Electronic Supplementary Material (ESI) for Chemical Communications

A C_{84} Selective Porphyrin Macrocycle with an Adaptable Cavity Constructed through Alkyne Metathesis

Chenxi Zhang,[a] *Hai Long,*[b] *Wei Zhang*[a,]*

[a]*Department of Chemistry and Biochemistry, University of Colorado, Boulder, CO 80309, USA*

[b]*National Renewable Energy Laboratory, Golden, CO 80401, USA*

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Materials and general synthetic methods

Reagents and solvents were purchased from commercial suppliers and used without further purification, unless otherwise indicated. Tetrahydrofuran (THF), toluene, CH_2Cl_2 and dimethylformamide (DMF) are purified by the MBRAUN solvent purification systems. 3-Formyl-*N*-hexadecyl-6-iodo-carbazole (**3**) and 4-benzoyl-4'-ethynylbiphenyl were synthesized following the reported procedures.[1]

All reactions were conducted under dry nitrogen in oven-dried glassware, unless otherwise specified. Solvents were evaporated using a rotary evaporator after workup. Unless otherwise specified, the purity of the compounds was $\geqslant$ 95 % based on ^{1}H NMR spectral integration.

Flash column chromatography was performed by using a 100-150 times weight excess of flash silica gel 32-63 μm from Dynamic Absorbants Inc. Fractions were analyzed by TLC using TLC silica gel F254 250 μm precoated-plates from Dynamic Absorbants Inc. Analytical gel permeation chromatography (GPC) was performed using a Viscotek GPCmaxTM, a Viscotek Model 3580 Differential Refractive Index (RI) Detector, a Viscotek Model 3210 UV/VIS Detector and a set of two Viscotek Viscogel columns (7.8 × 30 cm, l- MBLMW-3078, and l-MBMMW-3078 columns) with THF as the eluent at 30 °C. The analytical GPC was calibrated using monodisperse polystyrene standards. UV-Vis absorption measurements were carried out with Agilent 8453 spectrophotometer.

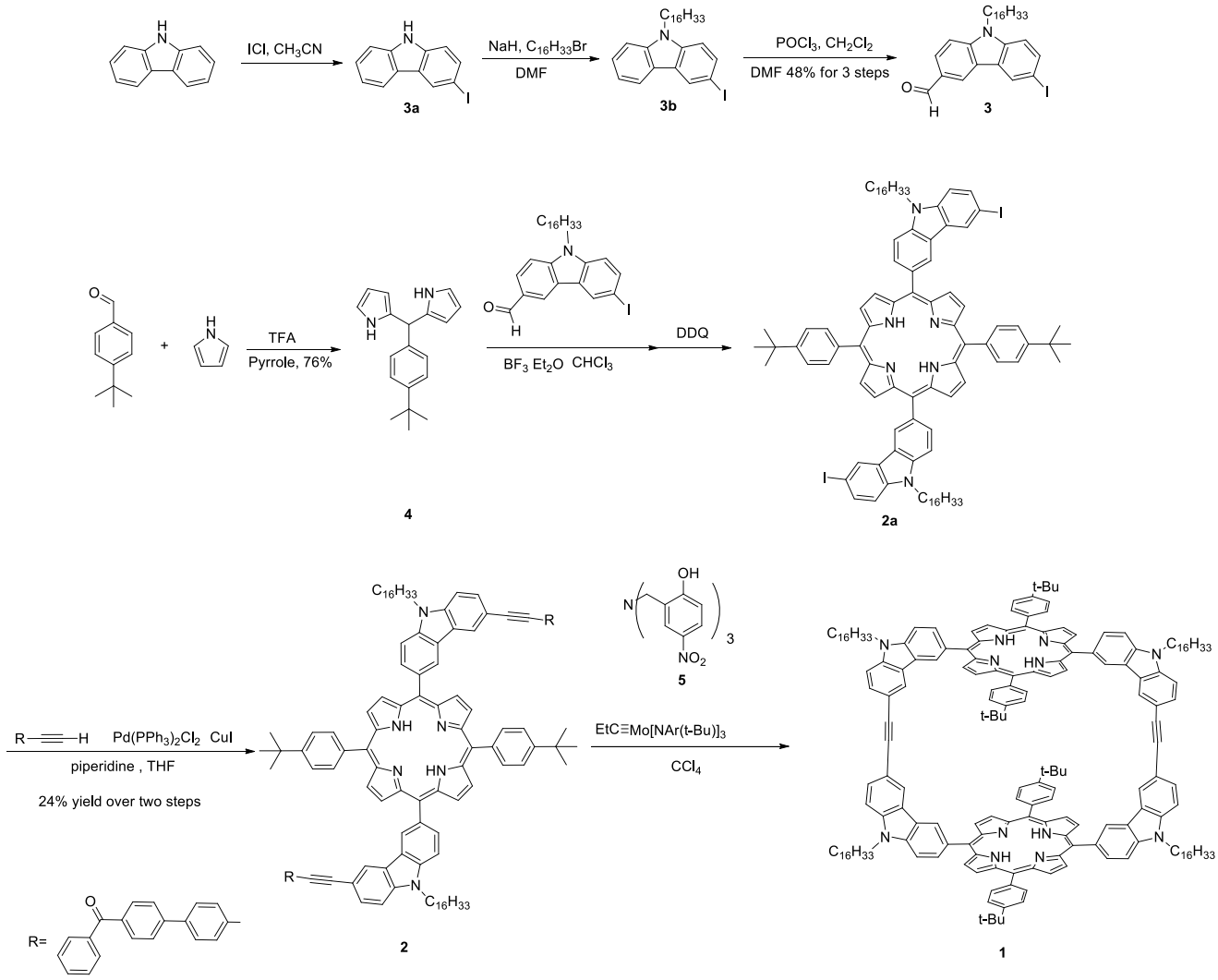
MALDI Mass spectra were obtained on the Voyager-DE™ STR Biospectrometry Workstation using 2,5-dihydroxybenzoic acid (DHB) as the matrix. The high-resolution Mass spectra were obtained on Waters SYNAPT G2 High Definition Mass Spectrometry System. Analyte molecules were diluted into ESI solvents, either methanol or acetonitrile/water mixture, for final concentrations of 10 ppm or lower. The solution was injected into the electrospray ionization (ESI) source at a rate of 5 μL/min. Either the ESI+ or ESI- mode was used in reference to the molecular properties. Accurate mass analysis was performed by using the Lock Mass calibration feature with the instrument.

NMR spectra were taken on Inova 400 and Inova 500 spectrometers. $CHCl_3$ (7.27 ppm), toluene (2.09 ppm) were used as internal references in ^1H NMR, and $CHCl_3$ (77.23 ppm) for ^{13}C NMR. ^1H NMR data were reported in order: chemical shift, multiplicity (s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet), coupling constants (J, Hz), number of protons.

The Amber 11.0 molecular dynamics program package[2] was used to optimize the structure of the fullerene, the cage and the cage/fullerene binding complexes. The force field used was the general Amber force field (GAFF field)[3] with the charge parameters computed by AM1-BCC method.[4] For each structure optimization run, the molecule was first minimized for 1000 steps using the conjugate gradient method, and then it was further optimized by simulated annealing method for 150 picosecond with a time-step of 1 femtosecond. During the simulated annealing, the system temperature was first raised up to 1000 K for 50 picosecond and then gradually cooled to 0 K for another 100 picosecond. Finally, the annealed structure was minimized again for another 1000 conjugate gradient steps and the final energy was recorded. The non-bonded interactions during the simulation were computed directly with a cutoff distance of 25 Å. A dielectric constant of 4.8 was assumed during the simulation, which is a typical value for organic solvents.

Experimental procedures

Reaction schemes:



3-Formyl-N-hexadecyl-6-iodo-carbazole (Compound 3): To a mixture of carbazole (5.00 g, 30 mmol) dispersed in CH_3CN (250 mL), ICl (1.88 mL, 36 mmol) was added slowly at 0 ^oC. The reaction was stirred in ice bath for 2 h, then slowly warmed up to room temperature and stirred for another 2 h. The reaction was quenched with aqueous Na_2SO_3. The mixture was extracted with CH_2Cl_2 (80 mL×3). The organic extracts were combined and the volatiles were removed. The crude product was collected as a white solid. (~60 % yield was determined by crude NMR integration.), and was used in the next step

without further purification. The crude 3-iodocarbazole (**3a**) was dissolved in DMF (100 mL). NaH (1.80 g, 45 mmol, 60 % dispersion in mineral oil) was added to the reaction mixture and stirred for 5 min at room temperature. Then 1-bromohexadecane (13.7 g, 45 mmol) was added and stirred for 4 h at room temperature. After completion of the reaction, the solvent was removed and the product was washed with HCl (1M, 100 mL). Extraction with CH_2Cl_2 (80 mL×3) followed by purification via flash column chromatography (CH_2Cl_2/Hexane, 1/3, v/v) provided *N*-hexadecyl-3-iodo-carbazole **(3b)** as a white solid. To a mixture of DMF (47 mL, 0.60 mol) and 1,2-dichloroethane (50 mL) was added $POCl_3$ (47.5 mL, 0.51 mol) dropwise at 0 ^oC. The mixture was then heated to 35 ^oC while *N*-hexadecyl-3-iodo-carbazole (**3b**) was added. After stirring for 24 h at 90 ^oC, the mixture was cooled to room temperature, then poured to water (500 mL). The product was extracted with chloroform (150 mL×3), dried over $MgSO_4$ and concentrated. The crude product was purified via flash column chromatography (CH_2Cl_2/Hexane, 1/1, v/v) to provide the pure compound **3** as a white solid (7.85 g, 48 %): ^1H NMR (500 MHz, $CDCl_3$): δ 10.08 (s, 1H), 8.51 (d, J =1.5 Hz, 1H), 8.44 (d, J =1.5 Hz, 1H), 8.03 (dd, J_1= 8.5 Hz, J_2=1.5 Hz, 1H), 7.77 (dd, J_1= 8.5 Hz, J_2=1.5Hz, 1H), 7.46 (d, J = 8.5 Hz, 1H), 7.22 (d, J = 8.5 Hz, 1H), 4.29 (t, J = 7.0 Hz, 2H), 1.85 (m, 2H), 1.39-1.21 (m, 26H), 0.89 (t, J =7.0 Hz, 3H). The spectroscopic data are consistent with those previously reported.[1]

Compound 4: To a solution of 4-*tert*-butylbenzaldehyde (0.81 g, 5.0 mmol) in pyrrole (15 mL) was added catalytic amount of TFA (0.57 g, 0.50 mmol). The mixture was stirred at rt for 15 min. Upon completion of the reaction, dilute NaOH solution (1 M, 15 mL) was added to quench the reaction. The product was extracted with CH_2Cl_2 (3 x 20 mL). After evaporating the solvent, the residue was purified by flash column chromatography using CH_2Cl_2 as the eluent to provide compound **4** as a grey solid (1.06 g, 76 %): ^1H NMR (500 MHz, $CDCl_3$) δ 7.93 (s, 2H), 7.34 (d, J = 8.2 Hz, 3H), 7.15 (d, J = 8.2 Hz, 2H), 6.71 (m, 2H), 6.17 (m, 2H), 5.95 (m, 2H), 5.47 (s, 1H), 1.31 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 31.4, 34.6, 43.6, 107.2, 108.5, 117.2, 125.7, 128.2, 132.9, 139.1, 149.9.[5]

Compound 2: To a solution of dipyrrolemethane **4** (278 mg, 1.00 mmol) and aldehyde **3** (546 mg, 1.00 mmol) in chloroform (100 mL) was added $BF_3 \cdot OEt_2$ (40 μL) dropwise. The reaction mixture was stirred for 1 h at rt. A solution of DDQ (0.17 g, 0.75 mmol) in toluene (10 mL) was added slowly. After stirring for1 h at rt, the reaction mixture was filtered through a silica gel pad. The volatiles were removed and the crude product was purified by flash column chromatography (CH_2Cl_2/Hexane, 1/1, v/v). The resulting porphyrin mixture was subjected to the next step. The general procedure for Sonogashira coupling was followed,[6,7] in which compound **2a** (428 mg, 0.53 mmol), 4-benzoyl-4'-ethynylbiphenyl (367 mg, 1.3 mmol), $Pd(PPh_3)_2Cl_2$ (22 mg, 0.032 mmol), CuI (3 mg, 0.016 mmol), piperidine (10 mL), and THF (50 mL) were used. The product **2** was obtained as a purple solid (230 mg, 24 %): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.98 (s, 2H), 8.92 (s, 8H), 8.46 – 8.37 (m, 4H), 8.20 (d, *J* = 8.2 Hz, 4H), 7.93 – 7.44 (m, 36H), 4.53 (t, *J* = 6.7 Hz, 4H), 2.14 (m, 4H), 1.61 (s, 18H), 1.51 – 1.12 (m, 52H), 0.95 – 0.78 (m, 6H), -2.55 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.50, 150.67, 144.62, 141.26, 140.68, 139.50, 139.17, 137.91, 136.55, 134.78, 133.87, 133.54, 132.62, 132.19, 131.00, 130.22, 129.84, 128.59, 128.53, 127.33, 127.12, 126.97, 126.92, 124.74, 124.10, 123.87, 123.27, 121.44, 120.96, 120.84, 120.56, 120.44, 113.69, 109.33, 107.16, 92.48, 87.71, 43.93, 35.14, 32.17, 31.94, 29.96, 29.92, 29.88, 29.77, 29.61, 29.50, 27.75, 22.94, 14.39; MALDI-TOF(m/z): $[M+H]^+$ calcd. for $C_{138}H_{140}N_6O_2$, 1915.12; found: 1915.14.

Compound 1: The target macrocycle compound **1** was obtained by following typical precipitation-driven alkyne metathesis procedures.[8] The multidentate ligand **5** (1.5 mg, 0.0032 mmol) and the Mo(VI) carbyne precursor (2.0 mg, 0.0031 mmol) were premixed in dry carbon tetrachloride (3 mL) for 5 minutes to generate the catalyst *in situ*. Subsequently, monomer **2** (77 mg, 0.040 mmol) was added and the resulting solution was stirred at 45 °C for 16 h. The reaction mixture was filtered to remove the byproduct. The filtrate was concentrated and subjected to column chromatography over alumina (CH_2Cl_2/Hexane, 1/2, v/v). The product **1** was obtained as a purple solid (33 mg, 60 %): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.78 (s, 4H), 8.75 (s, 16H), 8.35 – 8.28 (m, 8H), 8.04 (d, *J* = 7.9 Hz, 4H), 7.98 (d, *J* = 7.9 Hz, 4H), 7.79 (dd, *J* = 8.8, 1.4 Hz, 4H), 7.71-7.59 (m, 12H), 7.54 (d, *J* = 8.8 Hz, 4H), 4.53 (s, 8H), 2.19 – 1.99 (m, 8H), 1.69 –

1.55 (m, 8H), 1.54 (s, 36H), 1.45 (m, 8H), 1.41 – 1.16 (m, 88H), 0.87 (t, J = 6.8 Hz, 12H), -2.82 (s, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 150.41, 140.80, 140.57, 140.21, 139.37, 134.58, 134.49, 133.67, 132.81, 131.33, 129.44, 126.73, 124.26, 123.76, 123.60, 123.18, 121.26, 120.62, 120.32, 114.55, 109.15, 106.78, 89.21, 43.89, 35.12, 35.04, 32.15, 31.87, 29.95, 29.92, 29.91,29.90, 29.77, 29.70, 29.66, 29.60, 29.50, 27.76, 22.92, 14.37. MALDI-TOF(m/z): $[M+H]^+$ calcd. for $C_{196}H_{228}N_{12}$, 2752.84; found: 2752.53.

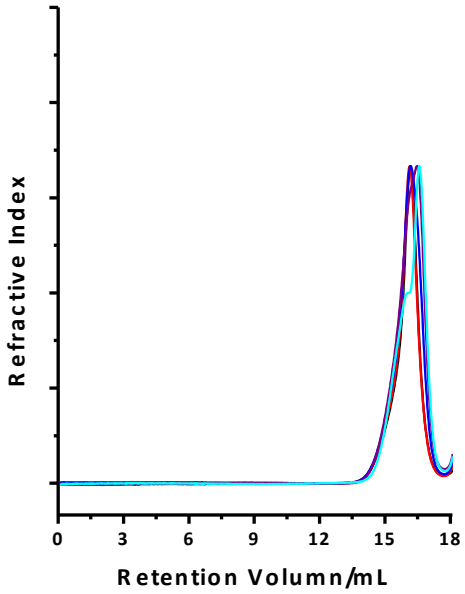


Figure S1. The GPC traces of the crude reaction mixture from the macrocycle formation via alkyne metathesis. The reaction was conducted at 45 ^{o}C for 10 min (cyan), 30 min (purple), 1 h (blue), 2 h (red), 4 h (black).

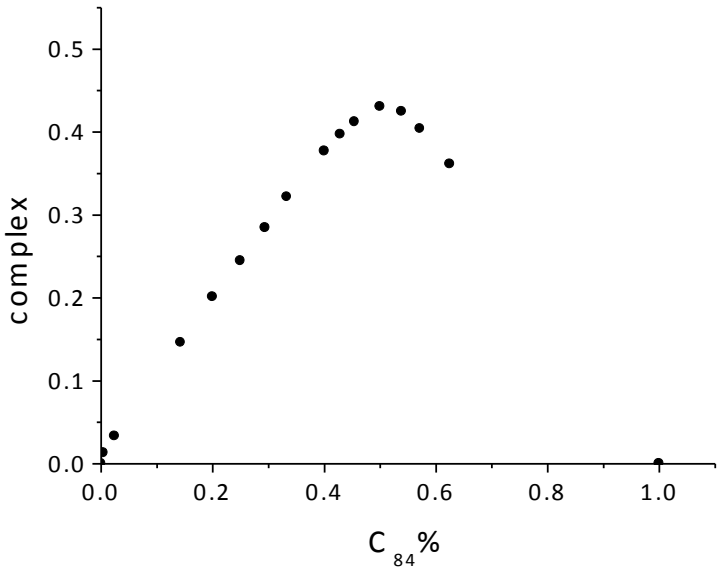


Figure S2. The Job plot from the titration of macrocycle **1** with C_{84}. The highest point at 50 % indicates 1:1 binding of **1** and C_{84}.

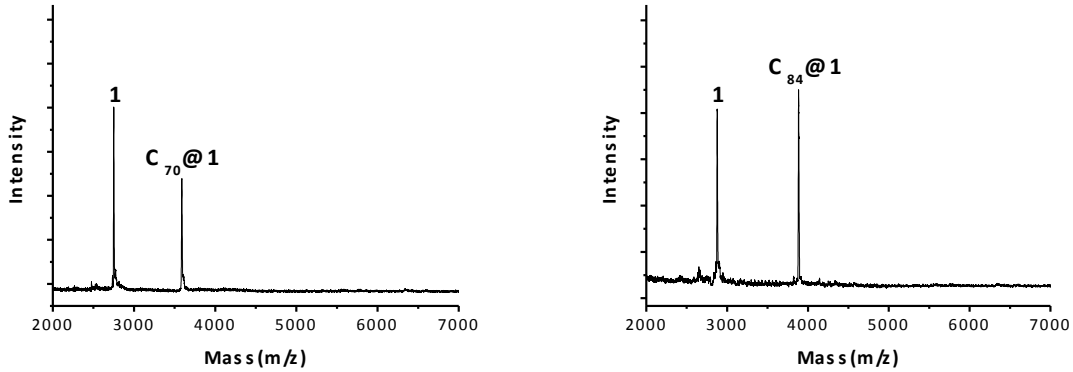


Figure S3. The MALDI-TOF Mass Spectra of 1:1 mixtures of **1** and fullerenes: C_{70}@1 (left), C_{84}@1 (right). The macrocycle peak was significant, presumably due to the premix of the complexes with acidic matrix solution (2,5-dihydroxybenzoic acid), which triggers the macrocycle-fullerene dissociation.

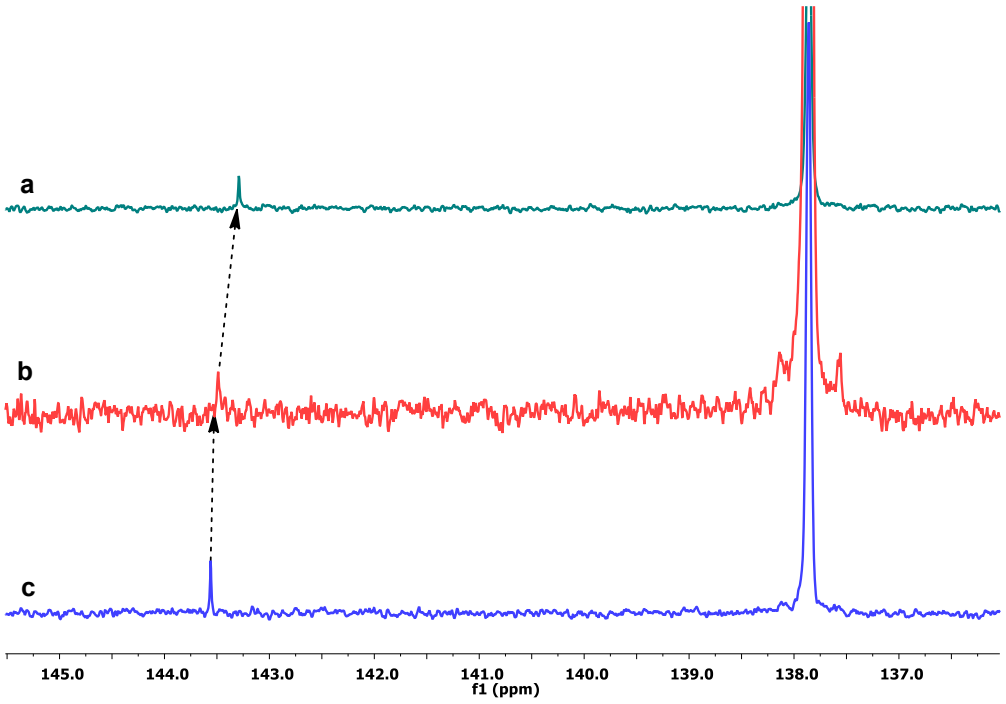


Figure S4. The ^{13}C NMR Spectra of (a) 2:1 mixture of C_{60}:**1**; (b) 1:1:1 mixture of C_{60}:C_{84}:**1**; (c) free C_{60} in toluene-d_8 at 20 ^{o}C. The C_{60} signal shifts to the higher field in (a) due to the shielding effect from macrocycle-fullerene binding interaction. However, in the presence of 1 equiv of C_{84}, the binding between C_{60} and **1** is less favored due to their significantly lower binding affinity, thus leading to the C_{60} signal shifting back almost to the same position as in the free C_{60} case (c).

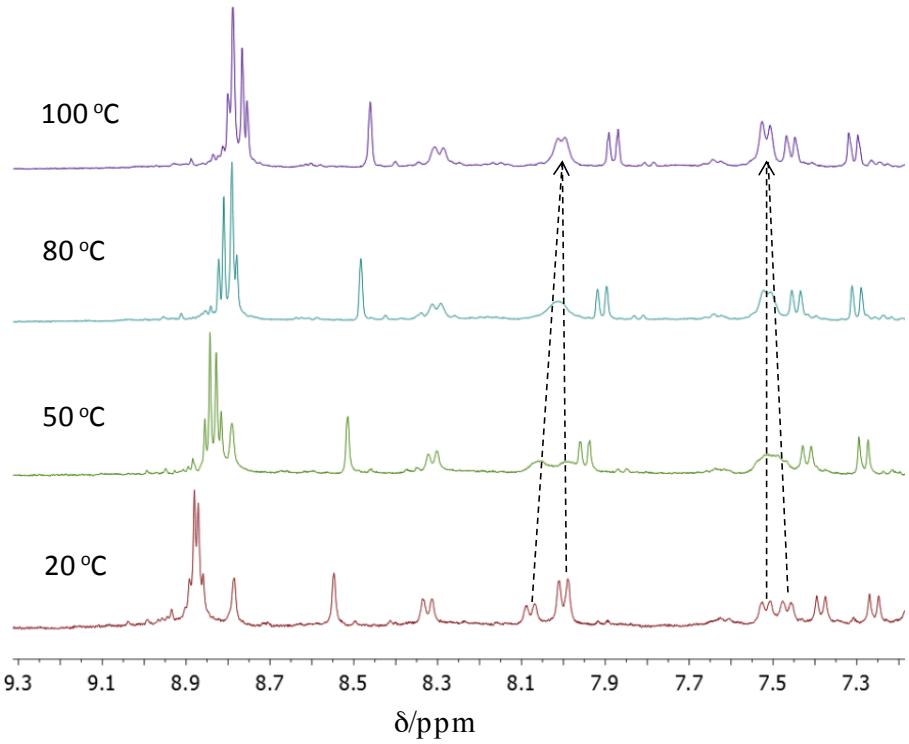


Figure S5. Variable temperature ^{1}H NMR spectra of the macrocycle **1** in toluene-d_8: 20 °C (red), 50 °C (green), 80 °C (blue), 100 °C (purple). The spectrum at 20 °C shows four sets of aromatic proton peaks for the *t*-butylphenyl groups. However, at elevated temperatures, those peaks coalesced into two sets. Such observation is consistent with the computer modeling study. At room temperature, two of those four phenyl groups are very close to porphyrin moieties due to the collapsed conformation of macrocycle **1**, thus showing different chemical shifts from the other two phenyl groups. However, at elevated temperatures, the rapid conformational interconversion leads to coalesce of their NMR signals.

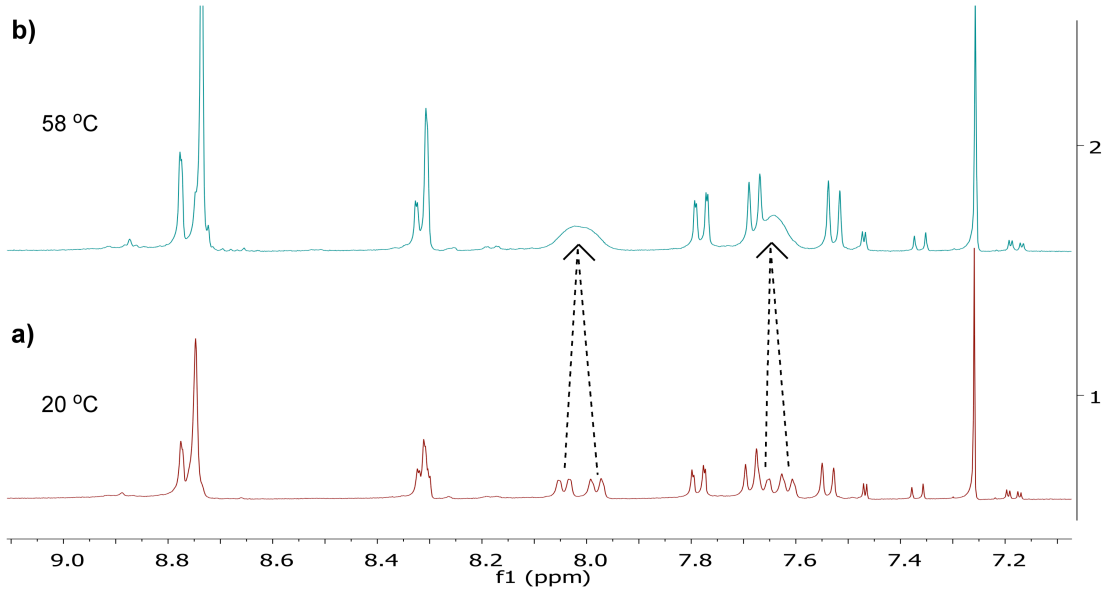


Figure S6. Variable temperature ^{1}H NMR spectra of the macrocycle **1** in $CDCl_3$: 20 °C (a), 58 °C (b). The spectrum at 20 °C shows four sets of aromatic proton peaks for the *t*-butylphenyl groups. However, at elevated temperatures, those peaks coalesced into two sets. Such observation is consistent with the computer modeling study. At room temperature, two of those four phenyl groups are very close to porphyrin moieties due to the collapsed conformation of macrocycle **1**, thus showing different chemical shifts from the other two phenyl groups. However, at elevated temperatures, the rapid conformational interconversion leads to coalesce of their NMR signals.

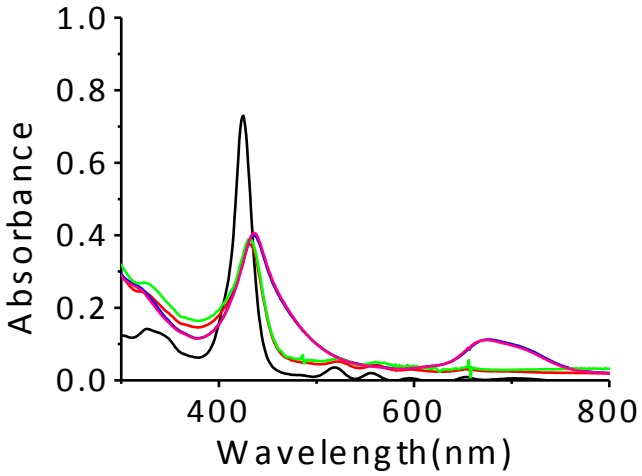


Figure S7. The UV-Vis absorption spectra of C_{84}@**1** with the stimuli of acid and base. The absorbance of **1** (black); C_{84}@**1** (red); C_{84}@**1** with addition of 100 eq. of TFA (blue); the C_{84}@**1** with 100 eq. TFA then add 100 eq. of TEA (green); **1** with addition of 100 eq. of TFA (pink). The absorbance of the acidified C_{84}@**1** (blue curve) is in good agreement with the acidified **1** itself (pink curve), which indicates release of C_{84} from the cage under acidic conditions. The overlap of absorption curve of C_{84}@**1** (red) and that after successive treatment with TFA and TEA (green curve) indicates the TFA-TEA triggered complexation-decomplexation process is fully reversible.

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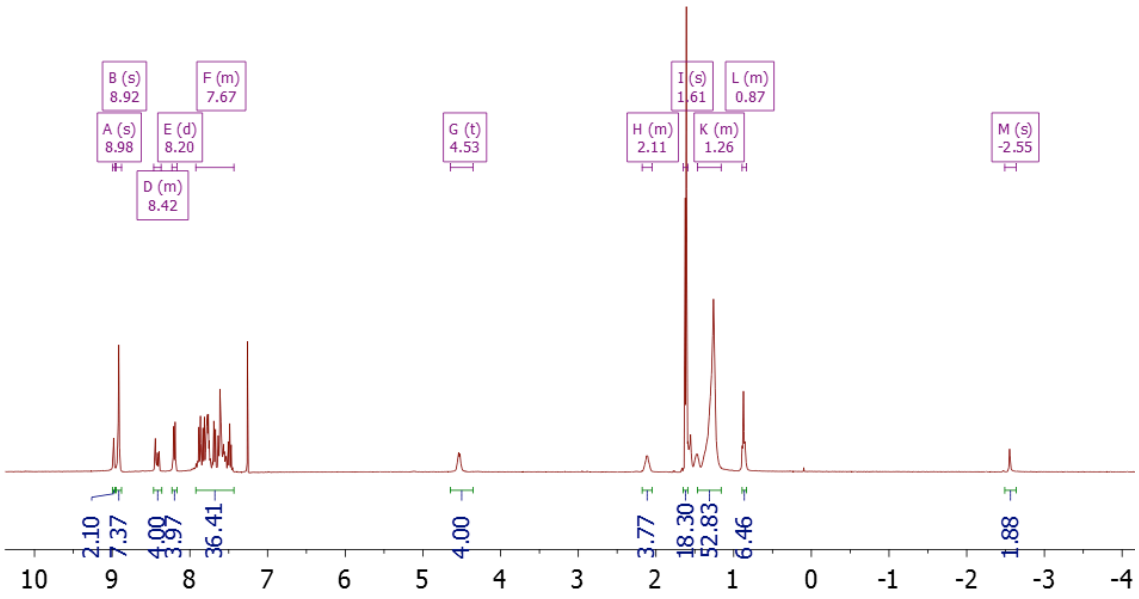

Figure S7. ^{1}H NMR spectrum of monomer **2**, 20 ^{o}C, $CDCl_3$.

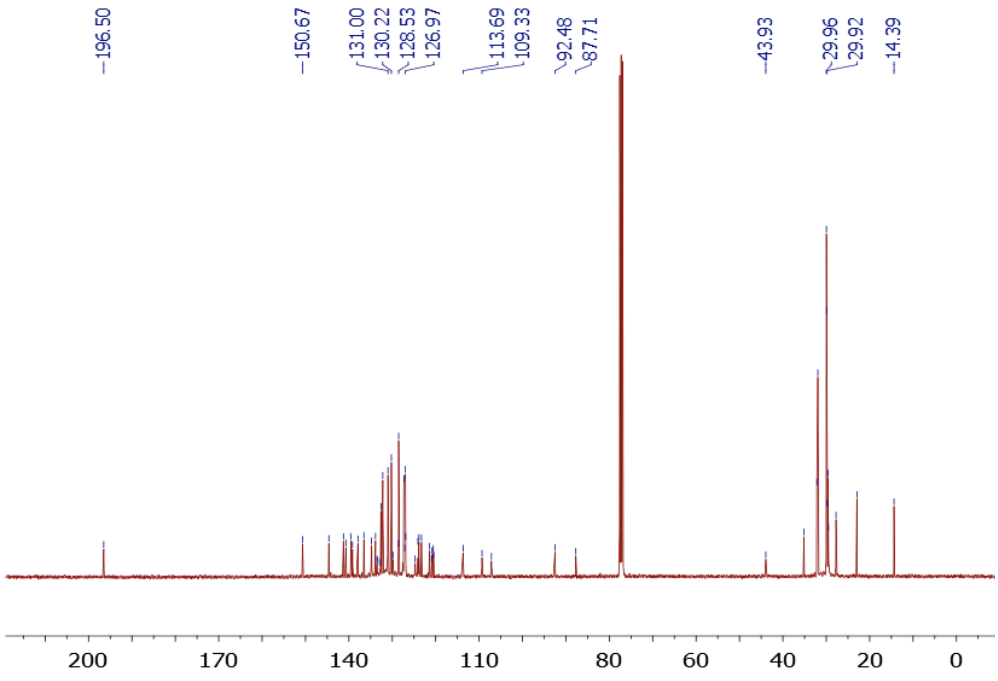

Figure S8. ^{13}C NMR spectrum of monomer **2**, 20 ^{o}C, $CDCl_3$.

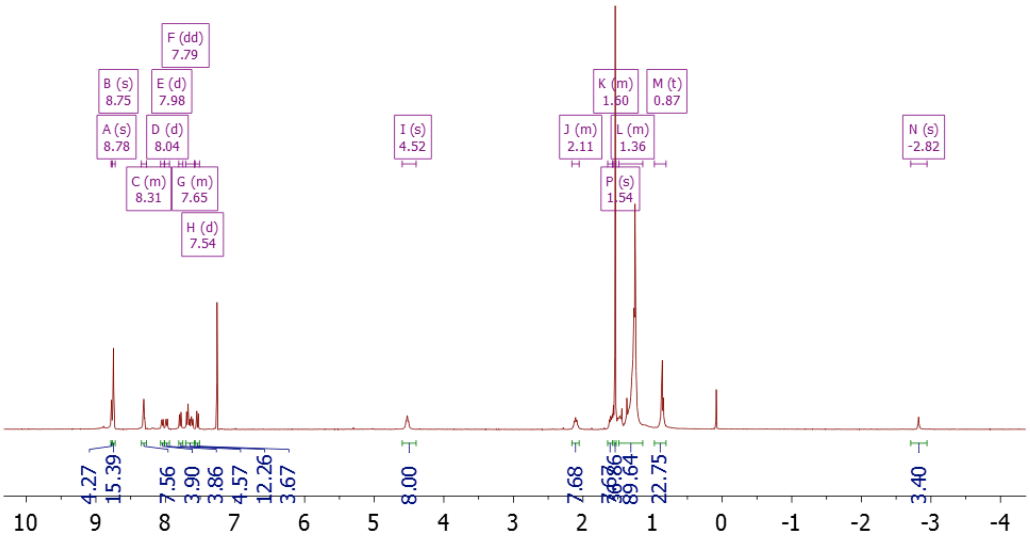

Figure S9. ^{1}H NMR spectrum of macrocycle **1**, 20 ^{o}C, $CDCl_3$.

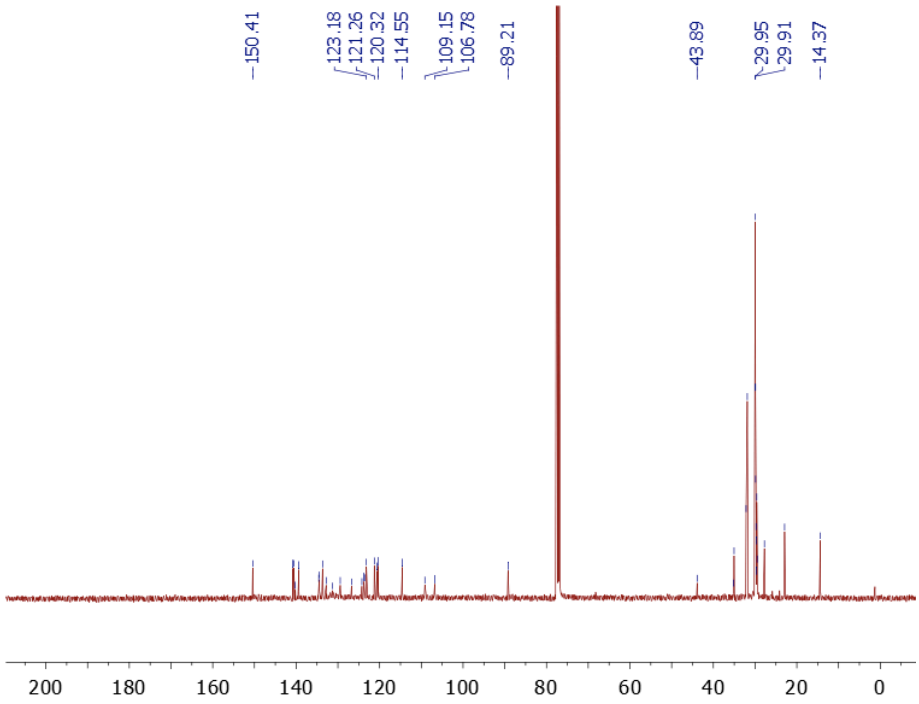

Figure S10. ^{13}C NMR spectrum of macrocycle **1**, 20 ^{o}C, $CDCl_3$.