Electronic Supplementary Material (ESI) for CrystEngComm.

Encapsulation of biogenic polyamines by carboxylcalix[5]arenes: when solid-state design beats recognition in solution

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Electronic Supplementary Information

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Contents

1. ^{1}H NMR measurements

^{1}H NMR spectra (500 MHz) were recorded at 25 °C in $CDCl_3/CD_3OD$ 9:1 v/v. Chemical shifts are reported in ppm, using TMS as an internal standard. Prior to use, $CDCl_3$ was filtered through neutral aluminium oxide to remove any traces of acid. Sample solutions were routinely prepared by mixing together appropriate aliquots of $CDCl_3/CD_3OD$ (9:1, v/v), stock solutions of **1**·H (10 mM) and guest (50 mM) to a final volume of 600 μL.

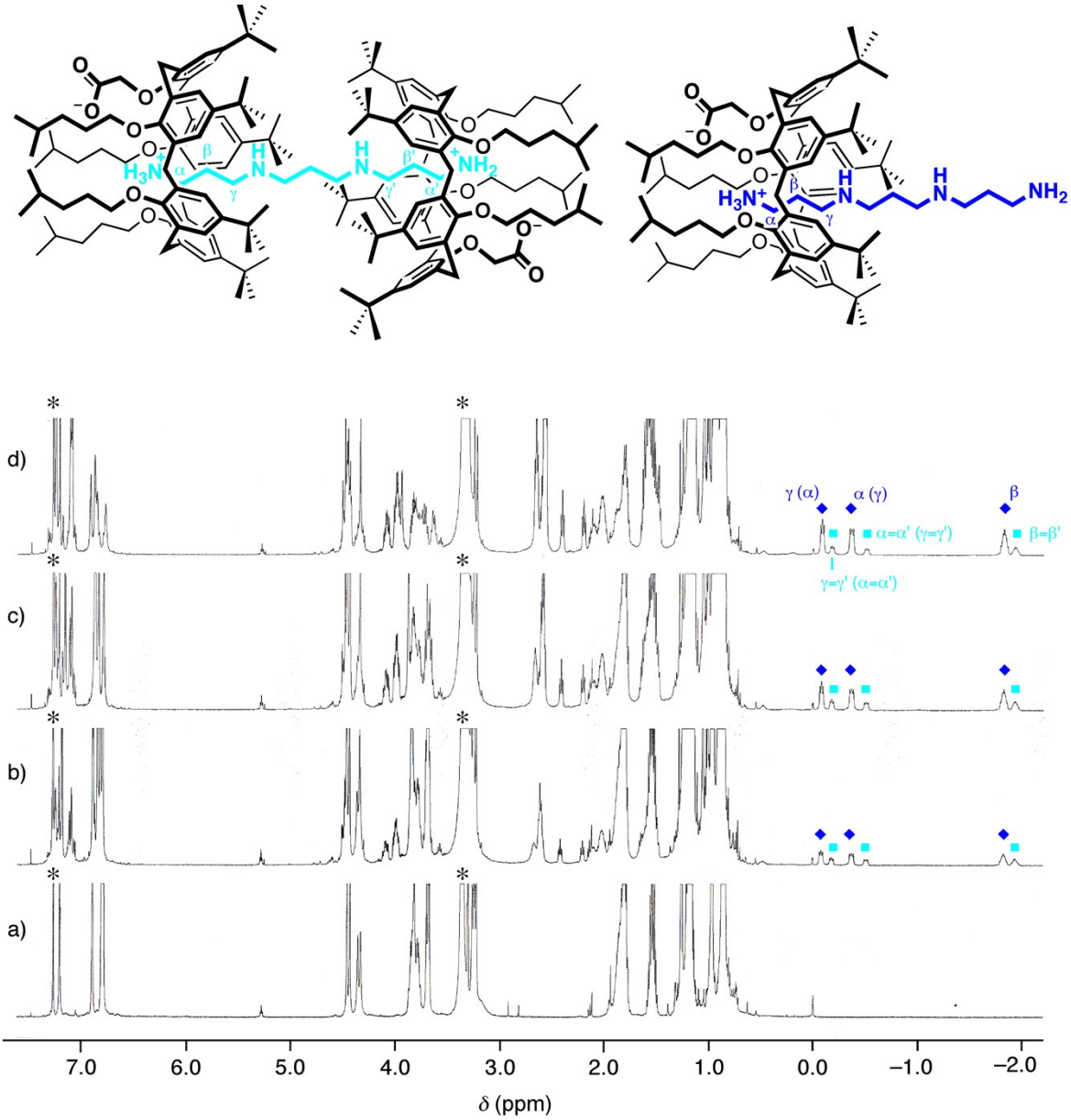

Figure S1. ^{1}H NMR spectra (500 MHz, 25 °C, $CDCl_3/CD_3OD$ 9:1, v/v) of a) [**1**·H] = 5 mM; b) [**1**·H] = 5 mM and [Nspm] = 1.25 mM; c) [**1**·H] = 5 mM and [Nspm] = 2.5 mM; d) [**1**·H] = 5 mM and [Nspm] = 5 mM. * Residual solvent peaks.

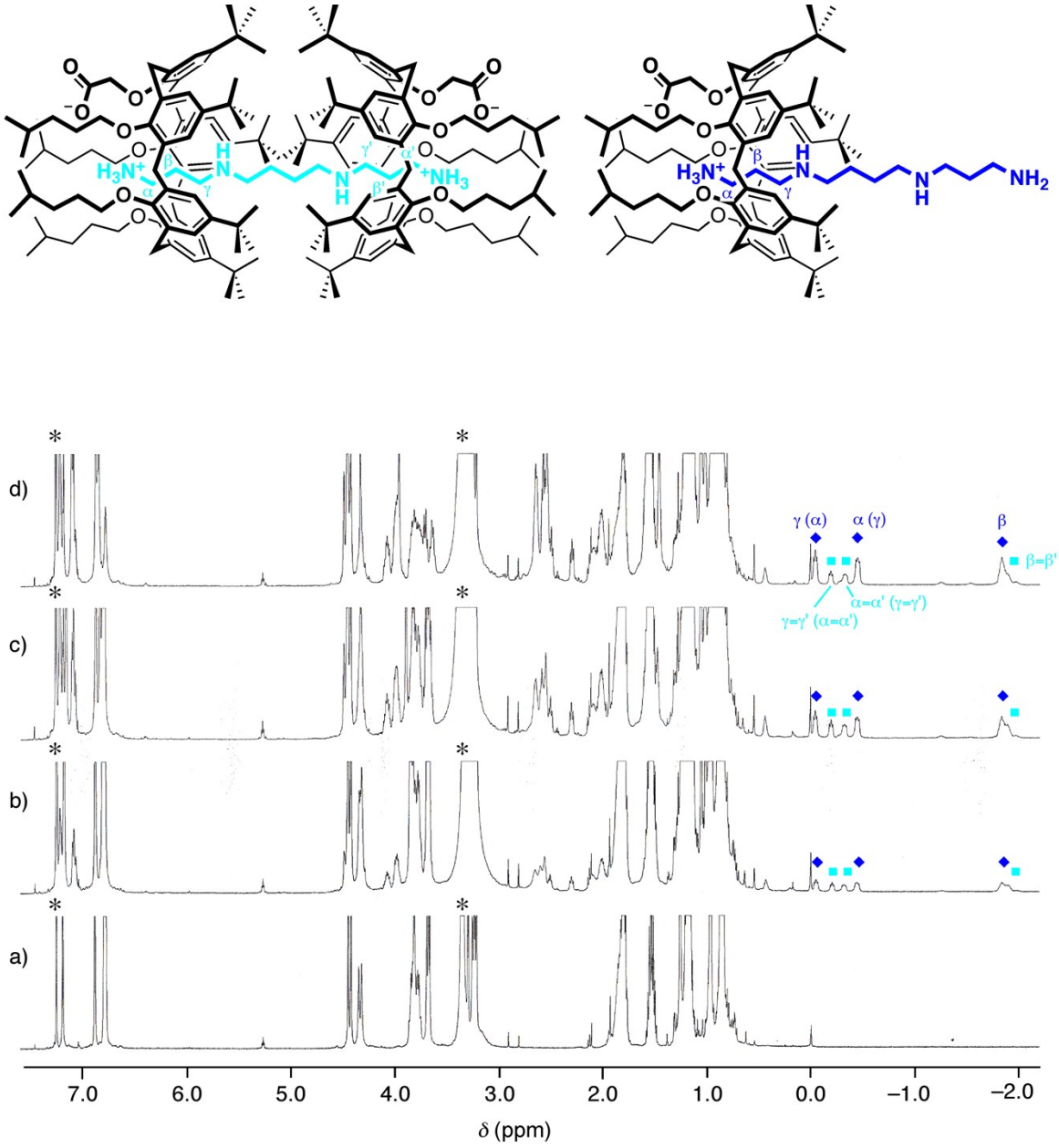

Figure S2. ^{1}H NMR spectra (500 MHz, 25 °C, $CDCl_3/CD_3OD$ 9:1, v/v) of a) [**1**·H] = 5 mM; b) [**1**·H] = 5 mM and [Spm] = 1.25 mM; c) [**1**·H] = 5 mM and [Spm] = 2.5 mM; d) [**1**·H] = 5 mM and [Spm] = 5 mM. * Residual solvent peaks.

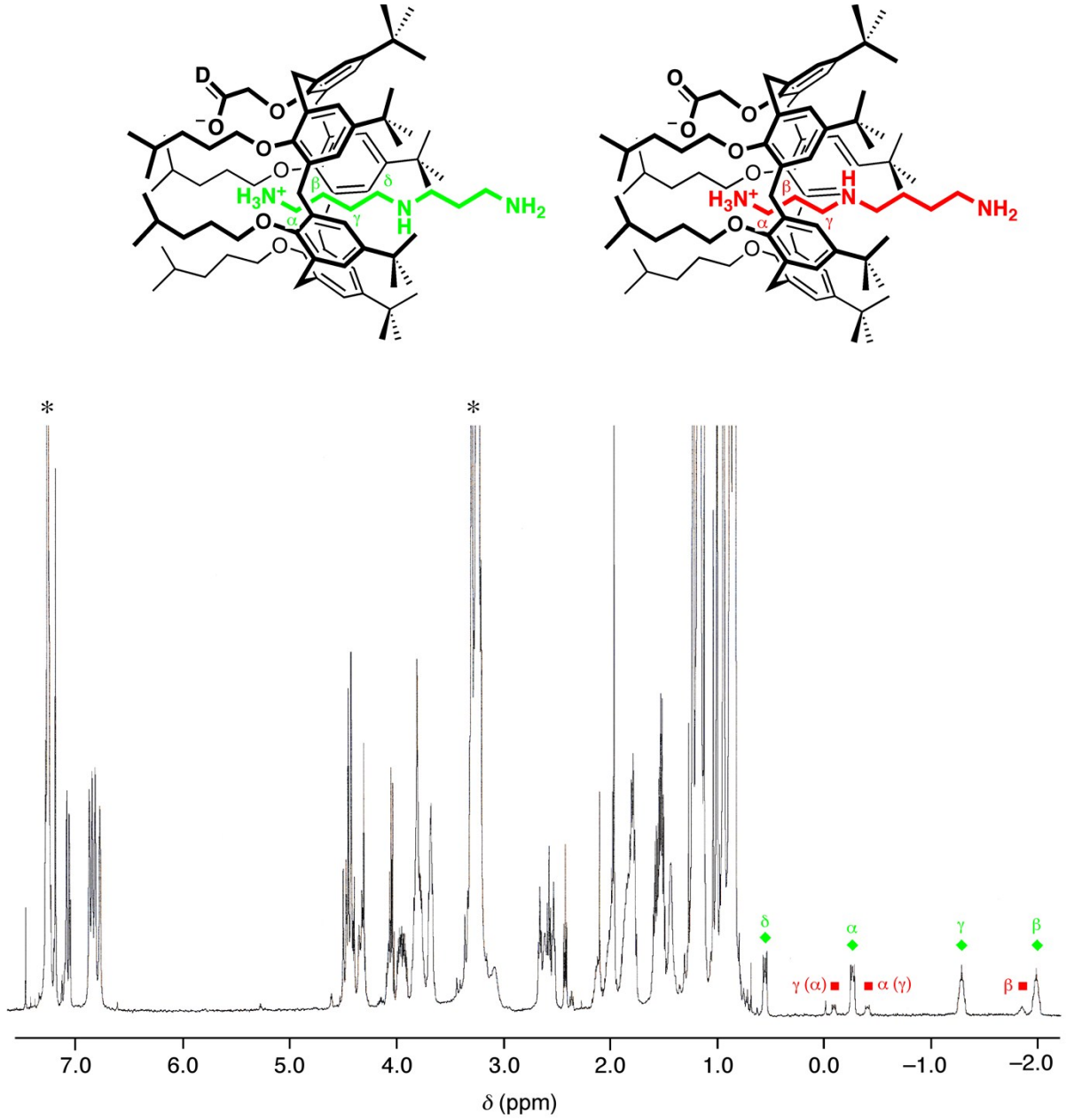

Figure S3. ^{1}H NMR spectrum (500 MHz, 25 °C, $CDCl_3/CD_3OD$ 9:1, v/v) of: [**1**·H] = 1 mM and [Spmd] = 1.25 mM.

* Residual solvent peaks.

2. Crystal structures

Table S1. Crystal data and structure refinement for **1**$^{-}$⊃Nspm·2H^{+}⊂**1**$^{-}$ and **1**$^{-}$⊃Spm·2H^{+}⊂**1**$^{-}$

	1^{-}⊃Nspm·2H^{+}⊂**1**$^{-}$	**1**$^{-}$⊃Spm·2H^{+}⊂**1**$^{-}$
Empirical formula	$2(C_{81}H_{119}O_7)$, $C_9H_{26}N_4$, $4.4(C_2H_3F_3O)$	$2(C_{81}H_{119}O_7)$, $C_{10}H_{28}N_4$, $2.5(C_2H_3F_3O)$
Formula weight	3040.04	2863.91
T (K)	100(2)	100(2)
λ (Å)	0.7000	0.6525
Crystal system	Orthorhombic	Orthorhombic
Space group	*P*can	*P*bcn
Unit cell dimensions (Å, °)	a = 23.22(1), α = 90	a = 23.45(1), α = 90
	b = 24.47(2), β = 90	b = 23.02(1), β = 90
	c = 32.46(1), γ = 90	c = 32.88(2), γ = 90
V (Å^3)	18444(18)	17749(15)
Z	4	4
$\rho_{(calc)}$ (g/mm^3)	1.095	0.978
μ (mm^{-1})	0.074	0.051
F(000)	6600	5814.5
Resolution range (Å)	11.69-0.85	11.01-0.80
Reflections collected	39363	77945
Independent reflections	16926	19078
Data / restraints / parameters	16926 / 23 / 1046	16955 / 224 / 971
GooF	1.437	1.049
R_1, wR_2 [I>2σ(I)]	0.1298, 0.3666	0.1128, 0.3043
R_1, wR_2 (all data)	0.1831, 0.4113	0.1338, 0.3384
CCDC code number	1432426	1452078

2.1. Disorder details for $1^{-}\supset$Nspm·$2H^{+}\subset 1^{-}$ and $1^{-}\supset$Spm·$2H^{+}\subset 1^{-}$

In the crystallographic model of $\mathbf{1}^{-}\supset$Nspm·$2H^{+}\subset\mathbf{1}^{-}$ two 4-methylpentyloxy chains at the narrow rim were found to be disordered over two orientations and were refined at 0.5/0.5 and 0.75/0.25 of partial occupancy. Two molecules of co-crystallization solvent (TFE) were refined at 0.75 of partial occupancy and a third one at 0.7.

Likewise, in the crystallographic model of the $\mathbf{1}^{-}\supset$Spm·$2H^{+}\subset\mathbf{1}^{-}$ capsular complex two disordered 4-methylpentyloxy moieties were refined at 0.5/0.5 and 0.4/0.6 of partial occupancy. A terminal methyl group of one of these moieties was also found to be disordered over two positions and refined at 0.4/0.6 of partial occupancy. The internal N-C-C group of the guest was also found to be disordered around a two-fold symmetry axis. The two orientations were refined at equal occupancy and, as a result, the structure of the encapsulated Spm·$2H^{+}$ dication is compatible with either of the two conformations (A and B) reported in Fig S4. Restraints on geometrical parameters for all the disordered fragments were introduced during the refinement cycles by using the DFIX, DANG and SAME cards, as were restraints on anisotropic thermal parameters for carbon atoms by using the SIMU card. The cell contained severely disordered solvent molecules with partial occupancy that were not modeled, but were taken into account using the SQUEEZE/PLATON[1] procedure. The residual electron density of 518.7 electrons/cell found in the hollow of the $\mathbf{1}^{-}\supset$Spm·$2H^{+}\subset\mathbf{1}^{-}$ capsule (corresponding to approximately 13% of the cell volume) was attributed to 10 TFE solvent molecules. A refinement using reflections modified by the SQUEEZE procedure gave good results and the *R*-factor was reduced from 22.2 to 16.7%.

2.2. Capsule internal volume calculations

Calculations of the capsular internal volumes ($\boldsymbol{V}_{G}$) of $\mathbf{1}^{-}\supset$Nspm·$2H^{+}\subset\mathbf{1}^{-}$ and $\mathbf{1}^{-}\supset$Spm·$2H^{+}\subset\mathbf{1}^{-}$ were carried out with the setting parameters of the VOIDOO software,[2] as previously described

1. (*a*) A. L. Spek, *Acta Crystallogr.*, 2015, **C71**, 9–18; (*b*) P. Sluis, v.d.; A. L. Spek, *Acta Crystallogr.,* 1990, **A*46***, 194–201.
2. G. J. Kleywegt and T. A. Jones, *Acta Crystallogr.*, 1994, **D50**, 178–185.

by us,[3] using a virtual probe with a 1.4 Å radius. Volumes of the Nspm·2H$^+$ and Spm·2H$^+$ dication guests ($\boldsymbol{V}_G$) were calculated with the same software.

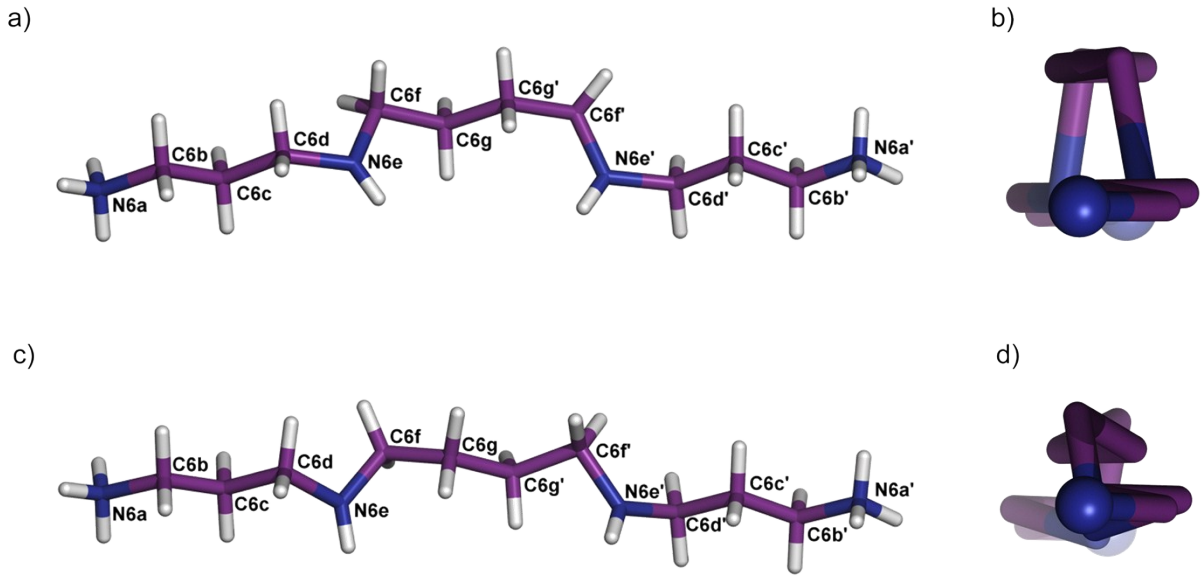

Figure S4. a) Side and b) front (from N6a) views of the solid-state structure of the dication guest (conformation A) encapsulated within **1**$^-$⊃Nspm·2H$^+$⊂**1**$^-$; N6e-C6f-C6g-C6g' torsion angle –92.1°. c) Side and d) front (from N6a) views of the dication guest (conformation B) encapsulated within **1**$^-$⊃Nspm·2H$^+$⊂**1**$^-$; N6e-C6f-C6g-C6g' torsion angle 120.4°.

3. G. Brancatelli, G. Gattuso, S. Geremia, N. Manganaro, A. Notti, S. Pappalardo, M. F. Parisi and I. Pisagatti, *CrystEngComm,* 2015, **17**, 7915–7921.