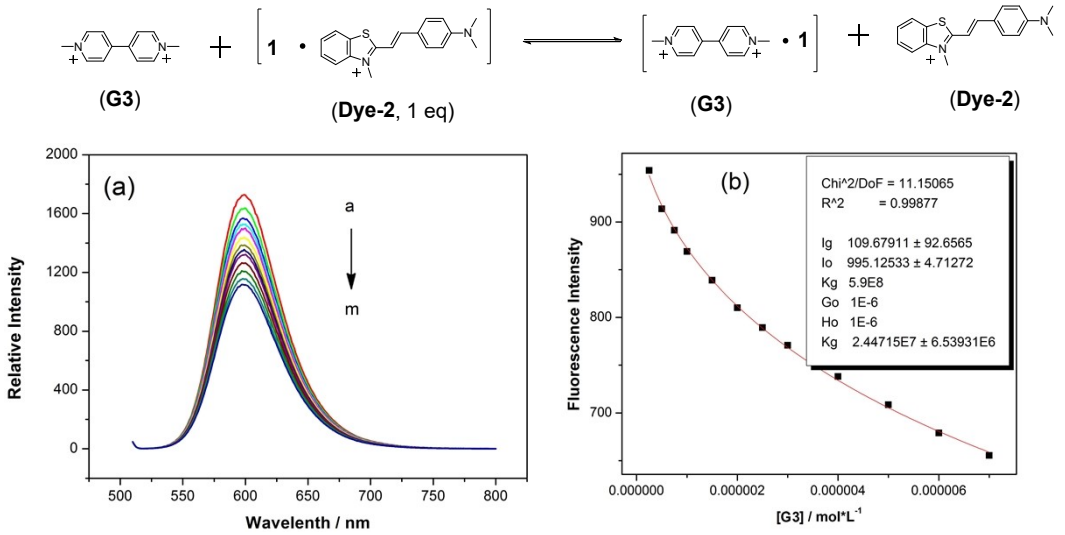


Figure S22. (a) Competitive fluorescence titration spectra of **Dye-2⊂1** upon sequential addition of **G5** ([**1**] = 0.001 mM, [**Dye-2**] = 0.001 mM, [**G3**] = 0 – 0.007 mM); (b) nonlinear curve-fitting of fluorescence changes at 630 nm.

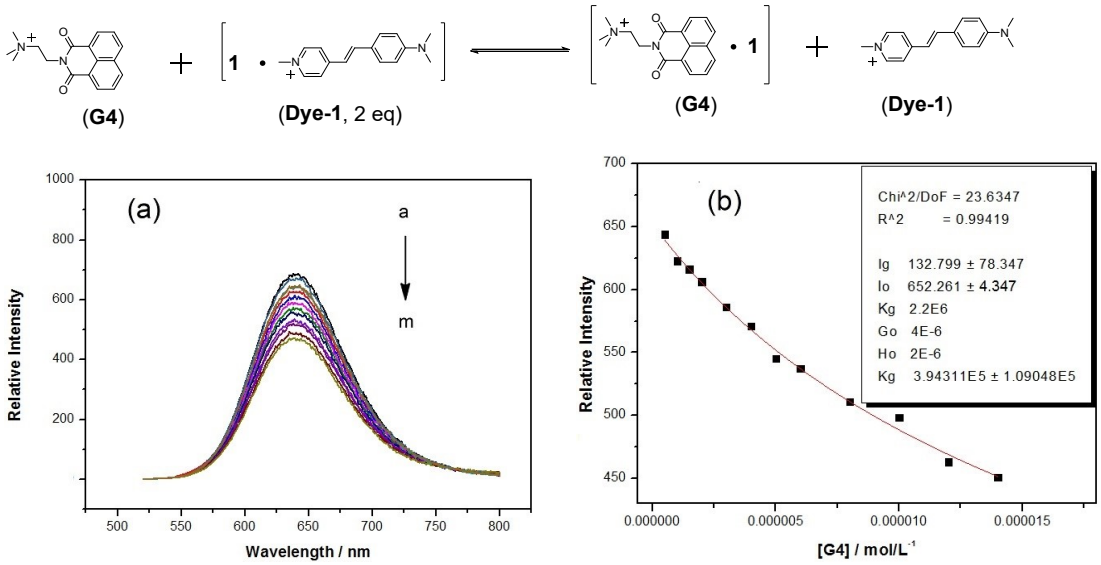


Figure S23. (a) Competitive fluorescence titration spectra of **Dye-1⊂1** upon sequential addition of **G4** ([**1**] = 0.002 mM, [**Dye-1**] = 0.004 mM, [**G4**] = 0 – 0.014 mM); (b) nonlinear curve-fitting of fluorescence changes at 630 nm.

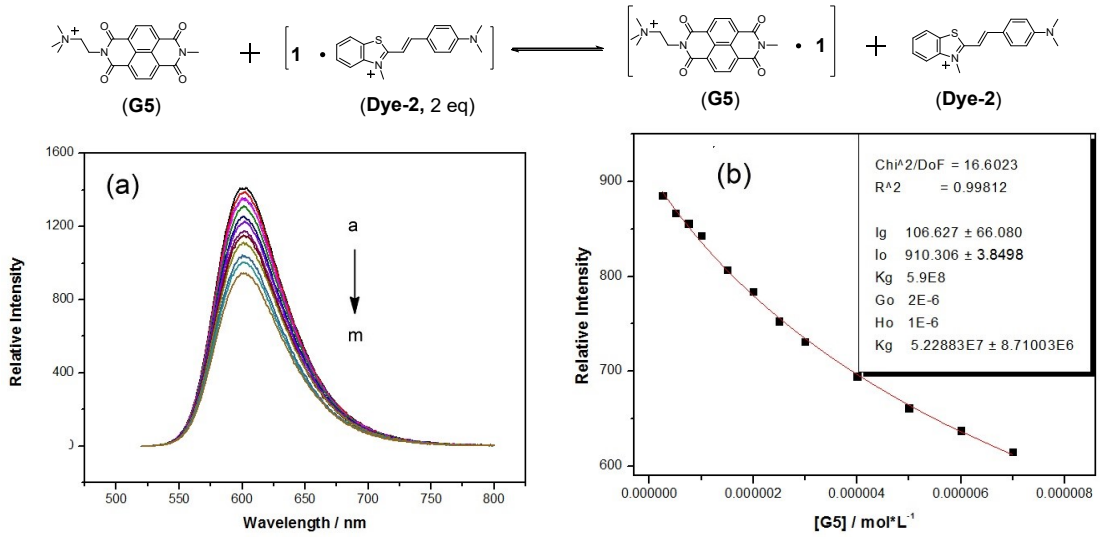


Figure S24. (a) Competitive fluorescence titration spectra of **Dye-2⊂1** upon sequential addition of **G5** ([**1**] = 0.001 mM, [**Dye-2**] = 0.002 mM, [**G5**] = 0 – 0.007 mM); (b) nonlinear curve-fitting of fluorescence changes at 630 nm.

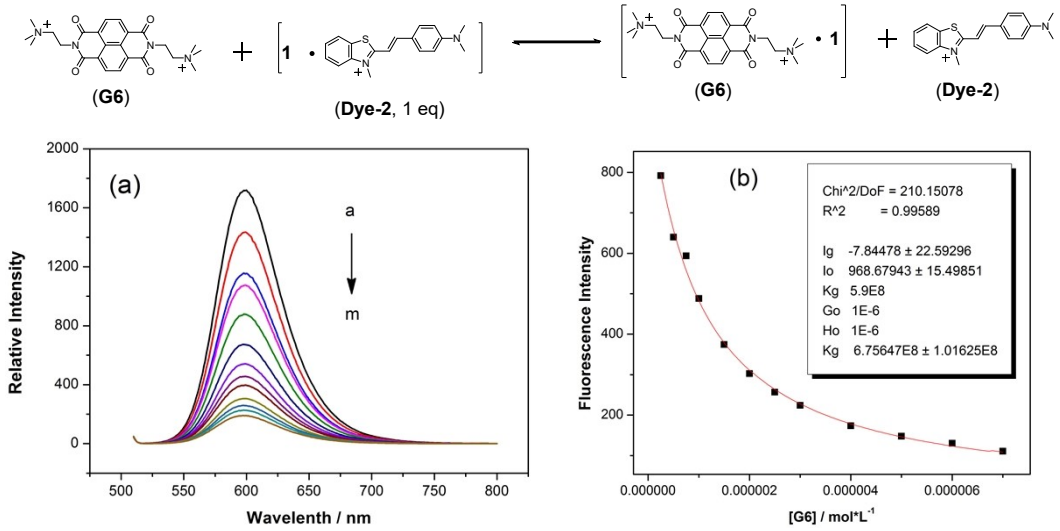


Figure S25. Competitive fluorescence titration spectra of (a) **Dye-2⊂1** upon sequential addition of **G6** ([**Dye-2**] = 0.001 mM, [**1**] = 0.001 mM, [**G6**] = 0 – 0.007 mM) and (b) nonlinear curve-fitting of fluorescence changes at 630 nm.

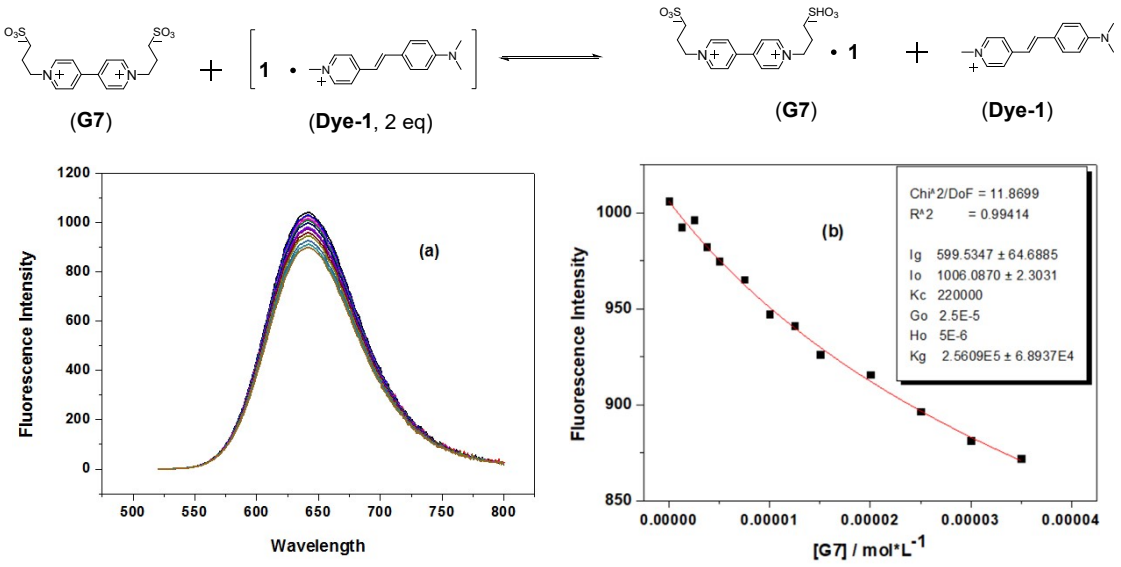


Figure S26. Competitive fluorescence titration spectra of (a) **Dye-1⊂1** upon sequential addition of **G7** ([**Dye-1**] = 0.010 mM, [**1**] = 0.005 mM, [**G7**] = 0 – 0.07 mM) and (b) nonlinear curve-fitting of fluorescence changes at 650 nm.