Synthesis and X-ray Structure of Amide-Based Macrocycles, Catenanes and Pretzelane

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The syntheses and crystal structure studies of amide-based catenanes derived from *m*-phenylene diacrylic acid and 5-acetoxy isophthalic acid (17% and 3% yield of **4a** and **4b** resp.) and octalactam macrocycles (21% yield of **3**) are described. Hydrogen bonding patterns play a key role in the formation of the different conformations of octalactam **3**. The crystal structures of **3** reveal a number of hydrogen-bonding interactions between the macrocycle and two different solvent molecules, which are presumably responsible for the different conformations. Furthermore, we report the X-ray structure of a catenane, which was converted into a "pretzelane" by bridging two phenolic hydroxy groups with a *p*-xylylene unit.

Introduction

Intertwined polymembered rings and interlocked species like catenanes[1−5] are fascinating molecular species because they are tied together in an unusual way. Such mechanically connected supramolecules have been synthesized from noncovalent templates.[6−10] Recently we reported the crystal structure of the first amide-based knot,[11,12] which encouraged us to try to gain a more general insight into the formation of these unusual uncharged structures.

Consequently, we carried out the synthesis of the different functionalized diamines **1b** and **1c** with the carboxylic acid dichlorides **2b, 2d** and **2e** under dilute conditions (Scheme 1).[13] After purification by column chromatography, the octalactam **3** was isolated in 21% yield and could be crystallized from MeOH or DMSO. Several conformations of this molecule were revealed by X-ray crystallography (see below). Catenane **4a** was isolated in 17% yield and the ester catenane was separated as the in/out isomer **4c** in 6% yield and the in/in isomer **4b** in 3% yield. After cleavage of the ester groups of **4c**, the pretzelane **4e**[14−18] was prepared (25% yield) by chemoselectively bridging the in/out catenane **4c** between the phenol groups[19] with *p*-dibromoxylene **5** in the presence of potassium carbonate in acetone at room temperature.

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Results and Discussion

The octalactam **3** was crystallized from two independent samples (different solvents) yielding crystals for two X-ray diffraction analyses. In both cases it crystallized[20,21] in a triclinic unit cell, $P\bar{1}$ (No. 2). Both structures contained two different halves of the macrocyclic molecule ($C_{122}H_{130}N_{10}O_8$) in the asymmetric unit, thus exhibiting two different conformations of the molecule in one crystal. Both samples revealed different conformations of the molecule and so, in total, four different conformations were obtained. Due to the diffuse solvents the packing of molecule **3** is disordered.

Compound **3** is a 68-membered macrocycle with crystallographic C_i symmetry. It forms two "cavities" as it is shaped like the number 8. A close face-to-face proximity is observed between the benzene ring (C53−C58) and the opposite double bond (C51*−C52*), and also between two opposite benzene rings (C53−C58, C53*−C58*). The former π-π proximity is more pronounced in molecules **3a**, **3b** and **3d**, whereas the latter type is observed in **3c**. The relatively short distances (4.062−6.242 Å) between the centers of the benzene rings (X2 and X3), and additionally the carbon distances from plane P1, hint at π-π interactions.

The shape of the "cavities" changes slightly between the different conformations. This change is demonstrated by the distances between C9 and C37 and between the center of the molecule X1 and N28. The width of the cavities varies between 12.373 and 12.665 Å and the length between 13.861 and 14.320 Å.

The modification of the planarity of **3** between the different conformations is indicated by the angles between planes P2 and P3, which are shown in Table 1. The angle between planes P2 and P3 varies from 17.3° (**3c**) to 39.8° (**3b**). Obviously there is a slight correlation between the distance of

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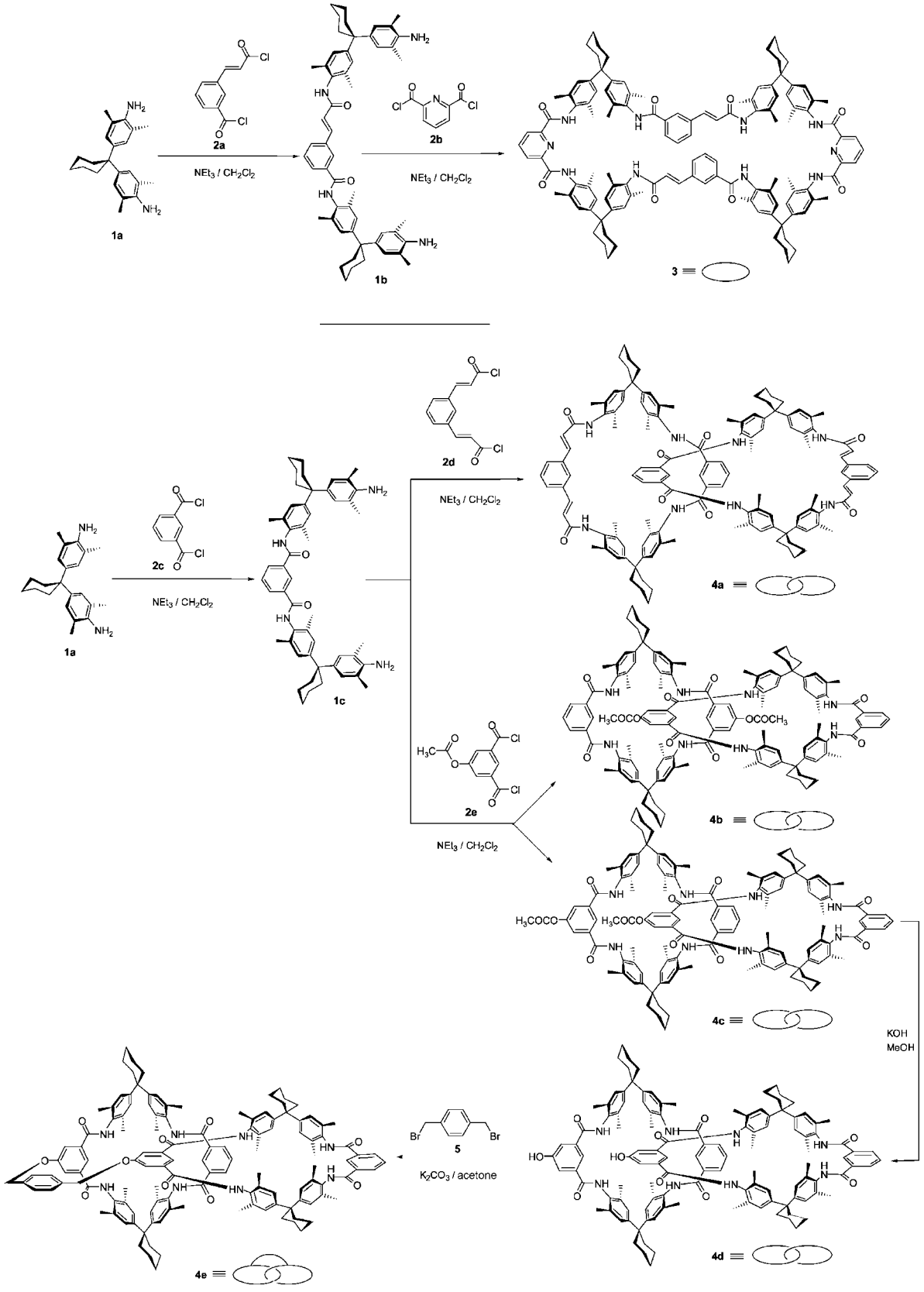

Scheme 1. Synthesis of the catenanes, octalactam and pretzelane

Table 1. Characterization of the four molecules of **3**

	3a	**3b**	**3c**	**3d**
N28−N28*	27.949 Å	27.722 Å	28.502 Å	28.640 Å
X1−N28[a]	13.975 Å	13.861 Å	14.251 Å	14.320 Å
X1−X2[b]	2.920 Å	3.121 Å	2.031 Å	2.614 Å
X2−X3 [b]	5.840 Å	6.242 Å	4.062 Å	5.228 Å
C9−C37	12.373 Å	12.575 Å	12.665 Å	12.625 Å
N28−C58	16.115 Å	16.154 Å	15.017 Å	16.544 Å
N28−C58*	12.573 Å	12.404 Å	13.952 Å	12.617 Å
P1−C50[c]	3.327 Å	3.302 Å	3.280 Å	3.091 Å
P1−C51	3.441 Å	3.395 Å	3.184 Å	3.112 Å
P1−C52	3.317 Å	3.323 Å	3.361 Å	3.168 Å
P1−C53	3.376 Å	3.352 Å	3.290 Å	3.141 Å
P1−C54	3.346 Å	3.360 Å	3.298 Å	3.125 Å
P1−C55	3.347 Å	3.323 Å	3.247 Å	3.139 Å
P1−C56	3.361 Å	3.319 Å	3.252 Å	3.109 Å
P1−C57	3.376 Å	3.354 Å	3.279 Å	3.077 Å
P1−C58	3.362 Å	3.350 Å	3.349 Å	3.157 Å
< P2−P3[d]	39.4°	39.8°	17.3°	38.8°
< P4−P5[e]	60.9°	61.4°	58.3°	36.4°

[a] X1 is a center of the molecule. − [b] X2 is a center of the benzene ring (C53, C54, C55, C56, C57, C58) and X3 is a center of the benzene ring (C53*, C54*, C55*, C56*, C57*, C58*). − [c] P1 is a plane formed by atoms (C50* to C58*). − [d] P2 is a plane formed by atoms (C23, C24, C25, C26, C27, N28) and P3 is a plane formed by atoms (C53, C54, C55, C56, C57, C58). − [e] P4 is a plane formed by points/atoms (X2, C51, X3, C51*) and P5 is a plane formed by atoms (N21, N28, N30).

the benzene rings (X2 and X3) and the planarity of the molecule. The closer the symmetry-equivalent benzene centers (X2 and X3), the more planar is the macrocycle.

The differences in conformation between **3a**, **3b**, **3c** and **3d** are mainly caused by different hydrogen bonding patterns (Tables 2 and 3).[22] The ring molecule forms hydrogen bonds to the other molecules as well as to the different solvent molecules present in the unit cell. Hydrogen bonding to solvent molecules occurs in two places of the ring molecule: between the hydrogens of N21, N30 and N21a, N30a, respectively. The conformation of these parts of molecule **3** in all four molecules is almost the same and so it has little influence on the conformation of the whole molecule. Hydrogen bonding is preferentially formed next to the π-π interaction region of the molecule. Both of the neighboring groups, the amide and the carbonyl group, are able to form a hydrogen bond. In molecule **3d** the carbonyl oxygen O1 forms a hydrogen bond to a water molecule which is hydrogen bonded to H49 of N49 (Figure 1d). This kind of hydrogen bonding seems to be advantageous for the two benzene ring centers X2 and X3, because they are further away from each other and thus the non-planarity of the ring molecule is induced. The opposite trend and a change in the conformation of the amide and the carbonyl groups are observed in **3c** (Figure 1c). The hydrogen H2 of N2 forms a hydrogen bond to a methanol molecule that is hydrogen bonded to the carbonyl oxygen O50. This kind of bonding drives the centers X2 and X3 closer to each other and contributes to a π-π interaction, and thus a more planar macrocycle is formed. In both molecules **3a** and **3b** a similar hydrogen bond bridge is replaced by one hydrogen bond from H49 of N49 to the neighboring molecule (Figure 1a, Figure 1b).

Table 2. Hydrogen bonds for **3a** and **3c**

	D−H···A	d(D−H)	d(H···A)	d(D···A)	<(DHA)
3a	N(2A)−H(2A)···O(1)[a]	0.88	2.09	2.954(11)	167.1
	N(21A)−H(21A)···O(1S)	0.88	2.28	3.077(8)	151.0
	N(30A)−H(30A)···N(28A)	0.88	2.22	2.651(8)	110.2
	N(21A)−H(21A)···N(28A)	0.88	2.28	2.683(9)	107.5
	N(30A)−H(30A)···O(1S)	0.88	2.28	3.062(9)	147.6
	N(49A)−H(49A)···O(22)	0.88	1.96	2.809(8)	160.6
	O(5S)−H(5S)···O(7S)	0.84	2.20	2.91(3)	141.3
	O(5S)−H(5S)···O(50)	0.84	2.38	2.82(2)	113.6
3c	N(2)−H(2)···O(5S)	0.88	2.10	2.96(2)	165.8
	N(21)−H(21)···O(6S)	0.88	2.29	3.063(13)	146.8
	N(21)−H(21)···N(28)	0.88	2.29	2.683(8)	106.8
	N(30)−H(30)···N(28)	0.88	2.30	2.689(8)	107.1
	N(30)−H(30)···O(6S)	0.88	2.43	3.218(13	148.5
	N(49)−H(49)···O(50A)[b]	0.88	1.93	2.788(11)	163.1

[a] Symmetry transformations used to generate equivalent atoms: $x - 1, y - 1, z$. − [b] Symmetry transformations used to generate equivalent atoms: $x + 1, y, z$.

Table 3. Hydrogen bonds for **3b** and **3d**

	D−H···A	d(D−H)	d(H···A)	d(D···A)	<(DHA)
3b	N(2A)−H(2A)···O(50)[a]	0.88	2.05	2.917(12)	168.2
	N(21A)−H(21A)···N(28A)	0.88	2.30	2.691(10)	106.8
	N(21A)−H(21A)···O(20S)	0.88	2.38	3.172(13)	149.1
	N(30A)−H(30A)···N(28A)	0.88	2.23	2.667(9)	110.4
	N(30A)−H(30A)···O(20S)	0.88	2.35	3.113(14)	145.0
	N(49A)−H(49A)···O(29)	0.88	1.96	2.797(8)	157.9
3d	N(2)−H(2)···O(50A)[b]	0.88	2.00	2.785(10)	148.6
	N(21)−H(21)···O(19S)	0.88	2.37	3.138(13)	146.0
	N(21)−H(21)···N(28)	0.88	2.31	2.694(9)	106.4
	N(30)−H(30)···O(19S)	0.88	2.34	3.133(12)	150.8
	N(30)−H(30)···N(28)	0.88	2.28	2.685(8)	107.8
	N(49)−H(49)···O(16S)	0.88	1.99	2.842(16)	161.7
	O(16S)···O1			2.69(2)	

[a] Symmetry transformations used to generate equivalent atoms: $x + 1, y + 1, z$. − [b] Symmetry transformations used to generate equivalent atoms: $x - 1, y, z$.

The out/out isomer **4a** possesses crystallographic C_2 symmetry. The intra- and intermolecular hydrogen bond pat-

Table 4. Hydrogen bonds for **4a**

D−H···A	d(D−H)	d(H···A)	d(D···A)	<(DHA)
N(21)−H(21)···O(1D)[a]	0.88	2.06	2.879(6)	153.5
N(2)−H(2)···O(54)[b]	0.88	1.97	2.828(6)	165.8
N(34)−H(34)···O(1)[b]	0.88	1.99	2.845(6)	164.9
N(53)−H(53)···O(22)[c]	0.88	2.03	2.900(6)	170.4
O1W···O33[a]			3.29	

[a] Solvent hydrogen bonding. − [b] Symmetry transformations used to generate equivalent atoms: $-x + 1, y, -z + 3/2$. − [c] Symmetry transformations used to generate equivalent atoms: $x + 1/2, y + 1/2, z$.

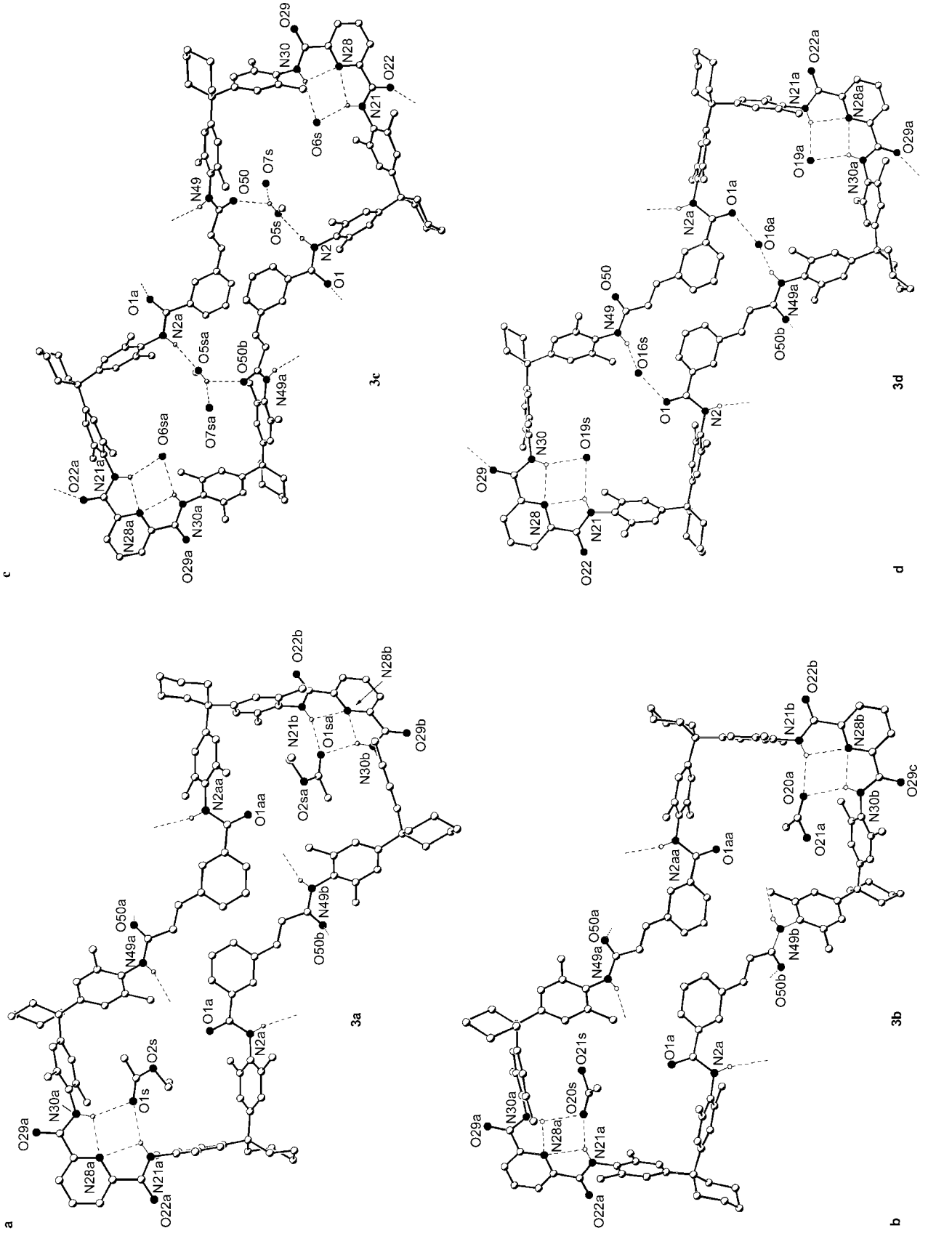

Figure 1. (a) X-ray crystal structure of **3a**; (b) X-ray crystal structure of **3b**; (c) X-ray crystal structure of **3c**; (d) X-ray crystal structure of **3d**

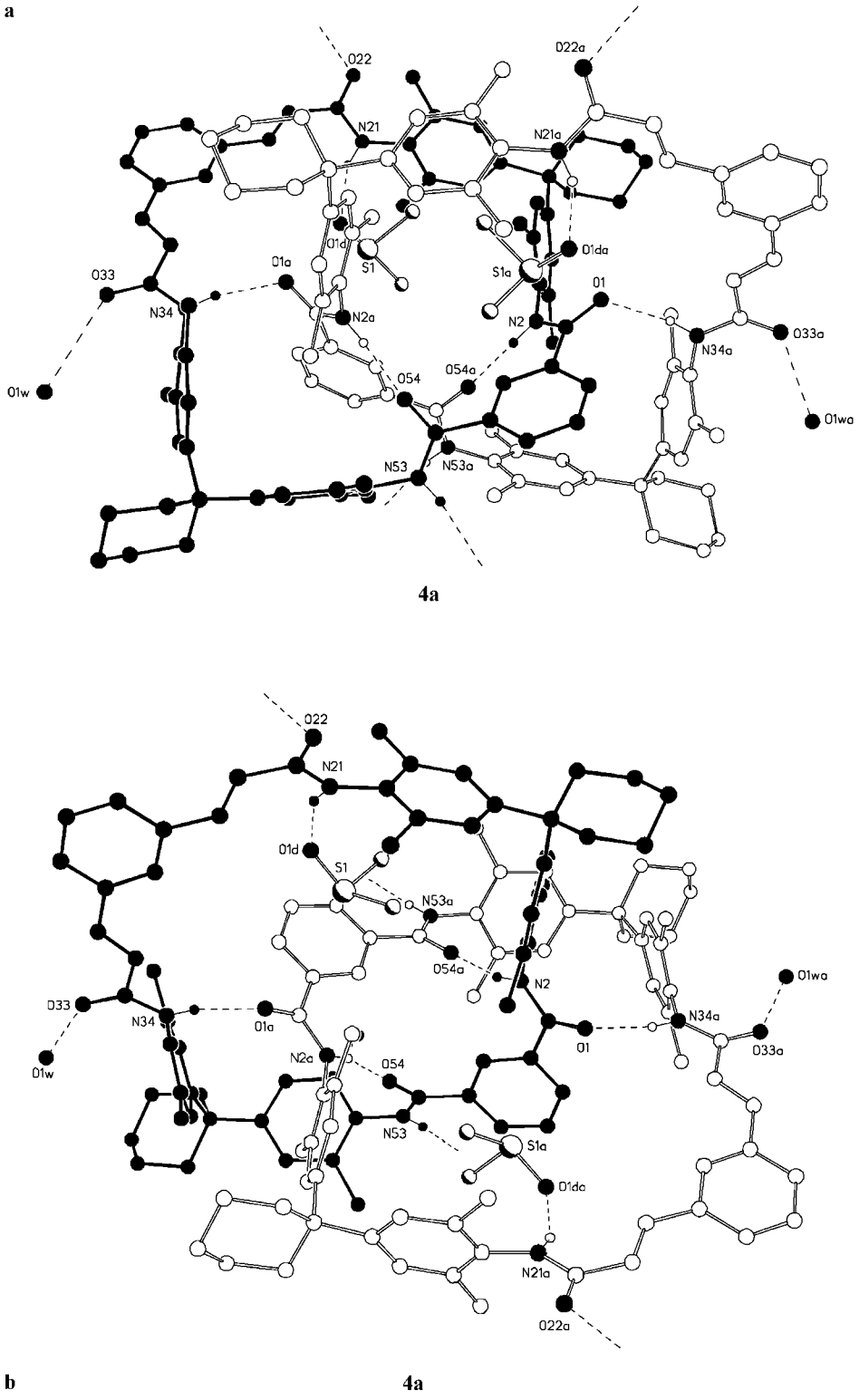

Figure 2. (a) + (b) X-ray crystal structures of **4a** showing the inter- and intramolecular hydrogen bonds; (b) X-ray crystal structure of **4a** showing the intermolecular hydrogen bonds

tern is shown in Figure 2a and Figure 2b, respectively, and in Table 4. The solvents DMSO and water are included in the hydrogen bonding. Only two of the four NH groups are involved in the intramolecular hydrogen bond pattern, due to their different conformations. The catenane **4b** and the furano-catenanes[23] show the more typical conformation of amide-based catenanes, with three of the four NH groups involved in the intramolecular hydrogen bond pattern.

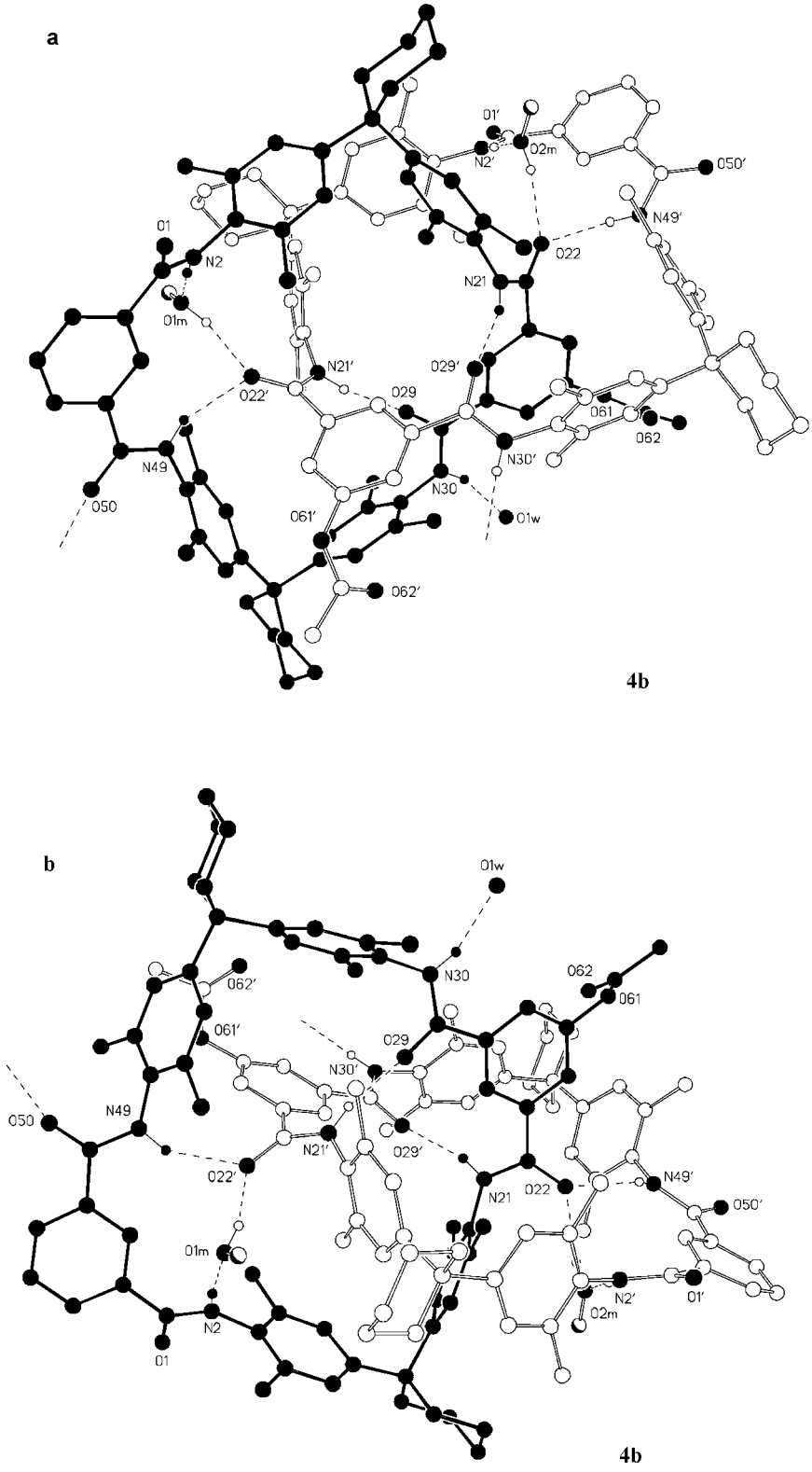

Figure 3. (a) + (b) X-ray crystal structures of **4b** showing the inter- and intramolecular hydrogen bonds

The in/in isomer **4b** possesses almost C_2 symmetry.[24] The intra- and intermolecular hydrogen bond pattern is shown in Figure 3a and Figure 3b, respectively, and in Table 5. The solvent molecule (MeOH) is involved in a bifurcal hydrogen bond between the carbonyl oxygens O22 and O22′ and the amide groups N2/N2′ and N49/N49′.

Table 5. Hydrogen bonds for **4b**

D−H···A	d(D−H)	d(H···A)	d(D···A)	<(DHA)
N(2)−H(2)···O(1M)[a]	0.88	2.08	2.955(6)	172.4
N(21)−H(21)···O(29′)	0.88	2.00	2.847(6)	162.4
N(30)−H(30)···O(1W)[a]	0.88	1.99	2.852(9)	166.1
N(49)−H(49)···O(22′)	0.88	2.14	2.947(5)	152.2
N(2′)−H(2′)···O(2M)[a]	0.88	1.94	2.819(8)	177.5
N(21′)−H(21′)···O(29)	0.88	1.99	2.857(5)	167.8
N(30′)−H(30′)···O(50)[b]	0.88	2.00	2.873(6)	173.4
N(49′)−H(49A)···O(22)	0.88	2.12	2.857(6)	141.4
O(1M)−H(1M)···O(22′)[a]	0.84	1.96	2.759(5)	159.2
O(2M)−H(2M)···O(22)[a]	0.84	2.06	2.837(8)	152.9

[a] Solvent hydrogen bonding. − [b] Symmetry transformations used to generate equivalent atoms: x, $-y + 3/2$, $z + 1/2$.

Such a hydrogen bond pattern is well-known from the structures of furano-based catenanes.[23]

Conclusion and Outlook

The X-ray analyses of different conformers obtained for the first time show the dependence on the length and pattern of the hydrogen bonds from this isomerism. The solvent molecules were exactly located in the crystal lattice, which allowed the planarity of the molecules to be explained by the hydrogen-bonding patterns. These results contribute to the understanding of conformer formation in crystals. Moreover, they might help to facilitate the design of new macrocyclic supramolecular and interlocked structures in the future.

Experimental Section

General Remarks: Solvents were purified by standard methods and dried if necessary. − Commercial quality reagents were used. − TLC was carried out on silica gel 60 F_{254} and column chromatography on silica gel 60, mesh size 40−60 and 63−100 μm (Merck, Darmstadt, Germany). − Melting points were determined on a microscope heating unit of Reichert, Vienna, Austria, and are not corrected. − The NMR spectra were obtained on AM-250 (^{1}H: 250 MHz, ^{13}C: 62.9 MHz) or on AM-400 (^{1}H: 400 MHz; ^{13}C: 100.6 MHz) spectrometers from Bruker Physik AG, Karlsruhe, Germany, at room temp. in commercially available deuterated solvents (internal reference was the residual undeuterated solvents). All chemical shifts are quoted in ppm and the coupling constants are expressed in Hertz. − FAB-MS: Concept 1 H, Kratos Analytical Ltd. (matrix: *m*-nitrobenzyl alcohol). − MALDI-TOF-MS: MALDI-TOF-Spec-E, Micromass, Manchester, UK (matrix: 9-nitroanthracene or 2,5-dihydroxybenzoic acid).

X-ray crystallographic studies of **3**, **4a**, and **4b**: Data were collected on a Nonius KappaCCD (**3** using a rotating anode generator). The structures were solved by direct methods [SHELXS-97[25] (**4a**, **4b**) and SHELXD[26] (**3**)]. The non hydrogen atoms were refined anisotropically on F^2 (SHELXL-97).[27] H atoms were refined isotropically using a riding model. In **4b** one isophthaloyl diamide group is disordered. Further details are given in Table 6.

Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication nos. CCDC--161425 (**3a, 3c**), -161426 (**3b, 3d**) -161427 (**4a**) and -161428 (**4b**) . Copies of the data can be obtained free of charge on application to The Director, CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [Fax: (internat.) +44-1223/336-033; E-mail: deposit@ccdc.cam.ac.uk].

Tetramer 3: *N*,*N*′-Bis{4-[1-(4-amino-3,5-dimethylphenyl)-cyclohexyl]-2,6-dimethylphenyl}cinnamonoyl diamide (**1b**; 1.20 g, 1.55 mmol) with 0.4 mL triethylamine, and 2,6-pyridine dicarboxylic acid dichloride (**2b**; 0.32 mg, 1.55 mmol) were each dissolved in dry dichloromethane (250 mL). Both solutions were added dropwise over a period of 8 h to a stirred solution of dry dichloromethane (150 mL) cooled with ice. After stirring for a further 12 h and removal of the solvent, the residue was purified by column chromatography (SiO_2; 63−100 μm). M.p. > 220 °C. − R_f = 0.48 ($CHCl_3$/$(CH_3)_2CO$ = 9:2). − Yield 150 mg (21%). − ^{1}H NMR (400 MHz, $CDCl_3$/CD_3OD, 25 °C): δ = 1.15−1.30 (br, 16 H, Cyh-CH_2), 1.32−1.63 (br, 16 H, Cyh-CH_2), 1.65−1.75 (s, 8 H, Cyh-CH_2), 6.67 (s, 2 H, arom. H), 6.68 (s, 2 H, arom. H), 6.85 (s, 8 H, arom. H), 7.00 (s, 8 H, arom. H), 7.25 (t, ^3J = 7.7 Hz, 2 H, arom. H), 7.50 (d, ^3J = 7.7 Hz, 2 H, arom. H), 7.58 (s, 2 H, amide-NH), 7.82 (s, 2 H, amide-NH), 7.83 (s, 2 H, amide-NH), 8.15 (s, 2 H, amide-NH), 8.16 (t, ^3J = 7.7 Hz, 2 H, arom. H), 8.41 (d, ^3J = 7.7 Hz, 8 H, arom. H). − ^{13}C NMR (100.6 MHz, $CDCl_3$/[D_6]DMSO, 25 °C): δ = 16.9, 17.0 (CH_3), 21.1, 23.9, 33.8, 38.5, 43.0 (Cyh-CH_2), 45.8, 46.3, 46.8 (Cyh-Cq), 113.3, 116.3, 124.0, 124.1, 124.3, 130.1, 130.2 (CH), 130.4, 132.5, 132.5, 133.3, 133.4, 133.9, 147.0 (Cq), 159.7, 163.0 (C=O). − MALDI-MS: 1864.1 [M^+], 1886.1 [M^+ + Na], 1904.1 [M^+ + K].

Catenane 4a: *N*,*N*′-Bis{4-[1-(4-amino-3,5-dimethylphenyl)cyclohexyl]-2,6-dimethylphenyl}isophthaloyl diamide (**1c**)[28−29] (1.20 g, 1.55 mmol) with 0.4 mL triethylamine, and *m*-phenylenediacrylic acid dichloride(**2d**; 0.39 g, 1.55 mmol) were each dissolved in dry dichloromethane (250 mL). At room temp., both solutions were simultaneously added within 8 h to dry dichloromethane (1000 mL). After stirring for a further 12 h and removal of the solvent, the residue was purified by column chromatography (SiO_2; 63−100 μm). M.p. > 220 °C. − R_f = 0.6 (CH_2Cl_2/$CH_3CO_2C_2H_5$ = 1:1). − Yield 50 mg (17%). − ^{1}H NMR (400 MHz, $CDCl_3$, 25 °C): δ = 1.45 (br, 8 H, Cyh-CH_2), 2.01 (br, 16 H, Cyh-CH_2), 2.05 (d, 24 H, CH_3), 2.2 (d, 24 H, CH_3), 2.33 (br, 16 H, Cyh-CH_2), 6.95 (d, ^3J = 16.0 Hz, 4 H, trans-H), 7.12 (m, 16 H, arom. H), 7.30 (d, ^3J = 16.0 Hz, 4 H, trans-H), 7.51 (t, 2 H, arom. H), 7.61 (t, 2 H, arom. H), 7.89 (s, 2 H, arom. H), 8.15 (m, 8 H, arom. H), 8.50 (s, 2 H, arom. H), 9.11 (s, 2 H, amide-NH), 9.35 (s, 2 H, amide-NH), 9.80 (s, 2 H, amide-NH), 9.91 (s, 2 H, amide-NH). − MALDI-MS: m/z = 1914.1 [M^+], 1937.1 [M^+ + Na], 1954.0 [M^+ + K].

Catenane 4b and 4c: *N*,*N*′-Bis{4-[1-(4-amino-3,5-dimethylphenyl)cyclohexyl]-2,6-dimethylphenyl}isophthaloyl diamide (**1c**)[28−29] (2.00 g, 2.58 mmol) with 0.67 mL triethylamine, and 5-acetoxyisophthaloyl acid dichloride **2e** (0.67 g, 2.58 mmol) were each dissolved in dry chlorofom (250 mL). Both solutions were added dropwise at room temp. over a period of 8 h to a stirred solution of dry dichloromethane (1500 mL). After stirring for a further 12 h and removal of the solvent, the residue was purified by column chromatography (SiO_2; 40−60 μm).

Catenane 4b: M.p. > 250 °C. − R_f = 0.55 ($CHCl_3$/$CH_3CO_2C_2H_5$ = 2:1). − Yield 76 mg (3%). − ^{1}H NMR (250 MHz, $CDCl_3$/CD_3OD,

Table 6. Crystallographic data and summary of data collection and refinement for **3**, **4a** and **4b**

	3 (a + c)	**3 (b + d)**	**4a**	**4b**
Formula	$C_{122}H_{130}N_{10}O_8$ ·5$CHCl_3$ ·0.5CH_2Cl_2 ·2MeCOOEt ·MeOH ·2.5H_2O	$C_{122}H_{130}N_{10}O_8$ ·2$CHCl_3$ ·2.5CH_2Cl_2 ·0.5MeCOOH ·3H_2O·EtOH ·0.5MeOH·EtCOOH	$C_{128}H_{128}N_8O_8$ ·2DMSO ·CH_2Cl_2·H_2O	$C_{124}H_{132}N_8O_{12}$ ·6CH_3OH·H_2O
M_r	2756.95	2535.65	2191.66	2136.64
Crystal system	triclinic	triclinic	monoclinic	monoclinic
Space group	$P\bar{1}$ (No. 2)	$P\bar{1}$ (No. 2)	$C2/c$ (No. 15)	$P2_1/c$ (No. 14)
a, Å	18.8175(6)	18.5740(7)	23.6234(7)	22.6738(6)
b, Å	18.8329(5)	19.0969(7)	25.4345(8)	31.1861(6)
c, Å	24.8076(8)	24.5382(9)	22.2523(7)	20.0472(5)
α, deg	96.458(2)	97.962(3)		
β, deg	97.167(2)	97.430(3)	92.738(2)	95.588(1)
γ, deg	117.839(2)	118.277(3)		
V, Å^3	7561.7	7399.3	13355.0(7)	14108.2(6)
Z	2	2	4	4
Crystal size, mm^3	0.33 × 0.27 × 0.09	0.20 × 0.30 × 0.40	0.30 × 0.10 × 0.05	0.40 × 0.15 × 0.10
ρ_{cacl}, g cm^{-3}	1.21	1.38	1.09	1.01
μ, mm^{-1}	0.350	0.265	0.138	0.067
F(000)	2892	2676	4680	4584
Diffractometer	Nonius KappaCCD	Nonius KappaCCD	Nonius KappaCCD	Nonius KappaCCD
Radiation	Mo-K_α	Mo-K_α	Mo-K_α	Mo-K_α
λ, Å	0.71073	0.71073	0.71073	0.71073
T, K	173(2)	123(2)	123(2)	123(2)
Max 2θ, deg	50.8	50.6	45.0	50.0
Index range	$-19 \le h \le 22$ $-22 \le k \le 21$ $-29 \le l \le 29$	$-22 \le h \le 22$ $-22 \le k \le 22$ $-29 \le l \le 29$	$-24 \le h \le 25$ $-27 \le k \le 27$ $-23 \le l \le 23$	$-26 \le h \le 26$ $-36 \le k \le 28$ $-23 \le l \le 13$
No. of data	54488	66444	32288	60448
No. of unique data	27024	23878	8685	24596
R_{int}	0.052	0.063	0.102	0.046
Parameters/restraints	1577/2010	1476/1678	714/21	1380/69
$R(F)$ for $I > 2\sigma(I)$	0.197	0.207	0.114	0.139
$wR2(F^2)$ for all data	0.595	0.570	0.344	0.432
Largest diff. peak and hole, e/Å^3	1.82/ −1.42 diffuse solvent	1.89/ −1.18 diffuse solvent	1.35/ −0.53	2.09/ −0.81 diffuse solvent
Goof on F^2	1.00	0.97	0.99	1.09

25 °C): δ = 0.40 (s, 6 H, CH_3), 0.84 (s, 6 H, CH_3), 1.02 (s, 6 H, CH_3), 1.05−1.32 (br, 16 H, Cyh-CH_2), 1.37 (s, 6 H, CH_3), 1.53 (br, 8 H, Cyh-CH_2), 1.66 (s, 6 H, CH_3), 1.75 (s, 3 H, CH_3), 1.95−2.40 (br, 16 H, Cyh-CH_2), 1.99 (s, 6 H, CH_3), 2.05 (s, 6 H, $OCOCH_3$), 2.10 (s, 6 H, $OCOCH_3$), 2.16 (s, 6 H, CH_3), 2.21 (s, 3 H, CH_3), 6.09 (s, 2 H, arom. H), 6.21 (s, 2 H, arom. H), 6.56 (s, 2 H, arom. H), 6.77−6.89 (m, 8 H, arom. H), 7.04 (s, 2 H, arom. H), 7.43 (t, ^3J = 7.5 Hz, 2 H, Iso-H), 7.59 (s, 2 H, arom. H), 7.76 (s, 2 H, arom. H), 7.86 (dd, ^3J = 7.5 Hz, 2 H, Iso-H), 8.10 (dd, ^3J = 7.5 Hz, 2 H, Iso-H), 8.62 (s, 2 H, arom H), 8.92 (s, 1 H, Iso-H), 9.15 (s, 1 H, arom H). − ^{13}C NMR (100.6 MHz, $CDCl_3/CD_3OD$, 25 °C): δ = 16.7, 18.0, 18.2, 18.4, 18.7, 19.2 (CH_3), 20.7 ($OCOCH_3$), 22.7, 22.9, 23.0, 26.1, 26.2, 29.5, 34.5, 34.7, 35.9, 36.3 (Cyh-CH_2), 44.6, 45.2 (Cyh-Cq), 122.0, 122.6, 123.0, 124.6, 125.2, 125.5, 127.7, 128.0, 128.5, 129.4, 132.0, 132.1 (CH), 114.3, 126.3, 129.3, 130.2, 130.6, 130.8, 131.0, 132.6, 133.4, 133.7, 134.0, 134.1, 134.5, 134.7, 134.9, 135.0, 135.9, 137.5, 146.5, 148.8, 149.5, 150.8 (Cq), 162.8, 164.1, 164.2, 166.7 (C=O), 167.8, 169.3 ($OCOCH_3$). − MALDI-MS: m/z = 1925.9 [M^+], 1948.9 [M^+ + Na], 1964.9 [M^+ + K].

Catenane 4c: M.p. > 250 °C. − R_f = 0.70 ($CHCl_3/CH_3CO_2C_2H_5$ = 2:1). − Yield 140 mg (6%). − MALDI-MS: m/z = 1925.5 [M^+], 1948.5 [M^+ + Na], 1964.5 [M^+ + K].

Catenane 4d: in/out-Acetoxycatenane **4c** (94.3 mg, 0.049 mmol) was dissolved in dioxane with 87.0 mg potassium hydroxide in 10 mL water. After stirring the solution for four days at room temp., the solvents were removed by distillation and the product was diluted with 2 mL water. Hydrochloric acid was added dropwise until pH 1. The product was filtered, washed with water and dried at reduced pressure. M.p. > 255 °C. − R_f = 0.26 ($CH_2Cl_2/CH_3CO_2C_2H_5$ = 2:1). − Yield 90 mg (100%). − ^{1}H NMR (400 MHz, $CDCl_3/CD_3OD$, 25 °C): δ = 0.41 (s, 3 H, CH_3), 0.44 (s, 3 H, CH_3), 0.78 (s, 3 H, CH_3), 0.90 (s, 3 H, CH_3), 1.04 (s, 6 H, CH_3), 1.17 (br, 4 H, Cyh-CH_2), 1.31 (s, 6 H, CH_3), 1.33 (br, 4 H, Cyh-CH_2), 1.35 (s, 6 H, CH_3), 1.53 (br, 16 H, Cyh-CH_2), 1.63 (s, 3 H, CH_3), 1.79 (s, 3 H, CH_3), 1.91 (s, 3 H, CH_3), 1.95 (s, 3 H, CH_3), 2.08 (s, 6 H, CH_3), 2.13 (br, 8 H, Cyh-CH_2), 2.31 (br, 8 H, Cyh-CH_2), 6.07 (s, 2 H, arom. H), 6.10 (s, 1 H, arom. H), 6.12 (s, 1 H, arom. H), 6.17 (s, 2 H, arom. H), 6.56 (s, 1 H, arom. H), 6.78 (s, 1 H, arom. H), 6.82 (s, 3 H, arom. H), 6.90 (s, 3 H, arom. H), 7.09 (s, 1 H, arom. H), 7.18 (s, 1 H, arom. H), 7.21 (s, 1 H, arom. H), 7.23 (s, 1 H, arom. H), 7.25 (s, 1 H, arom. H), 7.30 (s, 1 H, arom. H), 7.35 (t, ^3J = 7.4 Hz, 1 H, Iso-H), 7.44 (t, ^3J = 7.8 Hz, 1 H, Iso-H), 7.53 (s, 1 H, arom. H), 7.83 (d, ^3J = 7.2 Hz, 2 H, Iso-H), 7.89 (d, ^3J = 7.4 Hz, 1 H, Iso-H), 8.13 (d, ^3J = 7.8 Hz, 1 H, Iso-

H), 8.30 (s, 1 H, arom. H), 8.73 (s, 1 H, arom. H), 8.95 (s, amide-NH), 9.02 (s, amide-NH), 9.06 (s, amide-NH), 9.14 (s, amide-NH), 9.16 (s, amide-NH). − ^{13}C NMR (100.6 MHz, $CDCl_3/CD_3OD$, 25 °C): δ = 17.2, 18.4, 18.5, 18.8, 19.3, 29.2 (CH_3), 23.3, 23.4, 26.7, 34.6, 34.7, 35.1, 36.4, 36.8 (Cyh-CH_2), 45.1, 45.2, 45.6, 45.7 (Cyh-Cq), 115.6, 116.6, 117.3, 119.0, 119.4, 122.7, 123.3, 125.2, 125.5, 127.9, 128.2, 128.3, 128.6, 128.9, 129.9, 130.1, 131.4, 132.5, 132.6, 133.3 (CH), 130.6, 130.7, 130.8, 131.3, 131.5, 131.6, 132.8, 133.1, 133.6, 134.3, 134.4, 134.6, 134.7, 135.0, 135.3, 135.4, 136.2, 136.4, 137.5, 146.7 (Cq), 163.7, 164.0, 164.8, 165.1, 167.4, 167.5, 169.3, 169.4, 169.5 (C=O). − MALDI-MS: *m*/*z* = 1842.0 [M^+], 1864.8 [M^+ + Na], 1881.9 [M^+ + K].

Pretzelane 4e: Potassium carbonate (45.0 mg) was added to a solution of *p*-dibromoxylene (**5**; 430.0 mg, 1.63 mmol), and unprotected in/out-catenane (**4d**; 150.0 mg, 0.08 mmol) in 30 mL dioxane. The mixture was stirred at room temp. for seven days. After filtration the organic phase was washed with water several times and dried over magnesium sulfate. The solvent was removed by distillation and the purification of the product was achieved by column chromatography (SiO_2; 40−60 μm). M.p. > 300 °C. − R_f = 0.15 ($CH_2Cl_2/CH_3CO_2C_2H_5$ = 10:1). − Yield 40 mg (25%). − ^{1}H NMR (400 MHz, [D_8]THF, 25 °C): δ = 0.73 (s, 6 H, CH_3), 1.01 (s, 6 H, CH_3), 1.08 (s, 6 H, CH_3), 1.26 (s, 6 H, CH_3), 1.29 (s, 6 H, CH_3), 1.44 (br, 8 H, Cyh-CH_2), 1.54 (br, 16 H, Cyh-CH_2), 1.87 (br, 16 H, Cyh-CH_2), 2.24−2.36 (m, 12 H, CH_3), 2.67 (s, 6 H, CH_3), 3.80 (s, 4 H, OCH_2), 6.32 (s, 2 H, arom. H), 6.36 (s, 2 H, arom. H), 6.43 (s, 2 H, arom. H), 6.51 (s, 2 H, arom. H), 6.79 (s, 2 H, arom. H), 7.02 (s, 2 H, arom. H), 7.08 (s, 2 H, arom. H), 7.12 (s, 2 H, arom. H), 7.19 (s, 2 H, xylylene-H), 7.28 (s, 2 H, xylylene-H), 7.45 (s, 1 H, Iso-H), 7.48 (t, 1 H, Iso-H), 7.57 (t, ^3J = 7.7 Hz, 1 H, Iso-H), 7.68 (s, 1 H, arom. H), 7.80 (s, 2 H, arom. H), 7.87 (s, 2 H, arom. H), 7.99 (s, 1 H, arom. H), 8.05 (dd, ^3J = 6.8 Hz, 2 H, Iso-H), 8.19 (s, 1 H, Iso-H), 8.31 (dd, ^3J = 7.1 Hz, 2 H, Iso-H), 9.05 (s, 1 H, amide-NH), 9.07 (s, 1 H, amide-NH), 9.12 (s, 1 H, amide-NH), 9.18 (s, 1 H, amide-NH), 9.22 (s, 1 H, amide-NH), 9.31 (s, 1 H, amide-NH), 9.42 (s, 1 H, amide-NH), 9.50 (s, 1 H, amide-NH), 10.92 (s, 8 H, amide-NH). − ^{13}C NMR (100.6 MHz, [D_8]THF, 25 °C): δ = 19.0, 19.1, 19.5, 19.6, 19.7 (CH_3), 23.1, 24.1, 24.2, 24.4, 24.6, 24.7, 27.6, 28.1, 30.1, 30.2, 30.3, 30.8, 35.4, 35.5, 35.7, 37.0, 37.8 (Cyh-CH_2), 45.8, 46.0, 46.1, 46.2, 46.4, 48.6 (Cyh-Cq), 61.4, 61.6, 68.8, 73.2, 74.5, 74.9 (OCH_2), 107.1, 108.4, 108.5, 118.0, 118.1, 119.7, 124.2, 125.3, 125.6, 126.0, 127.3, 128.7, 128.9, 129.1, 129.2, 129.8, 131.8, 131.9, 132.5 (CH), 126.2, 129.8, 132.3, 132.6, 132.8, 133.1, 133.4, 133.6, 133.7, 134.6, 134.9, 135.1, 135.3, 135.8, 135.9, 136.6, 136.8, 137.1, 137.6, 137.8, 138.4, 139.1, 146.9, 147.0, 149.7, 149.9 (Cq), 159.1, 161.6, 163.4, 164.2, 164.7, 165.4, 166.0, 168.9, 169.6, 177.2 (C=O). − MALDI-MS: *m*/*z* = 1944.1 [M^+], 1967.3 [M^+ + Na], 1983.2 [M^+ + K].

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