Catenated Cyclodextrins

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Abstract: A novel synthetic approach is described for the construction of catenanes in aqueous solution from a partially methylated cyclodextrin (CD)—namely, heptakis(2,6-di-*O*-methyl-β-cyclodextrin) (**DM-β-CD**)—and a range of substrate molecules that contain a hydrophobic central core in the form of a 4,4′-disubstituted biphenyl unit (usually bitolyl) carrying two hydrophilic polyether side chains terminated by primary amine functions. In water, the amphiphilic catenane precursors form 1:1 complexes with **β-CD** and **DM-β-CD** and 2:1 (guest:host) complexes with the larger **γ-CD**. Macrocyclizations of the biphenyl-containing substrates with aromatic diacid chlorides in aqueous solution and in the presence of **DM-β-CD** under Schotten–Baumann conditions afforded—in low yields—a range of [2]- and [3]catenanes. When a consitutionally asymmetrical diamine was employed as the substrate, orientational isomers of a [2]catenane were obtained. A [3]catenene incorporating a macrocyclic tetralactam was found to exist as a mixture of head-to-head and head-to-tail isomers, which could be separated by high pressure liquid chromatography and identified unambiguously by nuclear magnetic resonance spectroscopy. One of the [2]catenanes afforded good single crystals from which the solid state structure was determined by X-ray crystallography. Other techniques which aided the characterization of these novel compounds included ultraviolet/visible and luminescence spectroscopy, dynamic nuclear magnetic resonance spectroscopy and fast atom bombardment mass spectrometry. Generally speaking, the catenated cyclodextrins are soluble in halogenated and aromatic hydrocarbons as well as in hydroxylic solvents. The existence of these new compounds gives us a unique insight into the nature of the noncovalent bonding interactions that cyclodextrins employ in binding substrate molecules.

Keywords
catenanes · cyclodextrins · macrocycles · orientational isomerism

Introduction

The naturally occurring cyclic oligosaccharides, the so-called cyclodextrins (CDs), have been the subject of much research for more than 100 years.[1] The three most important CDs are **α-CD**, **β-CD** and **γ-CD**. They are composed, respectively, of six, seven and eight α(1 → 4)-linked D-(+)-glucopyranose units (Fig. 1). These nontoxic torus-shaped macrocycles have been recognized[2] to form inclusion complexes with a wide range of substrates usually, but not always,[3,4] in water. As a result, they have found many commercial applications in the field of chemical technology.[5–7] Because size and shape complementarity is so important for substrate-binding by CDs, different ways of controlling their cavity sizes are required. Traditionally, this objective has been achieved by covalent modification[8] of the primary and/or secondary hydroxyl groups associated with the CD tori. One of the most challenging goals in CD chemistry is the alteration of the interiors of the cavities of the CDs. In recent years, the production of permanently threaded CDs[9,10] on dumbbell-shaped molecules, the so-called rotaxanes,[11] has to

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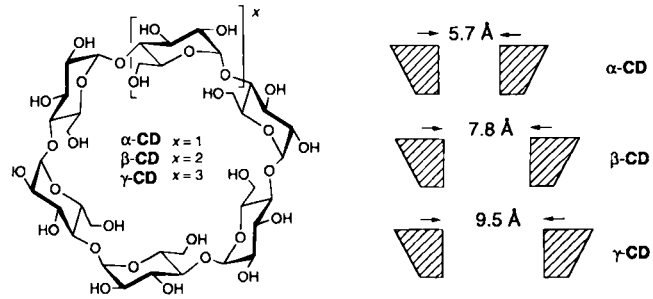

Fig. 1. The molecular formulas of **α-CD**, **β-CD** and **γ-CD**, and their respective cartoons indicating the internal radii of the cavities. These cartoons are employed in Figures and Schemes throughout the paper.

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some extent opened up the way to such modifications. However, it occurred to us that the incorporation of CD rings into catenated structures[12] might provide an alternative way of modifying and controlling the physical, electronic and receptor properties of these carbohydrate-based host molecules. More specifically, it was believed that the reduction in size of the cavity of a **γ-CD** derivative through catenation would allow the development of novel ditopic receptors (Fig. 2) that could potentially bind specific hydrophobic molecules in aqueous solution.

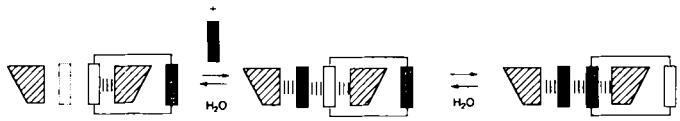

Fig. 2. Schematic representation of a catenated **γ-CD** molecule showing its binding potential for hydrophobic macrocyclic species and substrates in water. Left: [2]Catenane containing a synthetic macrocycle with two possible binding portions, indicated by shaded and unshaded rectangles. Middle: A 1:1 complex between a substrate (block rectangle) and the [2]catenane in water. Right: A translationally isomeric [2]catenane complexing the substrate in water. The diagram indicates a possible molecular switching action in the [2]catenane following substrate binding.

Catenanes have been prepared traditionally by statistical methods and by multistep-directed synthesis.[13] The use of transition metals in recent times as templates has allowed the relatively facile construction of a large range of different catenanes, rotaxanes and knots.[14] Two different methods have been recently employed to generate organometallic catenanes. One of them involves the coordination of a metal centre to the oxygen atoms of a crown ether in an intraannular fashion.[15] In the second approach, Pd or Pt metal centres are part of the entangled macrocycles, but do not intervene in the catenation itself, as the latter is promoted at high concentrations by π–π stacking and hydrophobic interactions between the bridging ligands.[16] Alternatively, π–π stacking and edge-to-face interactions involving aromatic π-donors and π-acceptors, along with hydrogen bonding, have been shown to promote simultaneously cyclization and interlocking to produce catenanes and rotaxanes in high yields.[17] A similar template-directed self-assembly process,[18] which also relies upon a combination of hydrogen-bonding and π–π stacking interactions to form interlocked ring systems, has recently resulted in the formation of novel [2]catenanes with identical rings as a result of one pot macropolycyclizations. Such topologically interesting molecules have already found some potential applications with the construction of a fascinating structure,[19] formed from perpendicular interpenetrating graphite-like networks of manganese and copper spin carriers. They have been shown to act as as a permanent molecular magnet below 22.5 K.

Although the first attempt to make a CD catenane was undertaken more than 35 years ago,[20] there was to our knowledge, when we began our research, no successful synthesis of catenated CDs in the literature.[21] Here, we describe how noncovalent interactions between a chemically modified CD and various difunctionalized amphiphilic compounds can be harnessed by macrocylization in water to produce both [2]catenanes and [3]catenanes. We then describe how we investigated the intriguing physical properties of these novel compounds by a variety of methods, including 1) fast atom bombardment mass spectrometry (FABMS), 2) X-ray crystallography, 3) NMR spectroscopy and 4) UV visible and luminescence spectroscopy. In particular, the relationship between their dynamic behaviour, in *organic* media as well as in *aqueous* solution, and their local symmetries is thoroughly discussed.

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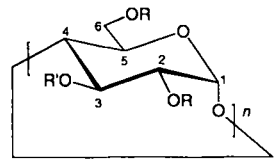
[*] Members of the Editorial Board will be introduced to the readers with their first manuscript.

Results and Discussion

Names and Cartoons: It will be convenient in presenting the results to employ acronyms composed of letters to identify the cyclodextrin components. Thus, heptakis-(2,6-di-*O*-methyl)-*β*-cyclodextrin is abbreviated to **DM-β-CD** and heptakis(2,6-di-*O*-methyl-6-*O*-benzoyl)-*β*-cyclodextrin to **DMBzl-β-CD**. All acronyms and their corresponding structural formula are listed in Figure 3. In the cartoon versions of the structural formulas displayed in other Figures and Schemes, the **DM-β-CD** torus is represented by two identical shaded trapezi. In the representations of the guest molecules, the unshaded rectangles indicate disubstituted aryl residues.



Acronym	n	R	R'
β-CD	7	H	H
DM-β-CD	7	Me	H
TM-β-CD	7	Me	Me
DMBzl-β-CD	7	Me	PhCO
γ-CD	8	H	H
DM-γ-CD	8	Me	Me
DMBzl-γ-CD	8	Me	PhCO

Fig. 3. The acronyms employed in this paper to identify the parent cyclodextrins (**β-CD** and **γ-CD**) and their chemically modified derivatives.

Strategy: The template strategy, which is based on the ability of cyclodextrins to form 1:1 inclusion complexes, has been used

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successfully for the preparation of rotaxanes.[9, 10] The present approach utilizes similar principles. The main difference in the present investigation is that the substrate molecule can undergo cyclization after inclusion in a CD cavity to afford a catenane. It is remarkable that, already by 1958, Lüttringhaus, Cramer, Prinzbach and Henglein[20] had recognized all the essential elements of design that has to be incorporated in a CD guest molecule in order to produce catenated CDs. The general strategy employed in this research, which bears some resemblance to the original approach (Fig. 4), is decribed in Scheme 1. It involves the threading of the cyclodextrin **DM-β-CD** by a molecular "string" containing a rigid and hydrophobic core substituted with two hydrophilic polyether-based side chains[22] of identical or different lengths. Unlike **β-CD** itself, the solubility of **DM-β-CD** in water, as well as in organic media, make it a very attractive host molecule that is not only capable of binding small aromatic compounds strongly, but is also easily purified by standard chromatographic techniques after it has been interlocked by a synthetic macrocycle. Both ends of the substrate molecules can be functionalized with primary amino groups that can then be cyclized in a basic aqueous solution of **DM-β-CD** with relatively water-insensitive aromatic diacid chlorides to yield catenanes. The use of the Schotten–Baumann[23] reaction is essential to the ring-closure step, since it does not require any external reagent or catalyst that could interfere with the complexation process. Furthermore, the acylation of diamines by diacid chlorides has been shown to be an extremely useful reaction for the closure of large and medium-sized macrocycles under high-dilution conditions.[24] Finally, it is vital for the success of the synthesis to prepare guest molecules with appropriate lengths of polyether chains emanating from their hydrophobic cores. After examination of CPK space-filling molecular models, we decided to investigate the catenation of substrates having at least three bismethyleneoxy units per side chain.

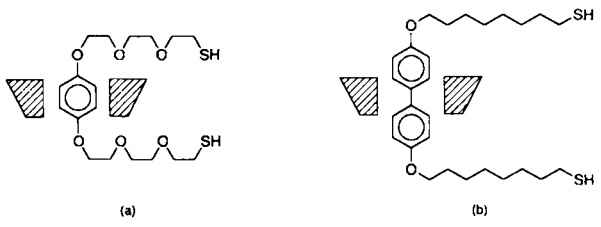
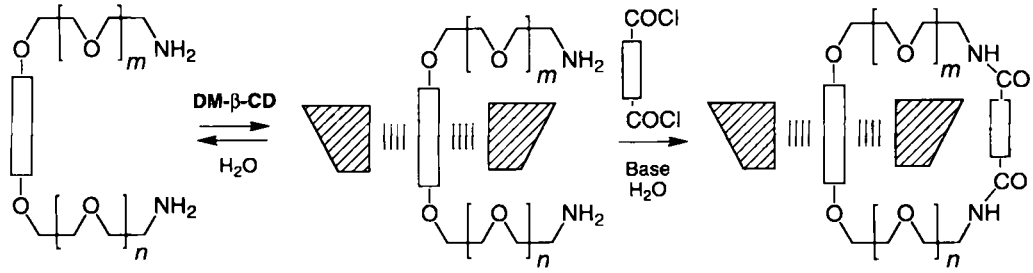


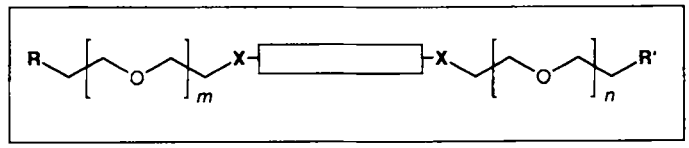
Fig. 4. Two of the 1:1 complexes that were proposed by Lüttringhaus, Cramer, Prinzbach and Henglein to be formed between **β-CD** and dithiols containing (a) a paraphenylene ring and (b) a 4,4'-biphenyl ring.

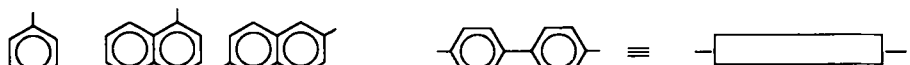


Scheme 1. The general strategy employed in the synthesis of catenated cyclodextrin deivatives based on **DM-β-CD** (unshaded rectangle = aryl, $m = 2-4$, $n = 2-4$).

Synthesis: **γ-CD** was partially methylated[25] with methyl iodide (BaO, $Ba(OH)_2 \cdot 8H_2O$, DMF) to give a mixture of overmethylated **DM-γ-CDs** and **DM-γ-CD**.Benzoylation[26] (PhCOCl, C_5H_5N) of impure **DM-γ-CD** and commercially available but impure **DM-β-CD** gave pure **DM-Bzl-γ-CD** and **DMBzl-β-CD**, respectively, after purification by column chromatography (SiO_2). Hydrolysis (KOH, MeOH) of the benzoate afforded pure **DM-γ-CD** and **DM-β-CD**, respectively.

The range of substrates for the cyclodextrins that have been synthesized is shown in Scheme 2. The diols **1**,[17d] **4**, **5** and **6**





m	3	3	0	3	3	3	3	2	2	2	3	3	4	4	2	2	2	3
n	3	3	0	3	3	3	3	2	2	2	3	3	4	4	2	4	4	3
X	O	CH_2O	CONH	O	O	O	O	CH_2O	CH_2O	CH_2O	CH_2O	CH_2O	CH_2O	CH_2O	CH_2O	CH_2O	CH_2O	CONH
R	OH	OH	OMe	OH	OH	OH	NH_2	OH	OTs	NH_2	OH	NH_2	OH	NH_2	OH	OH	NH_2	NH_2
R'	OH	OH	OMe	OH	OH	OH	NH_2	OH	OTs	NH_2	OH	NH_2	OH	NH_2	OTs	OH	NH_2	NH_2
Compound	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**

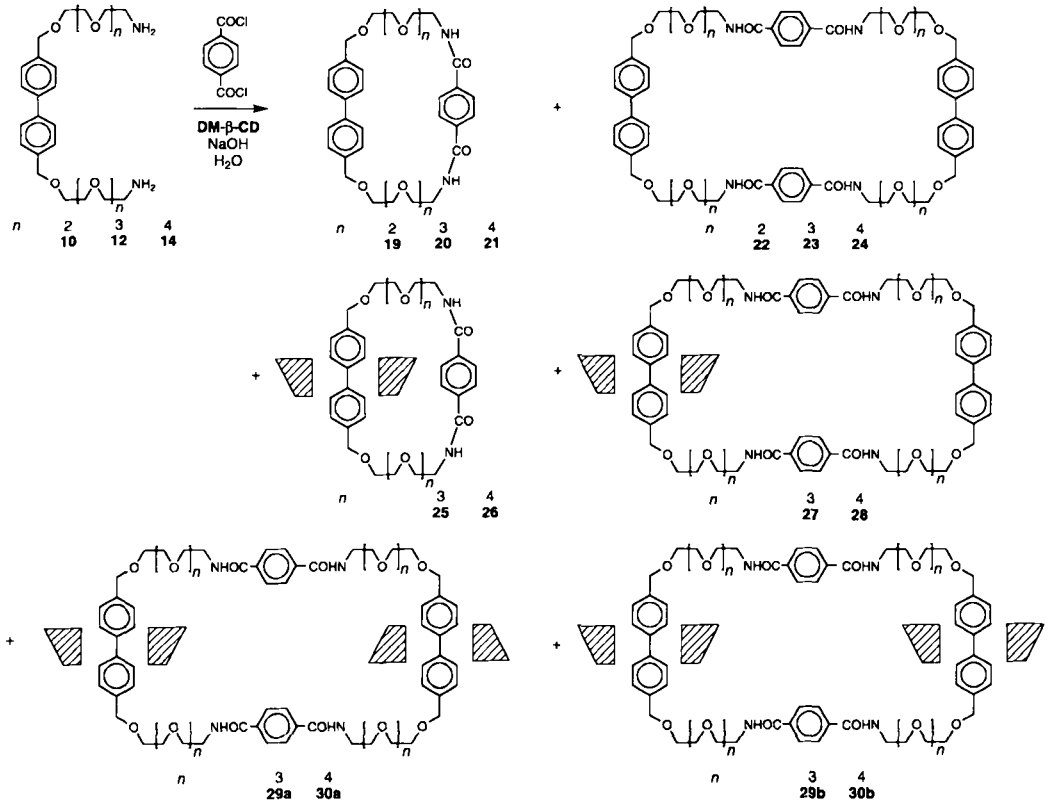
Scheme 2. The range of substrates (**1**–**18**) for **β-CD**, **DM-β-CD**, **TM-β-CD**, **γ-CD** and **DM-γ-CD**.

were obtained by Williamson ether type synthesis starting from 1,4-dihydroxybenzene, 1,5-dihydroxynaphthalene, 2,6-dihydroxynaphthalene and 4,4'-dihydroxybiphenyl, respectively, and tetraethyleneglycol monotosylate.[27] Tetraethyleneglycol monotosylate and monotosylate **15** were prepared under high-dilution conditions (1 mol equiv TsCl, NaOH, THF/H_2O[28] or 1 mol equiv TsCl, CH_2Cl_2, Et_3N, 4-(dimethylamino)pyridine (DMAP)[28]) from an excess of tetraethyleneglycol and diol **8**, respectively. The diols **2**, **8**, **11**, **13** and **16** were prepared by a general alkylation procedure involving the reaction of 1,4-bis-(bromomethyl)benzene and 4,4'-bis(bromomethyl)biphenyl as well as ditosylate **9** and monotosylate **15** with the monosodium salt of di-, tri- or tetraethyleneglycol formed in situ. Bistosylation[28] (2 mol equiv TsCl, NaOH, THF/H_2O) of diols **8**, **11**, **13** and **16**, followed by bis-*N*-alkylation (potassium phthalimide, DMF),[29] afforded the corresponding diphthalimides, which were readily converted by hydrazinolysis (MeOH, $NH_2NH_2 \cdot H_2O$)[29] into the diamines **10**, **12**, **14** and **17**, respectively. The diamine **7** was obtained from diol **6** by direct bis-*N*-alkylation (phthalimide, THF, DEAD, PPh_3),[30] followed by hydrazinolysis (MeOH, $NH_2NH_2 \cdot H_2O$). Diamine **18** was prepared (Et_3N, CH_2Cl_2) under high-dilution conditions by treating biphenyl-4,4'-dicarbonyl dichloride[31] with an excess of 1,11-diamino-3,6,9-trioxaundecane.[29] Finally, bisamide **3** was obtained by treating (Et_3N, CH_2Cl_2) terephthaloyl chloride with 2-methoxyethylamine.

All cyclizations/catenations were carried out in a large volume of dilute (0.01 N) aqueous NaOH solution by treating an equimolar solution of the diamine and **DM-β-CD** with equimolar amounts of the aromatic diacid chloride under sonication. It was noticed that after two hours, although the diacid chloride was consumed entirely, some diamine remained. This situation arises because of partial hydrolysis of the diacid chloride under the reaction conditions. Full conversion of the diamine into acylated products was achieved finally by readjusting the pH to 12 and adding more (1 mol equiv) diacid chloride to the reaction mixture.

Reaction mixtures, following attempted catenations, were invariably found to be composed of free **DM-β-CD**, free macrocycles, and, in addition to catenated **DM-β-CDs**, polyamides. The polyamides were easily separated from the macrocyclic compounds by filtration on SiO_2, since they tend to be much more polar than their cyclic homologues. All the cyclic products were purified by chromatography on silica gel with the exception of the isomeric [2]catenanes **32** and **33**, and [3]catenanes **29a/b** and **30a/b**, which were separated by reverse-phase HPLC.

Under the acylating conditions described above with terephthaloyl chloride as the diacid chloride, the biphenol ether derivative **7** and bitolyl derivative **10** afforded moderate amounts of free macrocycles, both monomer and dimer, but no catenanes. In contrast, the related bitolyl derivative **12** afforded (Scheme 3) not only the free macrocycles **20** (12%) and **23** (3.5%), but also the [2]catenanes **25** (3%) and **27** (0.8%), and the isomeric [3]catenanes **29a** and **29b** (1.1%) in a 40:60 mixture. Similarly, the longer chain bitolyl derivative **14** yielded the free macrocycles **21** (8%) and **24** (0.6%), the [2]catenanes **26** (2.4%) and **28** (0.3%), as well as the isomeric [3]catenanes **30a** and **30b** (0.4%) as a 50:50 mixture. As expected, the constitutionally asymmetric diamine **17** gave free macrocycle **31** (6.5%) and an equimolar mixture of the oriented isomeric [2]catenanes[32] **32** and **33** (1.5%), together with a number of dimeric macrocyclic compounds whose separation was not attempted. The same acylation procedure was employed to produce free macrocycles **34** (41%) and **35** (2.2%) and the [2]catenane **36** (2.7%) from diamine **12** and biphenyl-4,4'-dicarbonyl dichloride, as well as the free macrocycle **37** (26%) and the [2]catenane **38** (0.7%) from diamine **18** and terephthaloyl chloride. In the case of this reaction, the formation of dimeric species was not observed.



Scheme 3. The range of reactions attempted in the catenation of **DM-β-CD** under Schotten–Baumann reaction conditions.

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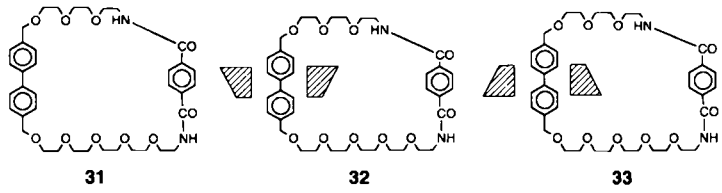

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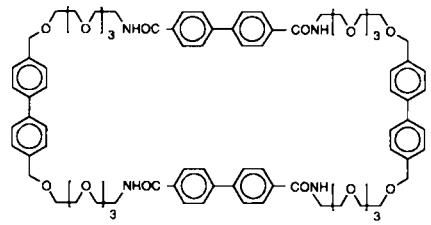

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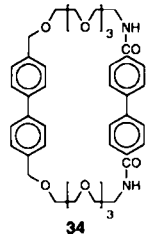

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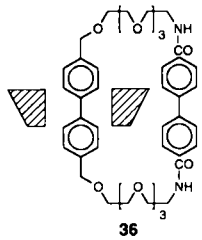

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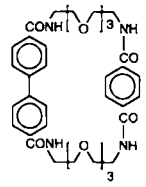

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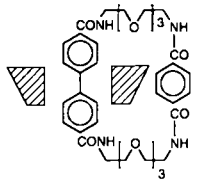

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The relative yields of free macrocycles and catenanes indicate that, somewhat disappointingly, the macrocyclization leading to catenane formation is apparently inhibited by the bound **DM-β-CD** components. This observation has been rationalized along the following lines: Since the CD component does not act as a template for cyclization, the catenation is no more energetically favourable than a simple macrocyclization and might even be inhibited by unfavourable steric interactions. By contrast, it is likely that the intramolecular stacking interactions, that prevail in water between the hydrophobic residues of the uncomplexed straight-chain bisaryl intermediates, template the formation of the free macrocycles. The fact that the yield of free monomeric macrocycle increases from 12 to 41 % when comparing **20** with the more lipophilic **34** lends further support to this hypothesis.

Stability Constants: Table 1 lists the stability constants and derived free energies of complexation for the 1:1 complexes[33] formed between **DM-β-CD** and **1**–**6**, **12** and **18**, as well as for the 1:1 complexes[33] formed between diol **11** and **β-CD**, **DM-β-CD** and **TM-β-CD**. All association constants were obtained in D_2O or 0.1 N NaOD/D_2O[34] at 25 °C by ^{1}H NMR spectroscopy[35] for the equilibrium H + G⇌HG,[36] where H is the host (e.g., **DM-β-CD**), G is the guest (e.g., diol **11**), and HG is the 1:1 complex formed between them. As usual, the K_a and $-\Delta G°$ values are given by $K_a = [HG]/[H][G]$ and $-\Delta G° = RT\ln K_a$,

Table 1. Stability constants (K_a) and derived free energies of complexation ($-\Delta G°$) for the 1:1 complexes formed between **DM-β-CD** and **1**, **2**, **3**, **4**, **5**, **6**, **11**, **12** and **18**, and between **11** and **β-CD** and **TM-β-CD** at 25 °C.

1:1 Complex	K_a (M^{-1})	$-\Delta G°$ (kcal mol^{-1})
[**1**·**DM-β-CD**]	350 ± 25 [a,d,f]	3.50 ± 0.04
[**2**·**DM-β-CD**]	310 ± 50 [a,d,f]	3.40 ± 0.08
[**3**·**DM-β-CD**]	6.8 ± 1.0 [a,d,f]	1.15 ± 0.07
[**4**·**DM-β-CD**]	1180 ± 100 [b,d,g]	4.20 ± 0.04
[**5**·**DM-β-CD**]	2800 ± 100 [c,d,g]	4.70 ± 0.02
[**6**·**DM-β-CD**]	37300 ± 2000 [c,d,g]	6.25 ± 0.04
[**11**·**DM-β-CD**]	31900 ± 3000 [c,d,g]	6.15 ± 0.05
[**12**·**DM-β-CD**]	32800 ± 2400 [c,e,g]	6.15 ± 0.05
[**18**·**DM-β-CD**]	2500 ± 100 [c,e,g]	4.65 ± 0.02
[**11**·**β-CD**]	7000 ± 300 [a,d,g]	5.25 ± 0.03
[**11**·**TM-β-CD**]	660 ± 50 [c,d,g]	3.85 ± 0.02

[a] H-3 probe (host). [b] H-4,8 probe (guest). [c] 6-OMe probe (host). [d] Measured in D_2O. [e] Measured in 0.1 N NaOD/D_2O. [f] ^{1}H NMR titration experiment. [g] ^{1}H NMR dilution experiment.

where R is the gas constant and T is the absolute temperature. A titration procedure[35] involving the measurement of chemical shifts on solutions in which one of the solute species is present in excess was employed for moderately weak complexes ($K_a > 1000\,M^{-1}$, e.g., [**1**·**DM-β-CD**]).[37] For stronger 1:1 complexes ($K_a > 1000\,M^{-1}$, e.g., [**11**·**DM-β-CD**]), the so-called dilution procedure[38] was the method of choice, since the measurement of chemical shifts are made on equimolar solutions of host and guest molecules.[39] It is obvious from the data recorded in Table 1 that the cyclodextrin cavity recognizes only the aromatic part of the guest. Indeed, the hydrophilic side chains have little influence on the binding, since the values of K_a for substrates having identical aromatic moieties, like **1** and **2** or **6** and **11**, are nearly identical. The fact that diamides **3** and **18**, which also contain the *p*-phenylene and 4,4′-biphenylene units, respectively, bind **DM-β-CD** less tightly than their analogues **1**/**2** and **6**/**11**, respectively, may be a result of a destabilizing interaction between the large stable solvation shells located around the bislactam units[40] and the apolar cavity walls of the host. Such solvation shells may arise from favourable multiple hydrogen bonding between the amide functionalities of the aromatic bislactam and water molecules. The data recorded in Table 1 also indicate that the size and the length of the aromatic core in the guest play a major role in the stabilization of the **DM-β-CD** complexes. The largest association constants are observed for the inclusion of 4,4′-biphenylene derivatives **6** and **11**, whereas the *p*-phenylene compounds **1**–**3** and naphthalene derivatives **4** and **5**[41] form weaker complexes. The 4,4′-biphenylene residues in **6** and **11** fill the hydrophobic **DM-β-CD** cavity most completely and provide maximum van der Waals contact with its walls. "High energy" water molecules are thus expelled efficiently from the apolar cavity.

The fact that **DM-β-CD** forms the strongest complex with the bitolyl diol **11** indicates that this CD possesses an extended hydrophobic cavity, which is capable of complexing 4,4′-biphenylene derivatives more efficiently than the **β-CD** cavity (Fig. 5). Because **DM-β-CD** retains the rigidity of its unsubstituted analogue (with intramolecular hydrogen bonding between the 3-OH and 2′-OH or 2′-OMe groups of adjacent glucose units), it is a much better host molecule than the conformationally mobile **TM-β-CD**. In summary, 4,4′-biphenylene compounds and **DM-β-CD** were found to be the best binding partners for achieving catenation.

The association of **γ-CD** and **DM-γ-CD** with bitolyl derivative **11** was also investigated by means of a dilution experiment.

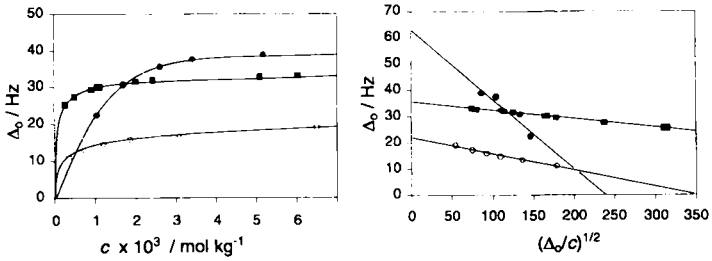

Fig. 5. Binding curves (left) and plots of Δ_0 against $(\Delta_0/c)^{1/2}$ (right) for the 1:1 complexes formed between **11** and **β-CD** (○), **DM-β-CD** (■) and **TM-β-CD** (●, CD H-1 signals).

However, linearization of the binding data according to the 1:1 complexation model failed to give the expected straight lines. The stoichiometry of the complex between **11** and **γ-CD** was shown to be 2:1 (guest:host) by Job plots (Fig. 6).[42] A method

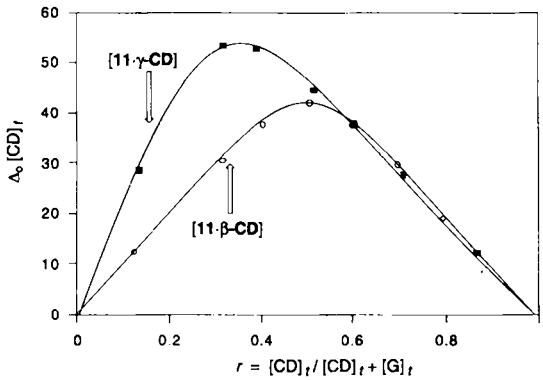

Fig. 6. The Job plots for the interaction between **11** and **β-CD** and **γ-CD**.

similar to the 1:1 dilution experiment, but involving measurements of ^{1}H NMR chemical shifts for solutions of guest and host in a 2:1 ratio,[43] was used to confirm the 2:1 stoichiometry and to provide the equilibrium constant K_a' ($K_a' = [HG_2]/[H][G]^2$). The complex [**11**·**DM-γ-CD**] fits the proposed 2:1 model quite well (Fig. 7). A K_a' value of $1.29 \times 10^{-7}\,M^{-2}$,[44]

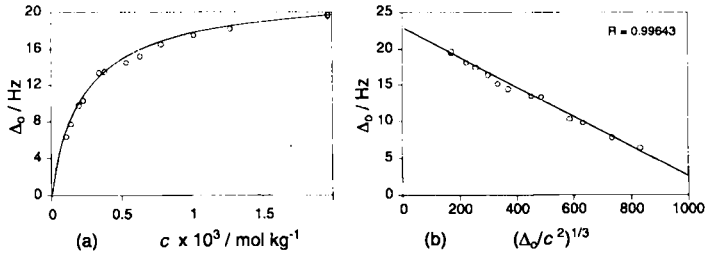

Fig. 7. (a) Binding curves and (b) plots of Δ_0 against $(\Delta_0/c^2)^{1/3}$ for the 2:1 complex formed between **11** and **DM-γ-CD** (CD 6-O-Me signal).

which corresponds to a binding energy of 9.7 kcal mol^{-1}, was obtained. These results are not surprising, since it is known[45] that the cavity of **γ-CD** and its chemically modified derivatives is sufficiently large to include two aromatic residues simultaneously.

FABMS: Ions characteristic of complexes formed between CDs and the amphiphilic guest molecules could not be observed by FABMS. However, in all catenanes, peaks were not only observed for the molecular ions—often including sodium cations—but also for the component macrocyclic rings, which are formed after ring-opening and subsequent mechanical disentanglement of any of the interlocked components. Thus, in addition to peaks for the molecular ions, the [2]catenanes **25**–**28**, **36** and **38**[46] produce fragmentation peaks corresponding to the free macrocyclic components and to a **DM-β-CD** ring, whereas the [3]catenanes **29a/b** (Fig. 8) and **30a/b** afford an additional

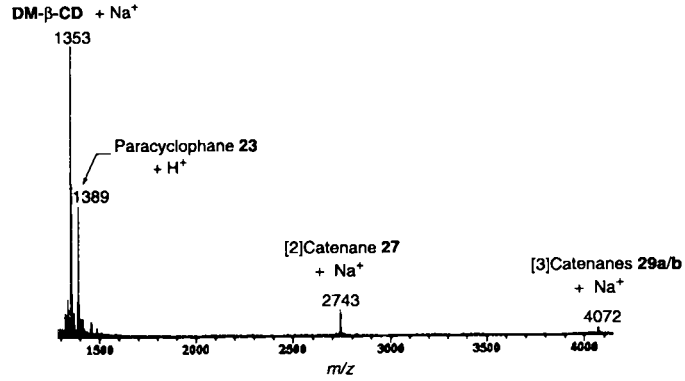

Fig. 8. The FABMS of the isomeric mixture of [2]catenanes, **29a** and **29b**.

peak for the transient [2]catenane formed upon ring-opening of one of the two **DM-β-CD** components. Table 2 lists the FABMS data for all the [2]catenanes and [3]catenanes mentioned.

Table 2. FABMS [a] data for the **DM-β-CD** catenanes.

Compound	*M* [b]	*M*−**DM-β-CD**	*M*−2 × **DM-β-CD**	*M*−Paracyclophane
25	2049 (+ Na)	695 (+ H)	–	1353 (+ Na)
26	2150 (+ K) 2136 (+ Na) 2114	783 (+ H)	–	1353 (+ Na)
27	2743 (+ Na) 2721 (+ H)	1389	–	1353 (+ Na)
28	2916 (+ Na)	1587 (+ Na)	–	1353 (+ Na)
29a/b	4072 (+ Na)	2742 (+ Na)	1389	1353 (+ Na)
30a/b	4245 (+ Na)	2918 (+ Na)	1588 (+ Na)	1354 (+ Na)
32/33	2049 (+ Na)	695 (+ H)	-	1353 (+ Na)
36	2140 (+ K) 2123 (+ Na) 2101	771 (+ H)	-	1353 (+ Na)
38	2074 (+ Na)	721 (+ H)	-	1353 (+ Na)

[a] FABMS were obtained with a Kratos MS80RF mass spectrometer coupled to a DS90 data system with an off-line Sun workstation for data processing. The atom gun (Ion Tech Limited) was operated at 8 keV with a tube current of 2 mA; the primary beam of atoms was produced from research grade Krypton. Samples were dissolved in a small amount of 3-nitrobenzyl alcohol that had previously been coated on to a stainless steel probe, and spectra were recorded in the positive ion mode at a scan speed of 30 sec per decade. [b] The recorded molecular ion for the catenated cyclodextrins.

X-Ray Crystallography: The structure of one of the **DM-β-CD**-containing [2]catenanes, namely **25**, was confirmed by a single-crystal X-ray diffraction study. Colourless single crystals suitable for X-ray crystallography were obtained by the vapour

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diffusion of diisopropyl ether into an ethanolic solution of the [2]catenane. The structure of the [2]catenane **25** (Fig. 9 and 10) reveals that, in the solid state, the bitolyl unit of the macrocyclic bislactam component is positioned inside the **DM-β-CD** torus, and the planar bislactam residue lies against its outer surface. The phenyl rings in the bitolyl unit do not lie in the same plane: the upper ring has a well-defined orientation, while the lower one is disordered and adopts two orientations, twisted by about ±40° with respect to the plane of the upper ring. As a consequence, the lower polyether strand adopts several different conformations. The conformation illustrated in Figure 9 represents

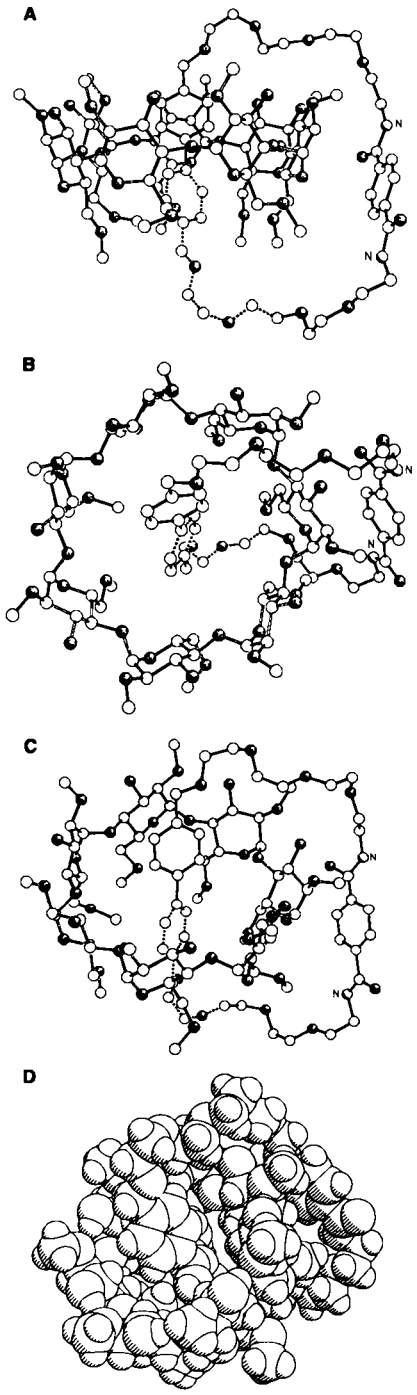

Fig. 9. Ball-and-stick representations of the [2]catenane **25** in the solid state in elevation (**A**), plan (**B**) and general (**C**) perspective. Broken bonds correspond to the disordered region of the macrocyclic bislactam component. **D**: General perspective space-filling representation of the solid state structure of the [2]catenane.

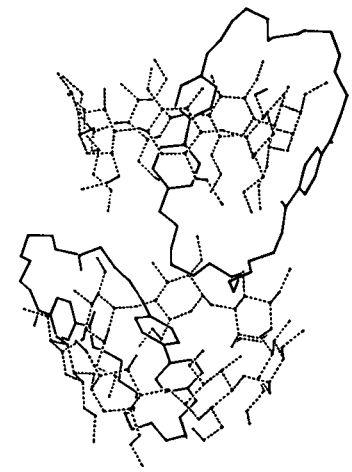

Fig. 10. The pseudo cone-in-cone packing arrangement of the [2]catenane molecules in the solid state.

one of many that can be fitted to the diffuse tube of electron density that appears in this region of the structure. The axis of the bitolyl unit is not inserted perpendicularly through the **DM-β-CD** torus, but is inclined by about 63° with respect to the plane defined by the seven glycosidic oxygen atoms. There is no hydrogen bonding between the polyether oxygen atoms and the 3-OH groups on the upper rim of the CD, which are already involved in intramolecular hydrogen bonding with 2-OMe groups of adjacent glucose units. Indeed, those polyether oxygen atoms that lie over the upper rim of the **DM-β-CD** torus are directed away from the hydroxyl groups. The partial weight included H_2O molecules (i.e., not all the potential sites for water of crystallization are occupied in different molecules of the crystal) lie within hydrogen-bonding distance of one of the amide nitrogen atoms. Interestingly, some of the 6-OMe groups are in van der Waals contact with the lower phenylene ring. On the other hand, the 2-OMe groups are directed away from the centre of the CD cavity as a consequence of the necklace of O–H···O hydrogen bonds. This geometry is consistent with an analysis of complexation-induced shift (CIS) values for [**11**·**DM-β-CD**], which suggests that the 6-OMe groups participate in positioning the guest molecule in the CD cavity.[47] Thus, the position of the biphenyl residue with respect to the **DM-β-CD** component must be similar in both crystalline **25** and [**11**·**DM-β-CD**] in solution. The molecules pack (Fig. 10) in a pseudo cone-in-cone arrangement such that the lower polyether strand of one [2]catenane is inserted partially into the upper orifice of another [2]catenane molecule. This packing phenomenon extends through the crystal.

^{1}H NMR Spectroscopy: The CIS values[48] obtained from the ^{1}H NMR spectra on 100% complexation are listed in Table 3 for non-overlapping probes. These values support the formation of 1:1 pseudorotaxane-like complexes in D_2O between **DM-β-CD** and **1**–**6**, **11**–**12** and **18**, respectively. In these 1:1 complexes, the most significant changes are experienced by the inner-cavity H-3 protons ($\Delta\delta_{max} = -0.17$ to -0.21) on the **DM-β-CD** ring. Interestingly, the CIS values of the signals for the 6-OMe protons increase on going from guests with small aromatic residues, such as **1** and **2**, to those with larger ones, such as **4**–**6** and **11**. This suggests that the 6-OMe groups participate in the binding of substrates with extended aromatic residues. Conversely, with the exception of H-1,[49] protons located at the periphery of the CD torus, such as H-2 and 2-OMe, are hardly

Table 3. ^{1}H NMR chemical shift data ($\Delta\delta$ values) [a] for **DM-β-CD** 1:1 complexes and for catenated **DM-β-CDs** in D_2O at 25 °C.

Compound or Complex	DM-β-CD Component					Synthetic Macrocyclic Component					
						Phenyl	Naphthyl			Biphenyl	
	H-1	H-2	H-3	2-OMe	6-OMe		H-2,6	H-3,7	H-4,8	H-2,2'	H-3,3'
[1·DM-β-CD][b]	−0.07	<0.02	−0.17	<0.02	−0.04	−0.19	—	—	—	—	—
[2·DM-β-CD][b]	−0.08	<0.02	−0.19	<0.02	−0.04	−0.16	—	—	—	—	—
[3·DM-β-CD][b]	−0.18	<0.02	−0.22	<0.02	−0.06	+0.12	—	—	—	—	—
[4·DM-β-CD][b]	−0.14	<0.02	−0.16	<0.02	−0.11	—	−0.03	−0.05	−0.17	—	—
[5·DM-β-CD][c]	−0.10	<0.02	−0.17	<0.02	−0.11	—	—	—	—	—	—
[6·DM-β-CD][c]	−0.08	<0.02	−0.20	<0.02	−0.09	—	—	—	—	—	—
[11·DM-β-CD][c]	−0.09	<0.02	−0.21	<0.02	−0.11	—	—	—	—	−0.22	<0.02
[12·DM-β-CD][c]	−0.09	<0.02	−0.21	<0.02	−0.10	—	—	—	—	−0.21	<0.02
[18·DM-β-CD][c]	−0.08	<0.02	−0.22	<0.02	−0.09	—	—	—	—	−0.25	+0.15
25	−0.22[d]	−0.20[d]	—	−0.06[d]	−0.12[d]	+0.07[e]	—	—	—	−0.30[e]	−0.05[e]
26	−0.21[d]	−0.12[d]	—	−0.05[d]	−0.11[d]	+0.08[e]	—	—	—	−0.27[e]	−0.02[e]
29a	−0.16[d]	−0.05[d]	—	−0.02[d]	−0.14[d]	+0.06[e]	—	—	—	−0.26[e]	−0.03[e]
30a	−0.15[d]	−0.05[d]	—	−0.02[d]	−0.14[d]	+0.06[e]	—	—	—	−0.28[e]	−0.04[e]
29b	−0.16[d]	−0.05[d]	—	<0.02[d]	−0.14[d]	+0.07[e]	—	—	—	−0.28[e]	<0.02[e]
30b	−0.16[d]	−0.05[d]	—	<0.02[d]	−0.13[d]	+0.08[e]	—	—	—	−0.27[e]	−0.05[e]
32	−0.18[d]	−0.13[d]	—	−0.06[d]	−0.08[d]	+0.05[e]	—	—	—	−0.28[e]	−0.04[e]
33	−0.22[d]	−0.15[d]	—	−0.03[d]	−0.10[d]	+0.07[e]	—	—	—	−0.28[e]	<0.02[e]
36	−0.30[d]	−0.18[d]	—	−0.08[d]	−0.17[d]	—	—	—	—	−0.35[e]	−0.10[e,f]
										<0.02[e]	+0.05[e,g]
38	−0.18[d]	−0.16[d]	—	−0.04[d]	−0.08[d]	+0.08[e]	—	—	—	—	—

[a] The $\Delta\delta$ values relate to the chemical shifts changes experienced by non-overlapping probe protons in both the substrate and the host on 100% 1:1 complexation (CIS values) or on catenane formation. **DM-β-CD** H-4, H-5, and H-6a,6b signals overlap with OCH_2 signals of the guest in the region. [b] $\Delta\delta$ was determined by titrating the host with the guest or the guest with the host. [c] $\Delta\delta$ was determined by using a dilution experiment. [d] $\Delta\delta$ = δ(catenane) − δ(free CD). [e] Since all signals for the synthetic component are doubled in the catenanes with respect to the complexes and free species, $\Delta\delta$ was defined as follows: $\Delta\delta$ = δ(catenane) − δ(free acyclic component), where δ(catenane) is the calculated average chemical shift of the no longer degenerate protons and the free acyclic components are **11** and **3** for **25**, **26**, **29a**, **29b**, **30a**, **30b**, **32** and **33**, respectively, **11** and **18** for **36**, and **3** for **38**. [f] Bitolyl protons. [g] Biphenyldicarbonyl protons.

affected ($\Delta\delta_{max} < 0.02$) by the inclusion of a guest molecule. As far as the guests are concerned, the "core" aromatic protons, such as H-2,2' in **11**, **12** and **18**, H-4,8 in **5**, and all the aromatic protons in **1** and **2**, are invariably shifted upfield ($\Delta\delta_{max}$ = −0.17 to −0.25). An exception is the bislactam **3** whose aromatic protons exhibit a downfield shift ($\Delta\delta_{max}$ = + 0.12). The aromatic protons located away from the centre of symmetry of the molecules are either shifted downfield (e.g., H-3,3' in **18**, $\Delta\delta_{max}$ = + 0.15) or slightly upfield ($\Delta\delta_{max}$ = − 0.01 to −0.03, e.g., H-3,3' and H-2,3,6,7 in **11** and **18**, respectively). The consequences of complexation upon the ^{1}H NMR spectra of a CD host and its amphiphilic guest molecule is illustrated in Figure 11 for the complex [**11**·**β-CD**].

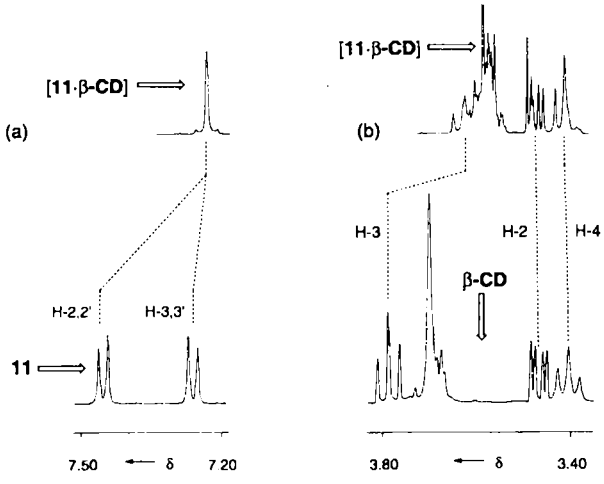

Fig. 11. The influence upon the chemical shifts (^{1}H NMR/400 MHz) of (a) the signals for the aromatic protons in the bitolyl residue of **11** when 1.0 molar equivalent of **β-CD** was added to an aqueous solution, and (b) the signals for H-2, H-3, H-4 (as well as H-5 and H-6a,6b which are not identified) in **β-CD** when 1.0 molar equivalent of **11** was added to an aqueous solution.

The spectroscopic investigations of the catenated CDs were facilitated by the fact that the interlocked species possess quite unusual and distinctive solubility characteristics. With the exception of **27** and **28**,[50] they are soluble in hydroxylic (e.g., H_2O and MeOH), halogenated (e.g., CH_2Cl_2 and $CHCl_3$) and aromatic hydrocarbon (e.g., C_6D_6 and MePh) solvents. In solution, catenated CDs exhibit intercomponent dynamic processes, such as the pirouetting of CD rings (Fig. 12, Process A) and the circumrotation of the synthetic macrocycle through the CD cavity (Process B). The ^{13}C and ^{1}H NMR spectra of all [2]catenanes, recorded in $CDCl_3$ and C_6D_6, as well as in D_2O, show that the **DM-β-CD** components retain their C_7 symmetry, in other words, the expected eight signals are observed, in keeping with rapid pirouetting of the synthetic macrocycle around the CD. However, the original C_{2v} symmetry of **20**, **21**, **34**, and **37** and D_{2h} symmetry of **27** and **28** are lowered to local symmetries that are C_1 and C_2, respectively, under the influence of the chiral **DM-β-CD** rings, which are rapidly circumrotating in all [2]catenanes (Process B). The outcome is a doubling in the number of ^{13}C NMR signals on going from the free synthetic macrocycles to the corresponding [2]catenanes. For example, the signals observed for the bitolyl methylene carbons at δ = 72.9

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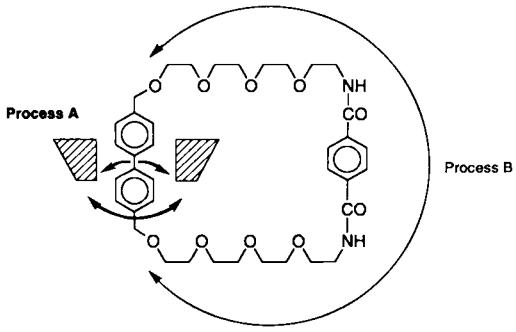

Fig. 12. A schematic representation of the dynamic processes (A and B) occurring rapidly on the ^{1}H NMR time scale at all temperatures investigated for the [2]catenane **25** in $CDCl_3$, C_6D_6 and D_2O. Process A involves the pirouetting of the **DM-β-CD** component about its C_7 axis around the cyclophane, Process B the circumrotation of the cyclophane component through the **DM-β-CD** cavity.

in both **20** and **22** are replaced by signals at $\delta = 72.5$ and 72.9 in **25** and at $\delta = 72.8$ and 72.9 in **27**. Also, in the ^{13}C NMR spectrum of **25**, the amide carbonyl carbons give rise to two signals at $\delta = 167.0$ and 168.0, whereas they resonate as one signal at $\delta = 166.5$ in the ^{13}C NMR spectrum of **20**. The consequences of catenane formation upon the local symmetries of the synthetically derived ring components are also reflected in the ^{1}H NMR spectrum of the [2]catenanes. Most strikingly, the ^{1}H NMR spectra of **25**/**26** in C_6D_6 solution (Fig. 13) reveal the imposed heterotopic character upon sets of aromatic protons within both bitolyl and terephthaloyl units as well as upon the bitolyl methylene protons, each pair of which display their expected diastereotopicities. These various topic relationships result in the presence of three AA′BB′ systems for the 12 aromatic protons and two AB systems for the four bitolyl methylene protons. Similarly, the ^{1}H NMR spectrum of **36** in C_6D_6 (Fig. 14) contains four AA′BB′ systems for the 16 aromatic protons as well as one singlet and an AB system for the four bitolyl methylene protons. In this particular case, the diastereotopicities of the protons of only one methylene group is expressed. Not surprisingly, the ^{1}H NMR spectrum of **38** (Fig. 15) shows three AA′BB′ systems for the 12 aromatic protons, as in **25**. The C_2 symmetry imposed by the **DM-β-CD** component on the cyclophane component in **27**/**28** relates to the three AA′BB′ systems observed in their ^{1}H NMR spectra (Fig. 16) for the 24 aromatic protons as well as to the two singlets observed for the

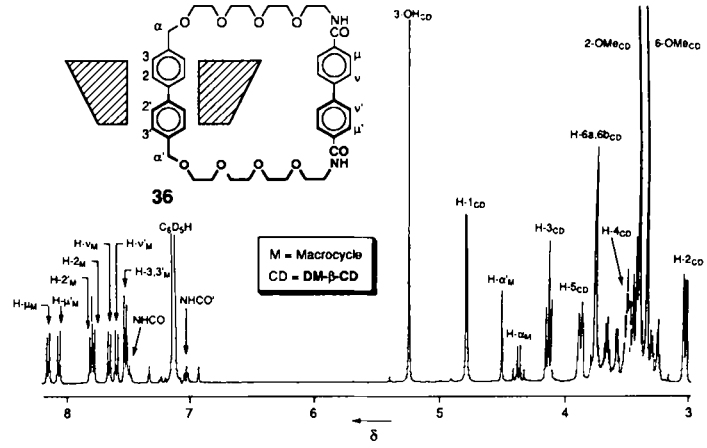

Fig. 14. The ^{1}H NMR spectrum of the [2]catenane **36** recorded at 400 MHz in C_6D_6 at room temperature. The partial shading of the cyclophane emphasizes the fact that the **DM-β-CD** component imposes its C_7 symmetry on the cyclophane, reducing it from its original C_{2v} symmetry to C_1 symmetry.

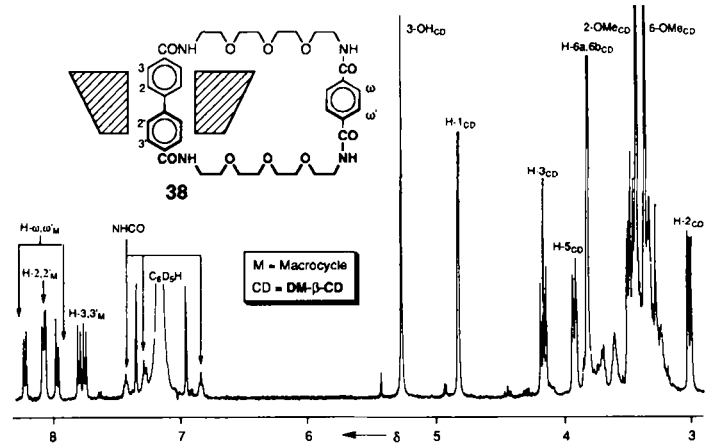

Fig. 15. The ^{1}H NMR spectrum of the [2]catenane **38** recorded at 400 MHz in C_6D_6 at room temperature. The partial shading of the cyclophane emphasizes the fact that the **DM-β-CD** component imposes its C_7 symmetry on the cyclophane, reducing it from its original C_{2v} symmetry to C_1 symmetry.

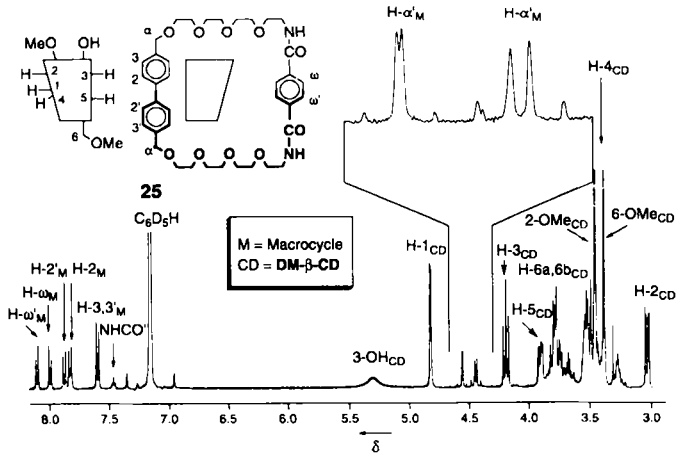

Fig. 13. The ^{1}H NMR spectrum of the [2]catenane **25** recorded at 400 MHz in C_6D_6 at room temperature. The partial shading of the cyclophane emphasizes the fact that the **DM-β-CD** component imposes its C_7 symmetry on the cyclophane, reducing it from its original C_{2v} symmetry to C_1 symmetry.

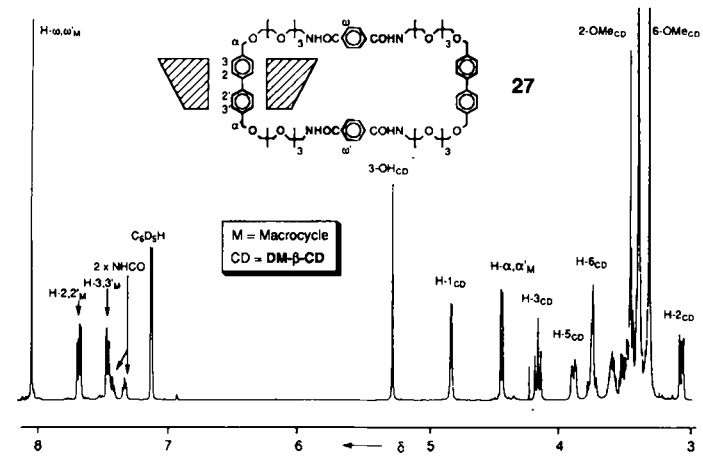

Fig. 16. The ^{1}H NMR spectrum of the [2]catenane **27** recorded at 400 MHz in C_6D_6 at room temperature. The partial shading of the cyclophane emphasizes the fact that the **DM-β-CD** component imposes its C_7 symmetry on the rapidly circumrotating cyclophane, reducing its original D_{2h} symmetry to C_2 symmetry.

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benzylic methylene protons whose diastereotopicities are, however, not revealed in C_6D_6. In all catenanes, the diastereotopic polyether protons overlap with some of the CD protons between $\delta = 3$ and 4. Introducing a further degree of dissymmetry into the synthetic macrocyclic component of catenated CDs gives rise to the two distinct orientational isomers **32** and **33**, which differ from each other only by the orientation of the CD component with respect to the desymmetrized and oriented cyclophane component. In both isomers, the ^{1}H NMR (Fig. 17) and ^{13}C NMR spectra, although distinct, have identical signal patterns in accordance with a local symmetry that is C_1 for both cyclophane components, as in **25**, **26**, **36** and **38**.

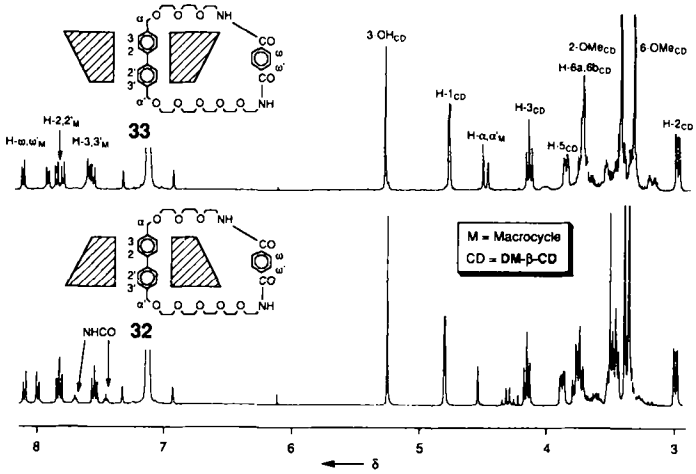

Fig. 17. The ^{1}H NMR spectra of the isomeric [2]catenanes **32** and **33** recorded at 400 MHz in C_6D_6 at room temperature.

Although structurally very similar, the head-to-tail [3]catenanes **29a/30a** and their head-to-head isomers **29b/30b** possess distinctive local symmetries. Both ^{1}H NMR (Fig. 18) and ^{13}C NMR spectra, recorded in C_6D_6 and $CDCl_3$, respectively, indicate that in **29a/30a** the synthetic macrocycles have averaged C_2 symmetry (i.e., they behave like **27/28**), whereas in **29b/30b**, they have D_2 symmetry (i.e., they behave like **23/24**). As for the [2]catenanes, pirouetting of the synthetic macrocycle

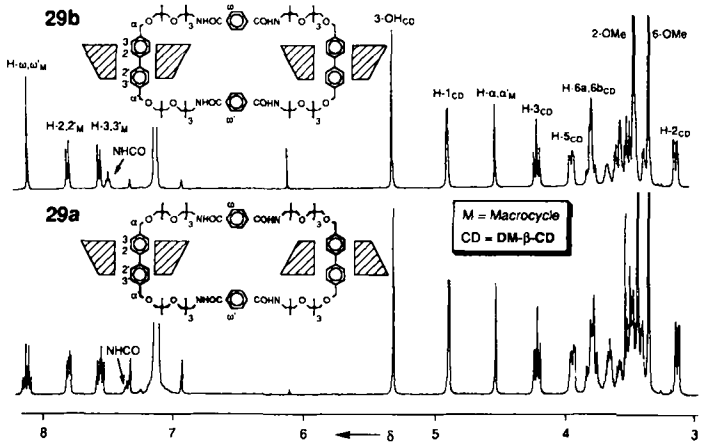

Fig. 18. The ^{1}H NMR spectra of the isomeric [3]catenanes **29a** and **29b** recorded at 400 MHz in C_6D_6 at room temperature. The partial shading of the cyclophane in **29a** highlights the symmetry related portions of the cyclophane, even assuming rapid circumrotation of the cyclophane through the cavity of the C_7 symmetrical **DM-β-CD**.

around the CD torus (Process A) and the circumrotation of the dimeric cyclophane through the CD cavities (process B) account for the observed local symmetries. Figures 19 and 20 highlight the relationship between the local symmetries experienced by the cyclophane component and the number of observed carbon

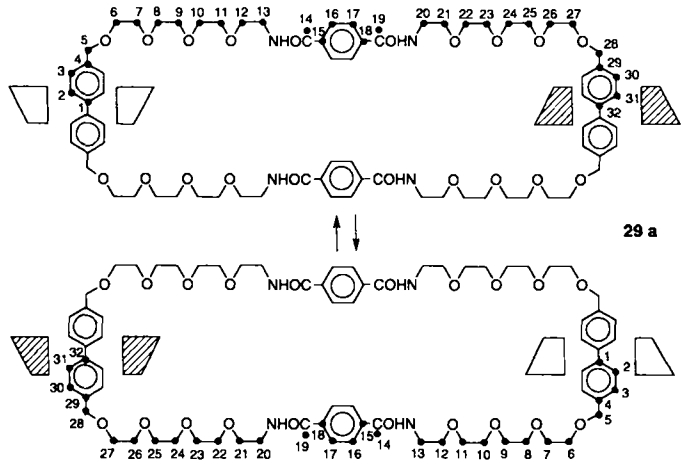

Fig. 19. A pictorial representation of the circumrotation of the cyclophane **23** through the **DM-β-CD** rings in [3]catenane **29a**. The carbon numbering illustrates the fact that, even when the **DM-β-CD** rings are rapidly exchanging on the ^{13}C NMR time scale, the head-to-tail arrangement necessarily induces a doubling up of signals for the cyclophane component.

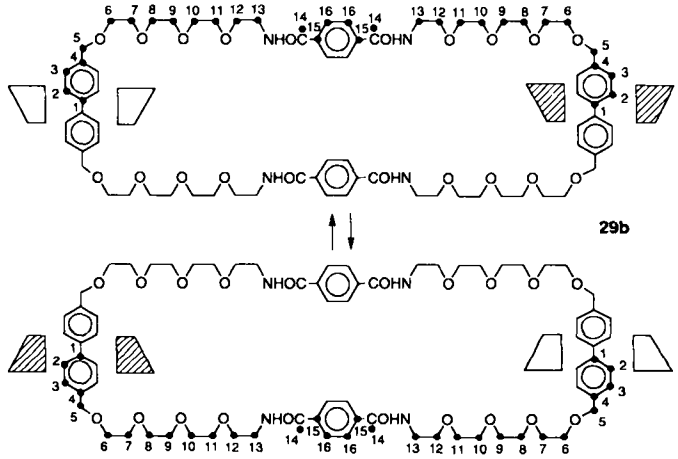

Fig. 20. A pictorial representation of the circumrotation of the cyclophane **23** through the **DM-β-CD** rings in the [3]catenane **29b**. The carbon numbering illustrates the fact that no ^{13}C NMR signal splitting for the cyclophane component occurs when two rapidly exchanging **DM-β-CD** rings on the ^{13}C NMR time scale are disposed in a head-to-head/tail-to-tail fashion.

signals for the synthetic component in isomeric [3]catenanes **29a/b** as a result of the relative orientation of the **DM-β-CD** tori and the rapid intercomponent motions.[51] For example, the bitolyl methylene groups in **29b** can be identified in the ^{13}C NMR spectrum ($CDCl_3$) as one degenerate signal at $\delta_C = 72.8$, but as two distinct signals at $\delta_C = 72.7$ and $\delta_C = 73.0$ in **29a**. Similarly, the terephthaloyl group in **29b** can be identified in the ^{1}H NMR spectrum as a singlet at $\delta = 8.15$, whereas an AA'BB' system is observed at $\delta = 8.13$ in **29a**. The C_7 local symmetries of the **DM-β-CD** components in **29a/b** are maintained, and both CD rings can be identified as a single set of CD signals in the ^{1}H and ^{13}C NMR spectra of the two orientational isomers; this indicates that the **DM-β-CD** tori are equivalent irrespective of

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their relative orientations. Thus, a simple inspection of the ^{1}H NMR and ^{13}C NMR spectra of the isomeric [3]catenanes allowed us to assign unequivocally their corresponding HPLC peaks. Under the reverse-phase elution conditions employed, the head-to-tail isomers **29a**/**30a** were always eluted ahead of the head-to-head isomers **29b**/**30b** (Fig. 21).

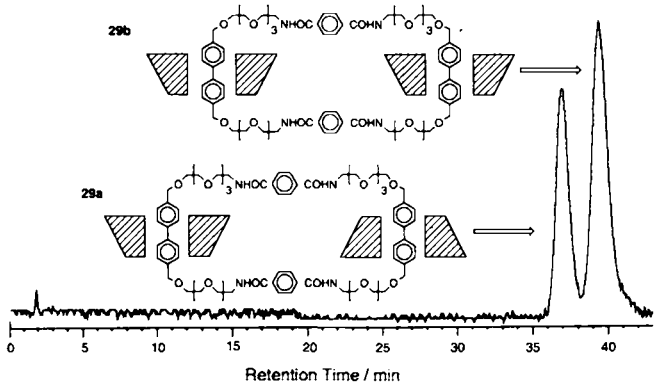


Fig. 21. The elution profile for the separation of the isomeric [3]catenanes **29a** and **29b** by reverse-phase HPLC.

All attempts to gain thermodynamic and kinetic information about the two intercomponent processes A and B by variable temperature ^{1}H NMR spectroscopy have been unsuccessful. The [2]catenane **27** is perfectly constructed for a degenerate process of exchange of the **DM-β-CD** ring to occur between the equivalent bitolyl units in the synthetic component, yet it continues to display local C_2 symmetry down to $-60\,^{\circ}C$ in CD_2Cl_2 solution, where, unfortunately, precipitation occurs. Similarly, the **DM-β-CD** rings interchange simultaneously between equivalent bitolyl units in **29b**/**30b**, and a slow exchange process on the ^{1}H NMR time scale should lower the average symmetry of the synthetic component from D_2 to C_2. The ^{1}H NMR spectrum of **29b** in CD_2Cl_2 does, however, not show any temperature dependence upon cooling to $-60\,^{\circ}C$. This situation arises because the noncovalent intercomponent interactions in catenated CDs are likely to be weak in solvents that allow such low temperature studies to be carried out. In addition, since only small changes in chemical shifts ($\Delta\delta < 0.3$) are detected for protons in the synthetic macrocyclic component upon interlocking, it is improbable that a slow exchange process on the ^{1}H NMR time scale would be observed, even at low temperature ($T < -60\,^{\circ}C$).[50]

The ^{1}H NMR chemical shift differences between the catenanes and the free compounds in D_2O (Table 3) correlate quite well with the CIS values obtained for structurally similar **DM-β-CD** complexes (e.g., [**11**·**DM-β-CD**]) as far as the internal **DM-β-CD** protons H-3 and 6-OMe and aromatic protons H-2,2′ and H-3,3′ are concerned. However, in contrast with the **DM-β-CD** complexes, significant upfield shifts arise for the external **DM-β-CD** protons H-1, H-2 and, to a lesser extent, the 2-O-Me protons upon catenation. Furthermore, these external **DM-β-CD** protons experience larger upfield shifts in [2]catenanes ($\Delta\delta = -0.06$ to -0.30) than in the case of the [3]catenanes ($\Delta\delta = -0.02$ to -0.16). These results suggest that, in the [2]catenanes, one of the aromatic units must be located alongside the CD torus, whereas, in the [3]catenanes the space between two CD rings must remain free.

Structural information in solution about the catenated CDs was also obtained from NOE studies. In the NOE difference spectrum of the [2]catenane **25** in C_6D_6, irradiation of the signals for H-3 and H-5 situated in the inner cavity of **DM-β-CD** produced positive NOE enhancements, principally in the signals for the biphenyl protons, but also, to a lesser extent, in the signals for the terephthaloyl protons in the synthetic component. Similarly, irradiation of the signals for the bitolyl aromatic protons produced small but significant NOEs in the signals for the internal **DM-β-CD** protons H-3 and H-5. Conversely, no such enhancements were observed when the signals for the terephthaloyl protons were irradiated. These results support the view that in organic solvents, like benzene, both bitolyl and terephthaloyl units occupy the cavity of the CD at different times. No such enhancement was observed when the same experiment was performed with **25** in D_2O, a solvent that is believed to promote the noncovalent interactions between the interlocked components. However, significant intercomponent dipolar interactions could be revealed in D_2O, as well as in other deuterated solvents (e.g., C_6D_6), by using the 2D ROESY experiment.[48, 53] The 2D ROESY spectra of **25**, **29a** (Fig. 22), **36**

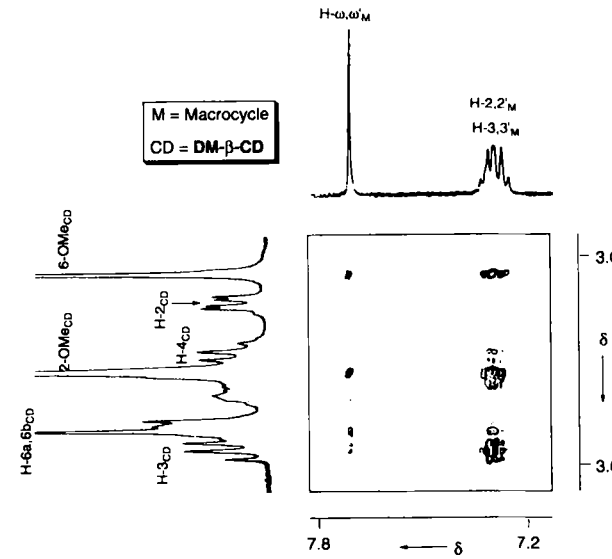
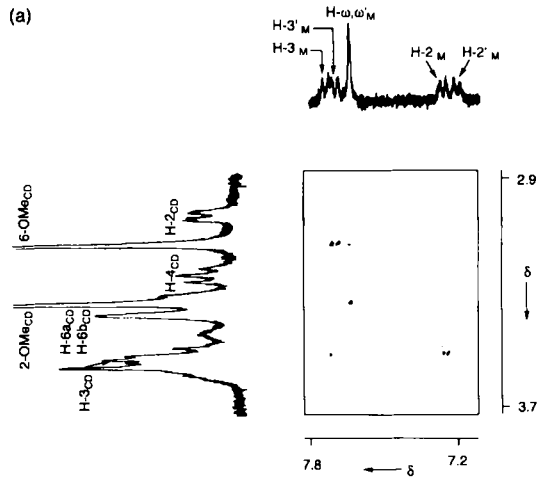


Fig. 22. The aromatic/CD region of the 2D ROESY spectrum of **29a** in D_2O at 298 K.

and **38** (Fig. 23), recorded in D_2O, all contain cross-peaks arising from intercomponent through-space correlation between the biphenyl protons (H-2,2′$_M$ and H-3,3′$_M$) and inner-cavity CD protons (H-3, H-5, H-6a,b and 6-OMe). By contrast, the terephthaloyl protons in **25**, **29a** and **38**, and the biphenyl-4,4′-dicarbonyl protons in **36**, all correlate only with outer-cavity protons of **DM-β-CD** (6-OMe and 2-OMe).[54] These results are consistent with the presence of a single translational isomer in which the bitolyl units in **25**, **29a**, and **36** and the biphenyl-4,4′-dicarbonyl unit in **38** are included in the **DM-β-CD** cavity, whereas the terephthaloyl units in **25**, **29a**, and **38** and the biphenyl-4,4′-dicarbonyl unit in **36** are located outside the **DM-β-CD** cavity. Surprisingly, clear evidence for the exclusive presence of a similar translational isomer was found following analysis of the 2D ROESY spectrum of **25** in C_6D_6 (Fig. 24). The discrepancy between NOE difference and ROESY experiments may arise because, even in C_6D_6, most of the molecules of **25**, but not all, adopt an arrangement in which the bitolyl unit lies inside the **DM-β-CD** cavity. The sensitivity of the ROESY experiment is apparently not high enough to detect any other translational isomer. Interestingly, the aromatic/CD region of the ROESY spectra of the dimeric [2]catenane **27** (Fig. 25) and the



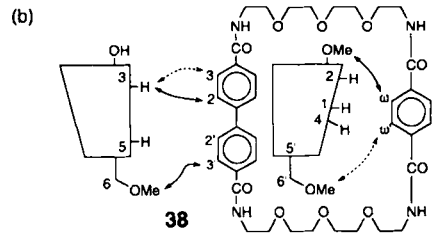


Fig. 23. (a) The aromatic/CD region of the 2D ROESY spectrum of **38** in D_2O at 298 K, and (b) the proposed assignments for the cross-peaks arising from through-space correlations; solid arrow = strong interaction, dotted arrow = weak interaction.

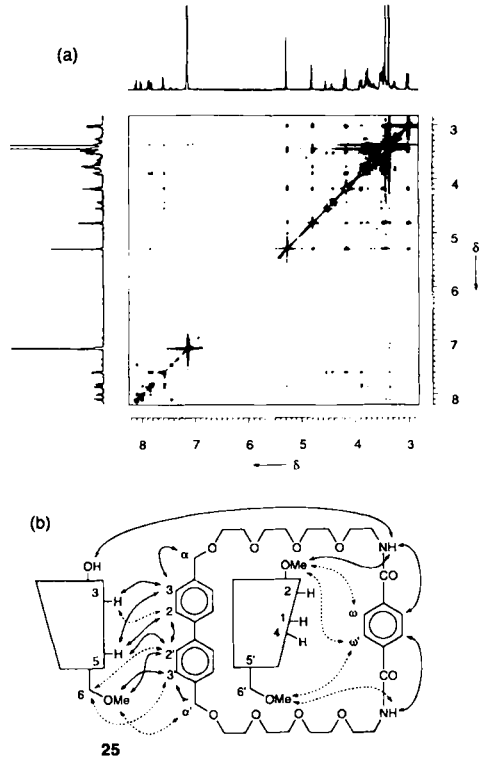


Fig. 24. (a) The 2D ROESY experiment on **25** in C_6D_6 at 298 K, and (b) the proposed assignments for the cross-peaks arising from through-space correlations; solid arrow = strong interaction, dotted arrow = weak interaction.

[2]catenane **36** (Fig. 26) in C_6D_6 contain major cross-peaks that can be assigned to the expected translational isomer in which the bitolyl unit is inserted into the **DM-β-CD** ring. In addition, minor cross-peaks indicate that the bislactam residues in **27** and **36** must also spend some time inside the **DM-β-CD** cavity. In the

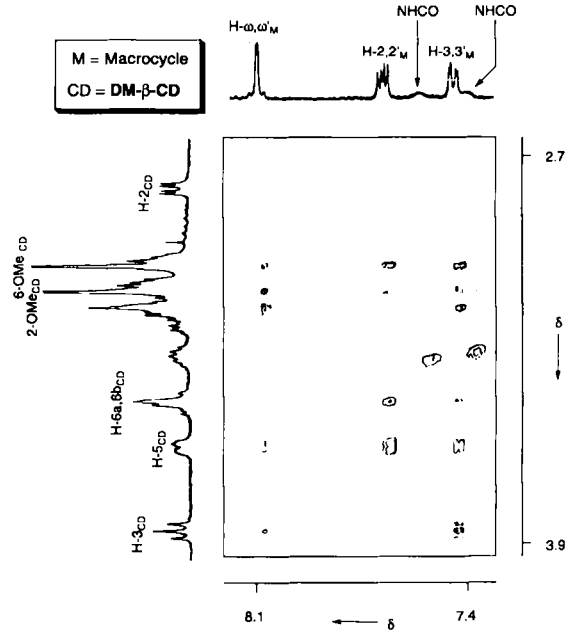


Fig. 25. The aromatic/CD region of the 2D ROESY spectrum of **27** in C_6D_6 at 298 K.

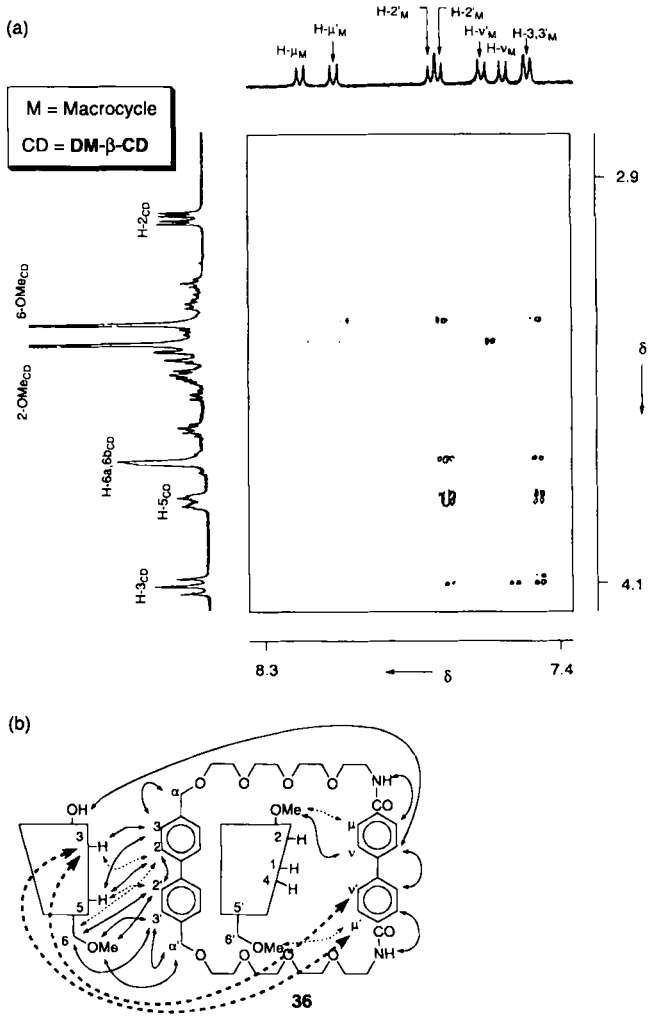


Fig. 26. (a) The aromatic/CD region of the 2D ROESY spectrum of **36** in C_6D_6 at 298 K, and (b) the proposed assignments for the cross-peaks arising from through-space correlations; solid arrow = strong interaction (major translational isomer), dotted arrow = weak interaction (major translational isomer), dashed arrow = weak interaction (minor translational isomer).

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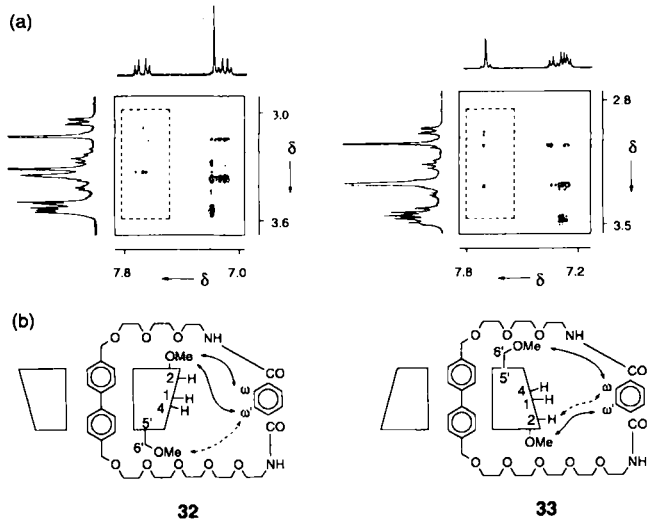

Fig. 27. (a) The aromatic/CD regions of the 2D ROESY spectra of **32** and **33** in C_6D_6 at 298 K, and (b) the proposed assignments for cross-peaks arising from intercomponent through-space correlations between the aromatic protons of the bislactam unit and outer cavity **DM-β-CD** protons (these cross-peaks are included in the dotted boxes).

absence of X-ray crystal structures, the orientational isomers **32** and **33** were identified by comparing their 2D ROESY spectra recorded in D_2O (Fig. 27). In both isomers, cross-peaks originating from through-space correlations between the bitolyl group protons and inner-cavity **DM-β-CD** protons show clearly the insertion of the bitolyl units in the **DM-β-CD** cavity. However, in **32** strong cross-peaks arising from through-space correlations between the terephthaloyl (H-ω,ω') and the secondary methoxy (2-OMe) protons are accompanied by only a very weak cross-peak between H-ω' in the terephthaloyl unit and the primary methoxy protons (6-OMe); this indicates the proximity of the bislactam unit to the upper rim of the CD torus. By contrast, in **33** strong cross-peaks corresponding to NOEs between the terephthaloyl protons (H-ω,ω') and both primary and secondary methoxy protons (6-OMe and 2-OMe) are detected in accordance with a location of the bislactam unit closer to the lower rim of the CD torus. It was therefore possible to conclude that isomer **33** is eluted ahead of isomer **32** under the reverse-phase HPLC elution conditions used (Fig. 28). Because catenated CDs adopt a preferred arrangement, not only in water but also in organic solvents, the ^{1}H NMR spectra of **25** and **36** in C_6D_6, with the exception of the overlapping bismethyleneoxy

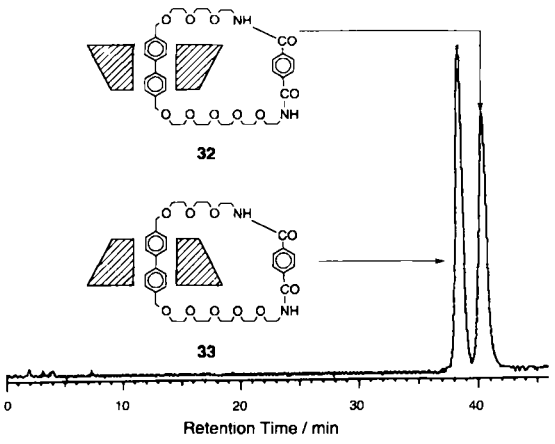

Fig. 28. The elution profile for the separation of **32** and **33** by reverse-phase HPLC.

protons, were fully assigned on the basis of intercomponent through-space correlations as well as from spin–spin correlations that appear in the aromatic-aromatic and CD/CD regions of the 2D ROESY spectra.

Since the synthetic macrocycle in every [2]catenane contains two separate aromatic units that have different sizes and shapes, the possibility of observing translational isomers enabled us to compare the two hydrophobic residues in terms of their affinities for the **DM-β-CD** cavity in water as well as in C_6D_6. Thus, the binding potential of the aromatic units increases in the order: terephthaloyl < biphenyl-4,4'-dicarbonyl < bitolyl. These observations are in full agreement with the stability constants determined for the 1:1 association of **DM-β-CD** with acyclic guest molecules containing the above aromatic residues.

In conclusion, the NMR spectroscopic studies have shown that the binding process in catenated CDs, which is characterized by the presence of translational isomers, is much less solvent-dependent than for a standard bimolecular CD complex. The "hydrophobic effect", which involves the expulsion of "high energy" water from the CD cavity, is no longer a major driving force of complexation since the solvent is not likely to interact significantly with the permanently occupied cavity interior. Stabilization of a given translational isomer may come, at least partially, from interactions between the solvent molecules and the outer-cavity portion of the synthetic macrocylic component. However, the most important contribution to the binding arises from enthalpically favourable van der Waals interactions between the aromatic residues and the inner walls of the **DM-β-CD** torus since the same translational isomers are observed over a range of solvents having different polarities.

Absorption and Luminescence Spectra: In order to understand the spectroscopic and photophysical behaviour of the catenated CDs, the luminescence properties of the [2]catenane **25** and of relevant reference compounds were examined in MeCN solution at room temperature.

[2]Catenane **25** is composed of a **DM-β-CD** unit interlocked with the artificial macrocycle **20**, which contains the diol **11** and the bisamide **3** as chromophoric groups. **DM-β-CD** does not show any absorption or emission. Diol **11** shows an absorption band with $\lambda_{max} = 258$ nm (Table 4) and a luminescence band with $\lambda_{max} = 320$ nm (Fig. 29) and $t = 6.0$ ns. The bisamide component **3** shows an absorption band with a maximum at 236 nm and no luminescence.

The cyclophane **20** shows exactly the absorption bands ($\lambda_{max} = 253$ nm, $\varepsilon_{max} = 30\,700\,M^{-1}cm^{-1}$) expected from the spectra of its two components **11** and **3**. Its luminescence spectrum is at first sight very surprising since it shows two weak

Table 4. UV Absorption and molecular ellipticity of catenated CDs and **DM-β-CD** complexes in H_2O and MeOH for the forbidden π-π^* transition.

Compound	λ_{max} (nm)		$\varepsilon_{max} \times 10^{-4}$ ($M^{-1}cm^{-1}$)		$[\theta_{max}] \times 10^{-4}$ (deg cm^2 dmol^{-1})	
	H_2O	MeOH	H_2O	MeOH	H_2O	MeOH
11	258	–	2.1	–	–	–
[**11**·**DM-β-CD**] [a]	258	–	2.0	–	+1.4 [c]	–
3	236	–	1.9	–	–	–
[**3**·**DM-β-CD**] [b]	242	–	1.7	–	+0.07 [d] +0.19 [e]	–
25	257	253	2.9	2.6	+1.3 [c]	+1.0 [c]
27	–	254	–	3.7	–	+0.9 [c]
29a	257	259	3.6	4.1	+1.3 [c]	+1.2 [c]
29b	257	255	3.7	4.1	+2.3 [c]	+2.1[c]

[a] 2 mol equiv **DM-β-CD**, [b] 30 mol equiv **DM-β-CD**, [c] $\lambda_{max} \approx 257$ nm, [d] $\lambda_{max} \approx 220$ nm, [e] $\lambda_{max} \approx 300$ nm.

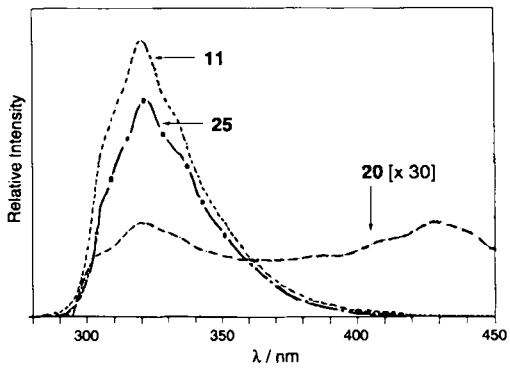

Fig. 29. Fluorescence spectra in MeCN solution at room temperature of diol **11**, free cyclophane **20** and [2]catenane **25**.

bands (Fig. 29) with maxima at 320 nm ($t < 0.5$ ns) and 420 nm ($t = 2.5$ ns). The first band is similar to that displayed by **11**, but much weaker in intensity and considerably shorter lived. The reason why this band is strongly quenched in **20** is most likely an exciplex-type interaction[55] with the bisamide moiety. This view is supported by the appearance of the new broad and weak exciplex-type emission band at 420 nm (Fig. 29). The excitation spectra of **20** recorded at $\lambda_{em} = 320$ and 420 nm have exactly the same shape. Compared with the absorption spectrum, the bisamide band with $\lambda_{max} = 236$ nm is missing. This indicates that the two emission bands originate (directly or indirectly) from excitation of the diol moiety and thus supports the assignment of a monomer-type and an exciplex-type emission.

[2]Catenane **25** shows an absorption spectrum similar but not identical to that of **20**. Its maximum is at 257 nm with $\varepsilon = 20000\,M^{-1}\,cm^{-1}$. A tail for $\lambda > 280$ nm can also be observed. These differences can be attributed to the different environment provided by the cyclodextrin to the chromophoric groups. The emission spectrum of **25** is very different from that of **20** and similar to that of **11** (Fig. 29). In fact, the 420 nm exciplex-type band of **20** is no longer present, while the monomer-type band with a maximum at 320 nm recovers most of the intensity (about 70%) exhibited in free **11**. That the monomer-type emission is not quenched by the presence of an excimer-type interaction in **25** is also shown by lifetime measurements ($t = 6.6$ ns). As expected, the shape of the excitation spectrum of **25** ($\lambda_{em} = 320$ nm) is identical to that of **11**.

The different luminescence behaviour of catenane **25** compared with cyclophane **20** can be easily explained. When **20** is interlocked with **DM-β-CD** in the catenane structure, the dimethylbiphenyl and bisamide moieties can no longer interact, since they are separated by the wall of the cyclodextrin torus-shaped cavity. The different luminescence behaviour of **20** and **25** is a direct proof of the interlocking between **DM-β-CD** and **20**, but unfortunately it does not offer any indication concerning translational isomerism, because the suppression of the excimer emission is expected to take place regardless of which chromophoric moiety of **20** is included in the cyclodextrin cavity.

Conclusion

In this paper, we have demonstrated, that, by using carefully designed components, the catenation of CDs can be achieved—albeit only in very low yields at this time. Attempts to catenate CDs had been made 37 years ago. Undoubtedly, only a combination of the powerful analytical methods available today, together with a judicious choice of reaction type for ring closure, allowed us to prepare these fascinating molecular compounds. Catenated cyclodextrins will, however, have to be made much more efficiently if they are to find applications. In the meantime, the fact that the [2]catenanes and [3]catenanes incorporating **DM-β-CD** units can be made opens up an opportunity for a fresh experimental insight into just how cyclodextrins practise their important inclusion-forming functions at a fundamental level.

Experimental Section

General Methods: Chemicals were purchased from Aldrich and used as received with the exception of 1) heptakis(2,6-di-*O*-methyl)-β-cyclodextrin (**DM-β-CD**), purchased from Teijin Limited (Japan) and purified according to a literature procedure; 2) toluene-*p*-sulfonyl chloride, which was dissolved in CH_2Cl_2 at room temperature, filtered, precipitated by adding light petroleum (b.p. 40–60 °C), isolated and then dried in vacuo and stored in a dessicator; and 3) terephthaloyl chloride, which was recrystallized from dry hexane, dried in vacuo and stored in a dessicator. Solvents were dried (CH_2Cl_2 from P_2O_5, DMF from CaH_2, MeCN from P_2O_5 and pyridine from CaH_2) according to procedures described in the literature [56]. 1,11-Diamino-3,6,9-trioxaundecane [29], biphenyl-4,4'-dicarbonyl dichloride [31] and 4,4'-bis(bromomethyl)biphenyl [57] were prepared according to published literature. Thin layer chromatography (TLC) was carried out on aluminium sheets precoated with silica gel 60 F (Merck 5554) or glass plates precoated with reverse-phase silica gel RP-8 F (Merck 15684). The plates were inspected by UV light and developed either with iodine vapour or with 5% H_2SO_4 in EtOH. Preparative TLC was performed on silica gel 60 F (Merck 5717). Column chromatography was carried out using silica gel 60 F (Merck 9385, 230–400 mesh). High performance liquid chromatography (HPLC) was attained with a Gilson 714 system fitted with a UV detector. Melting points were determined on an Electrothermal 9200 apparatus. Microanalyses were performed by the University of Birmingham Microanalytical Service. Low resolution mass spectra (MS) were obtained on a Kratos Profile spectrometer operating in electron impact (EIMS) or chemical ionisation (CIMS) mode, whilst fast atom bombardment mass spectra (FABMS) were recorded on a Kratos MS 80 spectrometer operating at 8 keV with a xenon primary atom beam. The matrix used was 3-nitrobenzyl alcohol (NOBA). Specific optical rotations were measured on a Perkin-Elmer 457 polarimeter. ^{1}H NMR Spectra were recorded on either a Bruker AC 300 (300 MHz) spectrometer or a Bruker AMX 400 (400 MHz) spectrometer with either the solvent reference or TMS as internal standards. When the spectra were recorded in D_2O, the sodium salt of 3-trimethylsilyl-2,2,3,3-tetradeuteropropionic acid (TSP) was used as external reference. ^{13}C NMR Spectra were recorded on a Bruker AC 300 (75.5 MHz) spectrometer or a Bruker AMX 400 (100.6 MHz) spectrometer using the JMOD pulse sequence.

Octakis(2,6-di-*O*-methyl-3-*O*-benzoyl)-γ-CD (DMBzl-γ-CD): Barium oxide (37.5 g, 262 mmol) and barium hydroxide octahydrate (19.3 g, 135 mmol) were added to a stirred solution of **γ-CD** (25.0 g, 19.2 mmol) in DMF (450 mL) at 0 °C under nitrogen. The temperature was maintained below 5 °C during the slow addition of methyl iodide (54.5 g, 384 mmol), and the mixture was then stirred for 3 h at room temperature. The inorganic material was collected on Celite and washed with $CHCl_3$. The combined filtrate and washings were neutralized with dilute aqueous H_2SO_4 and evaporated to dryness under high vacuum. The resulting cake was dissolved in $CHCl_3$ (200 mL), washed successively with aqueous sodium thiosulfate solution (75 mL, ca. 10%) and H_2O (75 mL), dried ($MgSO_4$), and evapourated to dryness to yield a white solid. Column chromatography (SiO_2, PhMe:Me_2CO:MeOH 58:33:9) and subsequent recrystallization from $CHCl_3$/hexane afforded a mixture of methylated γ-CDs (4.2 g) containing mainly **DM-γ-CD**. Distilled benzoyl chloride (46 mL, 396 mmol) was added to a solution of the mixture of the methylated **γ-CDs** (3.2 g) in dry pyridine (75 mL). The dark red solution was stirred at 40–50 °C under nitrogen for 4 days, and the resulting dark brown solution was evaporated to dryness in vacuo. The residual black tar was dissolved in pyridine (10 mL), MeOH (50 mL) was added with cooling, and the solution was stirred for 1 h at room temperature before being evaporated to dryness in vacuo. The residue was dissolved in $CHCl_3$ and was washed sequentially with 0.1 N HCl (75 mL) and H_2O (75 mL). The organic solution was dried ($MgSO_4$) and evaporated to dryness to yield a dark brown solid. The crude material chromatographed (SiO_2, PhMe:EtOH 8:2) to afford, in order of their elution from the column, a mixture of overmethylated **DM-γ-CD** benzoates (1.2 g) and **DMBzl-γ-CD** (2.6 g, 6%): m.p. 142 °C; $[\alpha]_D$ −78 (*c*, 1.0 in $CHCl_3$); FABMS: *m/z* 2376 $[M + Na]^+$, 2393 $[M + K]^+$; ^{1}H NMR (400 MHz, $CDCl_3$, 50 °C) $\delta = 2.86$ (24H, s, 2-*O*-Me), 3.37 (8H, dd, $^3J_{1,2} = 3.6$ Hz, $^3J_{2,3} = 9.6$ Hz, H-2), 3.44 (24H, s, 6-*O*-Me), 3.66 (8H, dd, $^3J_{5,6a} = 1.5$ Hz, $^2J_{6a,6b} = 11.0$ Hz, H-6a), 3.94 (8H, dd, $^3J_{3,4} = 8.8$ Hz, $^3J_{4,5} = 9.5$ Hz, H-4), 4.01 (8H, dd, $^3J_{5,6b} = 3.8$Hz, $^2J_{6a,6b} = 11.0$ Hz, H-6b), 4.17 (8H, ddd, $^3J_{4,5} = 9.5$ Hz, $^3J_{5,6a} = 1.5$ Hz, $^3J_{5,6b} = 3.8$ Hz, H-5), 5.09 (8H, d, $^3J_{1,2} = 3.6$ Hz, H-1), 5.62 (8H, dd, $^3J_{3,4} = 8.8$ Hz, $^3J_{2,3} = 9.6$ Hz, H-3), 7.20–7.25 (16H, m, *m*-benzoyl protons), 7.31–7.35 (8H, m, *p*-benzoyl protons), 7.92–7.97 (16H, m, *o*-benzoyl protons); ^{13}C NMR (75.5 MHz, $CDCl_3$, 50 °C) $\delta = 58.7$ (2-*O*-Me), 59.0 (6-*O*-Me), 71.0 (C-5),

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71.1 (C-6), 73.4 (C-3), 77.4 (C-4), 79.5 (C-2), 99.1 (C-1), 127.7, 129.8, 131.3, 131.9 (benzoyl carbons), 164.8 (*C*=O). Anal. calcd for $C_{120}H_{144}O_{48}$: C, 61.2; H, 6.16. Found: C, 60.0; H, 6.34.

Octakis(2,6-di-*O*-methyl)-γ-cyclodextrin (DM-γ-CD): Aqueous 6 N KOH solution (25 mL) was added to a solution of **DMBzl-γ-CD** (2.87 g, 1.21 mmol) in MeOH (100 mL). The mixture was stirred at room temperature for 18 h. The solvents were removed under reduced pressure and the residue was dissolved in H_2O (75 mL). The aqueous solution was extracted with Et_2O (2 × 75 mL) and subsequently with benzene (3 × 75 mL). The benzene extracts were washed with saturated NaCl solution (75 mL), dried ($MgSO_4$) and evaporated to dryness. Recrystallization of the residual solid from $CHCl_3$/hexane afforded **DM-γ-CD** (1.45 g, 78%): m.p. 261–263 °C (decomp.) (ref. [25]: m.p. 260–264 °C (decomp.)); $[\alpha]_D$ +134 (*c*, 1.0 in $CHCl_3$) (ref. [25]: $[\alpha]_D$ +180 (*c*, 1.0 in H_2O); FABMS: *m/z* 1545, 1561, 1645 and 1677 ([*M* + Na]$^+$, [*M* + K]$^+$, [*M* + 3-nitrobenzyl alcohol−CH_2OH + H]$^+$ and [*M* + 3-nitrobenzyl alcohol + H]$^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.17 (8H, dd, $^3J_{1,2}$ = 3.9 Hz, $^3J_{2,3}$ = 9.6 Hz, H-2), 3.35 (24H, s, 6-*O*-Me), 3.50 (24H, s, 2-*O*-Me), 3.53 (8H, t, $^3J_{3,4}$ = 9.4 Hz, $^3J_{4,5}$ = 9.4 Hz, H-4), 3.79 (8H, dd, $^3J_{5,6a}$ = 1.3 Hz, $^2J_{6a,6b}$ = 10.5 Hz, H-6a), 3.88 (8H, $^3J_{5,6b}$ = 4.9 Hz, $^2J_{6a,6b}$ = 10.5 Hz, H-6b), 3.99 (8H, ddd, $^3J_{4,5}$ = 9.4 Hz, $^3J_{5,6a}$ = 1.3 Hz, $^3J_{5,6b}$ = 4.9 Hz, H-5), 4.25 (8H, t, $^3J_{2,3}$, $^3J_{3,4}$ = 9.4 Hz, H-3), 4.97 (8H, d, $^3J_{1,2}$ = 3.9 Hz, H-1), 5.43 (8H, brs, 3-O*H*); ^{13}C NMR (75.5 MHz, C_6D_6) δ = 58.7 (6-*O*-Me), 60.4 (2-*O*-Me), 71.1 (C-5), 71.8 (C-6), 74.1 (C-3), 83.1 (C-2), 84.3 (C-4), 102.1 (C-1). Anal. calcd for $C_{64}H_{112}O_{40}$: C, 50.5; H, 7.42. Found: C, 50.4; H, 7.37.

Heptakis(2,6-di-*O*-methyl-3-*O*-benzoyl)-β-cyclodextrin (DMBzl-β-CD) [26]: Benzoylation of impure commercial **DM-β-CD** (13.8 g, 10.4 mmol) was carried out according to the procedure described previously for the **γ-CD** series. Column chromatography (SiO_2, PhMe:EtOH 8:2) of the crude afforded, in order of their elution from the column, a mixture of overmethylated **β-CD** benzoates (4.12 g) and **DMBzl-β-CD** (7.84 g, 38%): m.p. 134–136 °C (ref. [26]: m.p. 134–136 °C); $[\alpha]_D$ −96 (*c*, 1.0 in $CHCl_3$) (ref. [26]: $[\alpha]_D$ −93 (*c*, 1.0 in $CHCl_3$)); FABMS: *m/z* 2081 [*M* + Na]$^+$; ^{1}H NMR (400 MHz, CD_3COCD_3) δ = 2.69 (21H, s, 2-*O*-Me), 3.25 (7H, dd, $^3J_{1,2}$ = 3.5 Hz, $^3J_{2,3}$ = 10.0 Hz, H-2), 3.39 (21H, s, 6-*O*-Me), 3.67 (7H, dd, $^3J_{5,6a}$ = 1.5 Hz, $^2J_{6a,6b}$ = 11.0 Hz, H-6a), 3.85 (7H, dd, $^3J_{3,4}$ = 9.5 Hz, $^3J_{4,5}$ = 9.5 Hz, H-4), 4.01 (7H, dd, $^3J_{5,6b}$ = 4.0 Hz, $^2J_{6a,6b}$ = 11.0 Hz, H-6b), 4.10 (7H, ddd, $^3J_{4,5}$ = 9.5 Hz, $^3J_{5,6a}$ = 1.5 Hz, $^3J_{5,6b}$ = 4.0 Hz, H-5), 5.03 (7H, d, $^3J_{1,2}$ = 3.5 Hz, H-1), 5.61 (7H, dd, $^3J_{2,3}$ = 10.0 Hz, $^3J_{3,4}$ = 9.5 Hz, H-3), 7.29–7.34 (14H, m, *m*-benzoyl protons), 7.40–7.44 (7H, m, *p*-benzoyl protons), 8.03–8.08 (14H, m, *o*-benzoyl protons); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 58.7 (2-*O*-Me), 59.0 (6-*O*-Me), 71.5 (C-5), 71.7 (C-6), 73.9 (C-3), 78.7 (C-4), 79.6 (C-2), 99.7 (C-1), 127.7, 129.0, 131.7, 131.8 (benzoyl carbons), 164.6 (*C*=O).

Heptakis(2,6-di-*O*-methyl)-β-cyclodextrin (DM-β-CD) [26]: Debenzoylation of **DMBzl-β-CD** (6.4 g, 3.11 mmol) according to the procedure described previously for the **γ-CD** series afforded **DM-β-CD** as a colourless solid (3.12 g, 75%), m.p. > 270 °C (ref. [26]: m.p. > 270 °C); $[\alpha]_D$ +116 (*c*, 1.0 in $CHCl_3$) (ref. [26] $[\alpha]_D$ +110 (*c*, 1.1 in $CHCl_3$)); FABMS: *m/z* 1353, 1453 and 1484 ([*M* + Na]$^+$, [*M* + 3-nitrobenzyl alcohol−CH_2OH + H]$^+$ and [*M* + 3-nitrobenzyl alcohol + H]$^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.21 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.4 Hz, H-2), 3.29 (21H, s, 6-*O*-Me), 3.51 (21H, s, 2-*O*-Me), 3.62 (7H, dd, $^3J_{3,4}$ = 9.1 Hz, $^3J_{4,5}$ = 10 Hz, H-4), 3.76 (7H, dd, $^3J_{5,6a}$ = 1.7 Hz, $^2J_{6a,6b}$ = 10.6 Hz, H-6a), 3.84 (7H, dd, $^3J_{5,6b}$ = 4.6 Hz, $^2J_{6a,6b}$ = 10.6 Hz, H-6b), 4.10 (7H, ddd, $^3J_{4,5}$ = 10.0 Hz, $^3J_{5,6a}$ = 1.7 Hz, $^3J_{5,6b}$ = 4.6 Hz, H-5), 4.45 (7H, dd, $^3J_{2,3}$ = 9.4 Hz, $^3J_{3,4}$ = 9.1 Hz, H-3), 4.93 (7H, d $^3J_{1,2}$ 3.7 Hz, H-1), 5.44 (7H, s, 3-O*H*); ^{13}C NMR (100.6 MHz, C_6D_6) δ = 58.7 (6-*O*-Me), 60.4 (2-*O*-Me), 71.1 (C-5), 71.8 (C-6), 74.4 (C-3), 82.9 (C-2), 84.7 (C-4), 102.3 (C-1). Anal. calcd for $C_{56}H_{98}O_{35}$: C, 50.5; H, 7.42. Found: C, 50.2; H, 7.55.

2-[2-(2-(Toluene-*p*-sulfonyl)ethoxy)ethoxy)ethoxy]ethanol (Tetraethyleneglycol Monotosylate) [28]: A solution of toluene-*p*-sulfonyl chloride (20.0 g, 105 mmol) in CH_2Cl_2 (300 mL) was added dropwise over 3 h with vigorous stirring to a solution of tetraethyleneglycol (82.3 g, 424 mmol), triethylamine (39.9 g, 385 mmol), DMAP (0.65 g, 5.3 mmol) in CH_2Cl_2 (1.7 L) at 0 °C. The reaction mixture was then allowed to warm up to room temperature before being stirred for 2 h. After partial removal of the solvent in vacuo, the remaining solution (500 mL) was washed successively with saturated aqueous $NaHCO_3$ (2 × 200 mL), 1 M aqueous citric acid (2 × 200 mL) and H_2O (200 mL) before being dried ($MgSO_4$). Removal of the solvent in vacuo gave a colourless oil, which was chromatographed (SiO_2, CH_2Cl_2:MeOH 93:7). Evaporation of the appropriate fractions gave a colourless oil which was characterized as tetraethyleneglycol monotosylate (21.7 g, 60%): FABMS: *m/z* 349 and 371 ([*M* + H]$^+$ and [*M* + Na]$^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$), 2.46 (3H, s, tosyl C*H*$_3$), 2.62 (1H, s, O*H*), 3.59–3.74 (14H, m, OC*H*$_2$), 4.14–4.20 (2H, m, TsOC*H*$_2$), 7.35 (2H, m, $^3J_{AB}$ = 8.2 Hz, AA′ portion of tosyl AA′BB′ system), 7.77 (2H, m, $^3J_{AB}$ = 8.2 Hz, BB′ portion of tosyl AA′BB′ system); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 21.6 (tosyl *C*H$_3$), 61.7, 68.7, 69.2, 70.3, 70.4, 70.7, 70.8, 72.5 (all OCH$_2$), 127.9, 129.8 (tosyl aromatic *C*H), 133.1 (tosyl aromatic *C*CH$_3$), 144.8 (tosyl aromatic *C*SO$_2$). Anal. calcd for $C_{15}H_{24}O_7S$: C, 51.7; H, 6.94. Found: C, 50.2; H, 6.64.

General Procedure for the Synthesis of Diols 1, 4, 5 and 6 from the Diphenols and Tetraethyleneglycol Monotosylate: The diphenol and anhydrous potassium carbonate were stirred under nitrogen in dry MeCN and the temperature of the reaction was raised to 50 °C. After 20 min, a solution of tetraethyleneglycol monotosylate in anhydrous MeCN was added, and the reaction mixture was refluxed for 18 h. The suspension was then allowed to cool down to room temperature, before being filtered, and the residue washed with CH_2Cl_2 (3 × 10 mL). The solvent was removed from the filtrates in vacuo, and the residue was extracted with CH_2Cl_2 (100 mL) and washed with 1 N aqueous HCl (75 mL) and saturated NaCl solution (75 mL), before being dried ($MgSO_4$). Removal of the solvent in vacuo afforded a residue which was either purified by chromatography (SiO_2, CH_2Cl_2:Et_2O:MeOH 74:20:6) or by recrystallization from EtOH.

1,4-Bis[2-(2-(2-(2-hydroxyethoxy)ethoxy)ethoxy)ethoxy]benzene (1) was prepared in 93% yield (2.68 g) as a colourless oil from hydroquinone (0.5 g, 4.5 mmol) and anhydrous potassium carbonate (3.6 g, 25.5 mmol) in dry MeCN (25 mL), and a solution of tetraethyleneglycol monotosylate (3.2 g, 9.2 mmol) in anhydrous MeCN (25 mL). FABMS: *m/z* 462 and 484 ([*M*]$^+$ and [*M* + Na]$^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.85 (2H, brs, O*H*), 3.54–3.72 (24H, m, OCH_2), 3.76–3.82 (4H, m, OCH_2CH$_2$OAr), 4.01–4.07 (4H, m, ArOCH_2), 6.80 (4H, s, aromatic protons); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.7 (HOCH$_2$), 68.1, 69.9, 70.3, 70.6, 70.7, 70.8, 72.5 (all OCH$_2$), 135.6 (aromatic *C*H), 153.1 (aromatic *C*O). Anal. calcd for $C_{22}H_{38}O_{10}$: C, 57.1; H, 8.28. Found: C, 57.6; H, 8.60.

1,5-Bis[2-(2-(2-(2-hydroxyethoxy)ethoxy)ethoxy)ethoxy]naphthalene (4) was prepared in 78% yield (1.26 g) as a brownish oil from 1,5-dihydroxynaphthalene (0.5 g, 3.1 mmol) and anhydrous potassium carbonate (2.4 g, 16.9 mmol) in dry MeCN (25 mL), and a solution of tetraethyleneglycol monotosylate (2.2 g, 6.2 mmol) in anhydrous MeCN (25 mL). FABMS: *m/z* 512 and 535 ([*M*]$^+$ and [*M* + Na]$^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.62 (2H, brs, O*H*), 3.55–3.73 (20H, m, OCH_2), 3.78–3.84 (4H, m, OCH_2), 3.96–4.02 (4H, m, OCH_2CH$_2$OAr), 4.27–4.33 (4H, m, ArOCH_2), 6.85 (2H, d, $^3J_{2,3}$ = 8.0 Hz, H-2 and H-6), 7.35 (2H, t, $^3J_{2,3}$ and $^3J_{3,4}$ = 8.0 Hz, H-3 and H-7), 7.87 (2H, d, $^3J_{3,4}$ = 8.0 Hz, H-4 and H-8); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.7 (HOCH$_2$), 67.9, 69.8, 70.3, 70.7 [× 2], 71.0, 72.5 (all OCH$_2$), 105.8 (C-2 and C-6), 114.6 (C-4 and C-8), 125.1 (C-3 and C-7), 126.8 (quaternary naphthalene carbons), 154.4 (C-1 and C-5). Anal. calcd for $C_{26}H_{40}O_{10}$: C, 60.9; H, 7.86. Found: C, 59.6; H, 7.57.

2,6-Bis[2-(2-(2-(2-hydroxyethoxy)ethoxy)ethoxy)ethoxy]naphthalene (5) was prepared in 90% yield (2.9 g) as a white solid from 2,6-dihydroxynaphthalene (1 g, 6.2 mmol) and anhydrous potassium carbonate (4.7 g, 33.7 mmol) in dry MeCN (30 mL), and a solution of tetraethyleneglycol monotosylate (4.4 g, 12.4 mmol) in anhydrous MeCN (30 mL). Mp 76–77 °C; FABMS: *m/z* 513 [*M* + H]$^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.60 (2H, brs, O*H*), 3.57–3.78 (24H, m, OCH_2), 3.88–3.94 (4H, m, OCH_2CH$_2$OAr), 4.19–4.25 (4H, m, ArOCH_2), 7.10 (2H, d, $^4J_{1,3}$ = 2.5 Hz, H-1 and H-5), 7.15 (2H, dd, $^4J_{1,3}$ = 2.5 Hz, $^3J_{3,4}$ = 9.0 Hz, H-3 and H-7), 7.62 (2H, d, $^3J_{3,4}$ = 9.0 Hz, H-4 and H-8); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.8 (HOCH$_2$), 67.5, 69.8, 70.4, 70.6, 70.7, 70.8, 72.5 (all OCH$_2$), 107.2, (C-1 and C-5), 119.2 (C-3 and C-7), 128.2 (C-4 and C-8), 129.8 (quaternary naphthalene carbons), 155.3 (C-2 and C-6). Anal. calcd for $C_{26}H_{40}O_{10}$: C, 60.9; H, 7.86. Found: C, 60.7; H, 7.83.

4,4′-Bis[2-(2-(2-(2-hydroxyethoxy)ethoxy)ethoxy)ethoxy]biphenyl (6) was prepared in 84% yield (2.4 g) as a white solid from 4,4′-biphenol (1 g, 5.3 mmol) and anhydrous potassium carbonate (4.0 g, 28.0 mmol) in dry MeCN (30 mL), and a solution of tetraethyleneglycol monotosylate (3.7 g, 10.6 mmol) in anhydrous MeCN (30 mL). M.p. 76–77 °C; FABMS: *m/z* 538 and 561 ([*M*]$^+$ and [*M* + Na]$^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.71 (2H, s, O*H*), 3.57–3.72 (24H, m, OCH_2), 3.84–3.90 (4H, m, OCH_2CH$_2$OAr), 4.14–4.20 (4H, m, ArOCH_2), 6.97 (4H, m, $^3J_{2,3}$ = 8.8 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.46 (4H, m, $^3J_{2,3}$ = 8.8 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.8 (HOCH$_2$), 67.5, 69.8, 70.4, 70.6, 70.7, 70.8, 72.5 (all OCH$_2$), 114.9 (C-3,3′), 127.7 (C-2,2′), 133.6 (C-1,1′), 157.9 (C-4,4′). Anal. calcd for $C_{28}H_{42}O_{10}$: C, 62.4; H, 7.86. Found: C, 62.5; H, 7.78.

General Procedure for the Synthesis of Diols 2, 8, 11, 13 and 16 from Oligoethyleneglycols and Dibromides or Tosylates: Metallic sodium (4 equiv) was added to an oligoethyleneglycol (40 equiv) under an atmosphere of nitrogen. The suspension was stirred vigorously at 50 °C, and after dissolution of the sodium, the dibromide or tosylate (1 equiv) was added in one portion. The reaction mixture was then stirred for 18 h at 60 °C. After cooling, the clear yellow solution was poured into H_2O (100 mL). The aqueous solution was extracted with $CHCl_3$ (3 × 75 mL). The organic extract was washed with H_2O (2 × 50 mL) and dried ($MgSO_4$). Removal of the solvent afforded a yellow oil which was purified by column chromatography (SiO_2, CH_2Cl_2:Et_2O:MeOH 72–74:18–20:6–10).

1,4-Bis{1,1-[2-(2-(2-(2-hydroxyethoxy)ethoxy)ethoxy)ethoxy]methylene}-benzene (2) was prepared in 78% yield (2.93 g) as a colourless oil from sodium (0.69 g, 30 mmol), tetraethyleneglycol (55.2 g, 284 mmol) and α,α′-dibromo-*p*-xylene (2.0 g, 7.6 mmol). FABMS: *m/z* 491, 513 and 530 ([*M* + H]$^+$, [*M* + Na]$^+$ and [*M* + K]$^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.79 (2H, s, O*H*), 3.55–3.71 (32H, m, OCH_2), 4.53 (4H, s, H-α,α′), 7.30 (4H, s, aromatic protons); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.7 (HOCH$_2$), 69.4, 70.3, 70.6 [× 2], 72.6 (all OCH$_2$), 73.0

(C-α,α'), 127.8 (aromatic *C*H), 137.6 (aromatic *C*C). Anal. calcd for $C_{24}H_{42}O_{10}$: C, 58.5; H, 8.37. Found: C, 58.7; H, 8.62.

4,4'-Bis{1,1-[2-(2-(2-hydroxyethoxy)ethoxy)ethoxy]methylene}biphenyl (8) was prepared in 77% yield (10.8 g) as a colourless oil from sodium (2.7 g, 117 mmol), triethyleneglycol (147 mL, 1.10 mol) and 4,4'-bis(bromomethyl)biphenyl (10 g, 29 mmol). CIMS (NH_3): *m/z* 496 $[M + NH_4]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.63 (2H, s, O*H*), 3.60–3.76 (24H, m, OCH_2), 4.62 (4H, s, H-α,α'), 7.42 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.57 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.8 ($HOCH_2$), 69.5, 70.4, 70.6, 70.7, 72.6 (all OCH_2), 73.0 (C-α,α'), 127.1 (C-2,2'), 128.3 (C-3,3'), 137.2 (C-4,4'), 140.3 (C-1,1'). Anal. calcd for $C_{26}H_{38}O_8$: C, 65.2; H, 8.00. Found: C, 62.5; H, 7.62.

4,4'-Bis{1,1-[2-(2-(2-(2-hydroxyethoxy)ethoxy)ethoxy)ethoxy]methylene}-biphenyl (11) was prepared in 76% yield (12.5 g) as a colourless oil from sodium (2.7 g, 117 mmol), triethyleneglycol (160 mL, 1.10 mol) and 4,4'-bis(bromomethyl)-biphenyl (10 g, 7.6 mmol). FABMS: *m/z* 567, 589 and 605 $([M + H]^+$, $[M + Na]^+$ and $[M + K]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.84 (2H, s, O*H*), 3.54–3.60 (4H, m, OCH_2), 3.61–3.72 (28H, m, OCH_2), 4.59 (4H, s, H-α,α'), 7.39 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.54 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.7 ($HOCH_2$), 69.5, 70.3, 70.6 [× 2], 70.7 [× 2], 72.6 (all OCH_2), 73.0 (C-α,α'), 127.1 (C-2,2'), 128.3 (C-3,3'), 137.4 (C-4,4'), 140.3 (C-1,1'). Anal. calcd for $C_{30}H_{46}O_{10}$: C, 63.6; H, 8.18. Found: C, 63.5; H, 7.88.

4,4'-Bis{1,1-[2-(2-(2-(2-(2-hydroxyethoxy)ethoxy)ethoxy)ethoxy]-methylene}biphenyl (13) was prepared in 93% yield (2.32 g) as a colourless oil from sodium (0.71 g, 31 mmol), diethyleneglycol (30 mL, 315 mmol) and ditosylate **9** (3 g, 3.8 mmol). CIMS (NH_3): *m/z* 672 $[M + NH_4]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.98 (2H, s, O*H*), 3.57–3.63 (4H, m, OCH_2), 3.63–3.84 (36H, m, OCH_2), 4.61 (4H, s, H-α,α'), 7.41 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.57 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.7 ($HOCH_2$), 69.5, 70.3, 70.6 [× 3], 70.7 [× 3], 72.6 (all OCH_2), 73.0 (C-α,α'), 127.1 (C-2,2'), 128.3 (C-3,3'), 137.2 (C-4,4'). 140.3 (C-1,1'). Anal. calcd for $C_{34}H_{54}O_{12}$: C, 62.36; H, 8.31. Found: C, 59.58; H, 7.99.

4-{1,1-[2-(2([2-(2-Hydroxyethoxy)ethoxy)ethoxy)ethoxy]methylene}-4'-{1,1-[2-(2-(2-hydroxyethoxy)ethoxy)ethoxy]methylene}biphenyl (16) was prepared in 92% yield (1.64 g) as a colourless oil from sodium (0.95 g, 41 mmol), diethyleneglycol (40 mL, 420 mmol) and monotosylate **15** (3 g, 3.8 mmol). FABMS: *m/z* 589 $[M + Na]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.72 (2H, br s, O*H*), 3.55–3.72 (32H, m, OCH_2), 4.58 (4H, s, H-α,α'), 7.39 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.54 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 61.7, 61.8 ($HOCH_2$), 69.4, 69.5, 70.3, 70.4, 70.6 [× 3], 70.7 [× 5], 72.5, 72.6 (all OCH_2), 72.9, 73.0 (C-α,α'), 127.1 [× 2] (C-2,2'), 128.3 [× 2] (C-3,3'), 137.2, 137.4 (C-4,4'), 140.2, 140.3 (C-1,1'). Anal. calcd for $C_{30}H_{46}O_{10}$: C, 63.58; H, 8.18. Found: C, 61.75; H, 8.23.

General Procedure for the Synthesis of Diamines 7, 10, 12, 14 and 17 from Diols 6, 8, 11, 13 and 16: Method A: A solution of toluene-*p*-sulfonyl chloride in THF was added during 2 h to a stirred solution of diol in THF/20% aqueous NaOH (1/1 v/v). The temperature of the mixture was maintained between 0–5 °C. The reaction mixture was then stirred at 0–5 °C for 2 h before being poured into H_2O (150 mL). The aqueous solution was extracted with CH_2Cl_2 (3 × 75 mL), and the organic extracts were subsequently washed with H_2O (75 mL) and dried ($MgSO_4$). Removal of the solvent in vacuo afforded a colourless oil. Column chromatography (SiO_2) afforded the pure ditosylate. Potassium phthalimide (2.1 equiv) was added to a stirred solution of the ditosylate in anhydrous DMF. The suspension was stirred for 18 h at 90 °C under an atmosphere of nitrogen. The resulting clear solution was evaporated to dryness under high vacuum, leaving a solid residue which was partitioned between H_2O (100 mL) and CH_2Cl_2 (100 mL). The aqueous phase was discarded, and the organic layer was washed with 0.5 N aqueous NaOH (75 mL) and H_2O (75 mL), before being dried ($MgSO_4$). Evaporation of the solvent in vacuo yielded a colourless solid, which was chromatographed (SiO_2) to afford pure diphthalimide. Hydrazine hydrate (2.05 equiv) was added to a stirred solution of diphthalimide in MeOH and the reaction mixture was stirred for 1 h under reflux. Concentrated (6 N) HCl (2.7 mL) was then added before the reaction mixture was heated under reflux for an additional 30 min. After cooling, the resulting precipitate was filtered and the solid was washed with MeOH (3 × 25 mL). The filtrates were combined and the solvent was removed in vacuo. The residue was dissolved in 10% aqueous NaOH solution (75 mL) and the aqueous solution was extracted with CH_2Cl_2 (3 × 75 mL). The organic phase was washed with saturated NaCl solution (75 mL) and dried ($MgSO_4$). Removal of the solvent in vacuo afforded a yellow oil, which was subjected to column chromatography (SiO_2) to afford pure diamine.

Method B: A solution of diethyl azodicarboxylate (DEAD) (2 equiv) in anhydrous THF was added dropwise to a solution of diol, phthalimide (2 equiv) and triphenylphosphine (2 equiv) in THF at 0 °C. The reaction mixture was subsequently stirred overnight at room temperature before being evaporated to dryness in vacuo. The residue was suspended in MeOH (100 mL) and filtered. The collected precipitate was washed with MeOH and dried under high vacuum to give a colourless solid which was recrystallized from ethanol. Hydrazinolysis of the diphthalimide was carried out as described in method A.

4,4'-Bis[2-(2-(2-(2-aminoethoxy)ethoxy)ethoxy)ethoxy]biphenyl (7) was prepared according to method B. A mixture of diol **6** (4.0 g, 7.4 mmol), phthalimide (2.2 g, 15 mmol) and triphenylphosphine (3.4 g, 15 mmol) in THF (15 mL) was treated with DEAD (2.6 g, 15 mmol) in THF (6 mL) to afford the corresponding diphthalimide in 95% yield (5.6 g) as a white solid. M.p. 74–75 °C; FABMS: *m/z* 796 and 819 $([M]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.57–3.92 (28H, m, OCH_2 and NCH_2), 4.10–4.16 (4H, m, $ArOCH_2$), 6.95 (4H, m, $^3J_{2,3}$ = 8.8 Hz, AA < M' > portion of biphenyl AA'BB' system, H-3,3'), 7.44 (4H, m, $^3J_{2,3}$ = 8.8 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'), 7.65–7.71 (4H, m, phthaloyl H_m), 7.79–7.85 (4H, m, phthaloyl H_o); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 37.3 (NCH_2), 67.5, 67.9, 69.7, 70.2, 70.6, 70.7, 70.8 (all OCH_2), 114.9 (C-3,3'), 123.2 (phthaloyl CH_o-), 127.6 (C-2,2'), 132.2 (phthaloyl *C*C=O), 133.6 (C-1,1'), 133.9 (phthaloyl CH_m-), 157.9 (C-4,4'), 168.2 (*C*=O). Anal. calcd for $C_{44}H_{48}O_{12}N_2$: C, 66.3; H, 6.07; N, 3.52. Found: C, 65.6; H, 6.18; N, 3.58.

Treatment of the diphthalimide (5.6 g, 7.4 mmol) in MeOH (80 mL) with hydrazine hydrate (1 mL, 18 mmol) gave diamine **7** in 82% yield (3.3 g) as a white solid after purification by column chromatography (SiO_2, $CHCl_3$:MeOH:concentrated aqueous NH_3 solution 76:22:2). M.p. 63–64 °C; FABMS: *m/z* 537 and 559 $([M + H]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.86 (4H, br s, NH_2), 2.86 (4H, t, ^3J_H = 5.5 Hz, NCH_2), 3.51 (4H, t, ^3J_H = 5.5 Hz, OCH_2CH_2N), 3.60–3.78 (16H, m, OCH_2), 3.85–3.91 (4H, m, OCH_2CH_2OAr), 4.10–4.16 (4H, m, $ArOCH_2$), 6.96 (4H, m, $^3J_{2,3}$ = 8.8 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.46 (4H, m, $^3J_{2,3}$ = 8.8 Hz, BB' portion of AA'BB' system, H-2,2'); ^{13}H NMR (75.5 MHz, $CDCl_3$) δ = 37.8 (NCH_2), 61.7, 67.5, 69.8, 70.5, 70.7, 70.8, 72.5 (all OCH_2), 114.9 (C-3,3'), 127.7 (C-2,2'), 133.6 (C-1,1'), 157.8 (C-4,4').

4,4'-Bis{1,1-[2-(2-(2-aminoethoxy)ethoxy)ethoxy]methylene}biphenyl (10) was prepared according to method A. Diol **8** (9 g, 19 mmol) in THF/20% aqueous NaOH (30 mL, 1/1 v/v) was treated with toluene-*p*-sulfonyl chloride (8.2 g, 43 mmol) in THF (15 mL) to afford the ditosylate **9** in 98% yield (14.5 g) as a colourless oil after column chromatography (SiO_2, EtOAc:light petroleum, b.p. 40–60 °C, 75:25). CIMS (NH_3): *m/z* 804 $[M + NH_4]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.42 (6H, s, tosyl CH_3), 3.58–3.75 (20H, m, OCH_2), 4.13–4.19 (4H, m, $TsOCH_2$), 4.60 (4H, s, H-α,α'), 7.32 (4H, m, $^3J_{AB}$ = 8.2 Hz, AA' portion of tosyl AA'BB' system), 7.41 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.57 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system), 7.79 (4H, m, $^3J_{AB}$ = 8.2 Hz, BB' portion of tosyl AA'BB' system); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 21.6 (tosyl CH_3), 68.7, 69.3, 69.5, 70.6, 70.7, 70.8 (all OCH_2), 73.0 (C-α,α'), 127.1 (C-2,2'), 128.1, 129.8 (tosyl aromatic *C*H), 128.2 (C-3,3'), 133.1 (tosyl aromatic *C*CH_3), 137.6 (C-4,4'), 140.3 (C-1,1'), 144.8 (tosyl aromatic *C*SO_2). Anal. calcd for $C_{40}H_{50}S_2O_{12}$: C, 61.04; H, 6.40. Found: C, 59.97; H, 5.93.

Ditosylate **9** (5 g, 6.4 mmol) was treated with potassium phthalimide (2.5 g, 13.4 mmol) in anhydrous DMF (40 mL) to afford the corresponding diphthalimide in 86% yield (4.1 g) as a white solid after purification by column chromatography (SiO_2, EtOAc:light petroleum, b.p. 60–80 °C, 75:25). M.p. 64–65 °C; CIMS (NH_3): *m/z* 754 $[M + NH_4]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.56–3.70 (16H, m, OCH_2), 3.76 (4H, t, ^3J_H = 5.5 Hz, OCH_2CH_2N), 3.90 (4H, t, ^3J_H = 5.5 Hz, NCH_2), 4.56 (4H, s, H-α,α'), 7.39 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.55 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'), 7.68 (4H, m, phthaloyl H_m), 7.82 (4H, m, phthaloyl H_o); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 37.5 (NCH_2), 67.9, 69.5, 70.2, 70.6, 70.7 (all OCH_2), 72.9 (C-α,α'), 123.2 (phthaloyl CH_o), 127.0 (C-2,2'), 128.2 (C-3,3') 132.2 (phthaloyl *C*C=O), 133.9 (phthaloyl CH_m), 137.1 (C-4,4'), 140.2 (C-1,1'), 168.2 (*C*=O). Anal. calcd for $C_{42}H_{44}N_2O_{10}$: C, 68.5; H, 6.02; N, 3.80. Found: C, 68.2; H, 6.14; N, 3.65.

Treatment of the diphthalimide (3.6 g, 4.9 mmol) in MeOH (30 mL) with hydrazine hydrate (0.55 mL, 10 mmol) gave diamine **10** in 94% yield (2.2 g) as a colourless oil after purification by column chromatography (SiO_2, $CHCl_3$:MeOH:concentrated aqueous NH_3 solution 80:18:2). CIMS (NH_3): *m/z* 477 $[M + H]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.88 (4H, br s, NH_2), 2.82 (4H, t, ^3J_H = 5.5 Hz, NCH_2), 3.48 (4H, t, ^3J_H = 5.5 Hz, OCH_2CH_2N), 3.58–3.71 (16H, m, OCH_2), 4.58 (4H, s, H-α,α'), 7.38 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.53 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 41.7 (NCH_2), 69.5, 70.3, 70.6, 70.7 (OCH_2), 73.0 (C-α,α'), 73.4 (OCH_2), 127.1 (C-2,2'), 128.2 (C-3,3'), 137.3 (C-4,4'), 140.3 (C-1,1'). Anal. calcd for $C_{26}H_{40}N_2O_6$: C, 62.5; H, 8.46; N, 5.88. Found: C, 61.4; H, 8.01; N, 5.54.

4,4'-Bis{1,1-[2-(2-(2-(2-aminoethoxy)ethoxy)ethoxy)ethoxy]methylene}-biphenyl (12) was prepared according to method A. Diol **11** (10 g, 17.6 mmol) in THF/20% aqueous NaOH (20 mL, 1/1 v/v) was treated with toluene-*p*-sufonyl chloride (7.6 g, 40 mmol) in THF (10 mL) to afford the corresponding ditosylate in 94% yield (14.5 g) as a colourless oil. FABMS: *m/z* 874 and 897 ($[M]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.43 (6H, s, tosyl CH_3), 3.57–3.72 (28H, m, OCH_2), 4.13–4.19 (4H, m, $TsOCH_2$), 4.60 (4H, s, H-α,α'), 7.33 (4H, m,

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$^3J_{AB}$ = 8.2 Hz, AA′ portion of tosyl AA′BB′ system), 7.41 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.56 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system), 7.79 (4H, m, $^3J_{AB}$ = 8.2 Hz, BB′ portion of tosyl AA′BB′ system); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 21.6 (tosyl CH_3), 68.7, 69.2, 69.5, 70.5, 70.6 [×3], 70.7, (all OCH_2), 73.0 (C-α,α′), 127.1 (C-2,2′), 128.1, 129.8 (tosyl aromatic CH), 128.3 (C-3,3′), 133.1 (tosyl aromatic CCH_3), 137.3 (C-4,4′), 140.3 (C-1,1′), 144.8 (tosyl aromatic CSO_2). Anal. calcd for $C_{44}H_{58}S_2O_{14}$: C, 60.4; H, 6.68. Found: C, 60.1; H, 7.00.

The ditosylate (14 g, 16 mmol) was treated with potassium phthalimide (6.2 g, 33 mmol) in anhydrous DMF (100 mL) to afford the corresponding diphthalimide in 92% yield (12.1 g) as a colourless oil. FABMS: *m/z* 824 and 847 ($[M]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300MHz, $CDCl_3$) δ = 3.58–3.69 (24H, m, OCH_2), 3.73 (4H, t, ^3J_H = 5.5 Hz, OCH_2CH_2N), 3.90 (4H, t, ^3J_H = 5.5 Hz, NCH_2), 4.59 (4H, s, H-α,α′), 7.40 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.55 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′), 7.67–7.73 (4H, m, phthaloyl H_m), 7.80–7.86 (4H, m, phthaloyl H_o); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 37.3 (NCH_2), 67.9, 69.5, 70.1, 70.6 [×2], 70.7 [×2] (all OCH_2), 73.0 (C-α,α′), 123.2 (phthaloyl CH_o), 127.1 (C-2,2′), 128.2 (C-3,3′) 132.2 (phthaloyl CC=O), 133.9 (phthaloyl CH_m), 137.4 (C-4,4′), 140.2 (C-1,1′), 168.2 (C=O). Anal. calcd for $C_{46}H_{52}N_2O_{12}$: C, 66.97; H, 6.35; N, 3.35. Found: C, 66.67; H, 6.18; N, 3.66.

Treatment of the diphthalimide (12 g, 14.5 mmol) in MeOH (150 mL) with hydrazine hydrate (1.8 mL, 32.4 mmol) gave diamine **12** in 88% yield (7.2 g) as a colourless oil after purification by column chromatography (SiO_2, $CHCl_3$:MeOH:concentrated aqueous NH_3 solution 80:18:2). FABMS: *m/z* 565 and 587 ($[M + H]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.30 (4H, brs, NH_2), 2.80 (4H, brt, ^3J_H = 5.5 Hz, NCH_2), 3.52 (4H, t, ^3J_H = 5.5 Hz, OCH_2CH_2N), 3.62–3.72 (24H, m, OCH_2), 4.61 (4H, s, H-α,α′), 7.43 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.58 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 41.7 (NCH_2), 69.6, 70.3, 70.6 [×2], 70.7 [×2] (all OCH_2), 73.0 (C-α,α′), 73.3 (OCH_2), 127.1 (C-2,2′), 128.3 (C-3,3′), 137.3 (C-4,4′), 140.3 (C-1,1′).

4,4′-Bis{1,1-[2-(2-(2-(2-(2-(2-aminoethoxy)ethoxy)ethoxy)ethoxy)ethoxy]-methylene}-biphenyl (14) was prepared according to method A. Diol **13** (2 g, 3.1 mmol) in THF/20% aqueous NaOH (13 mL, 1/1 v/v) was treated with toluene-*p*-sulfonyl chloride (1.3 g, 6.8 mmol) in THF (7 mL) to afford the corresponding ditosylate in 99% yield (2.9 g) as a colourless oil. CIMS (NH_3): *m/z* 980 $[M + NH_4]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.42 (6H, s, tosyl CH_3), 3.54–3.72 (36H, m, OCH_2), 4.16–4.19 (4H, m, $TsOCH_2$), 4.59 (4H, s, H-α,α′), 7.32 (4H, m, $^3J_{AB}$ = 8.2 Hz, AA′ portion of tosyl AA′BB′ system), 7.40 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.55 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′), 7.79 (4H, m, $^3J_{AB}$ = 8.2 Hz, BB′ portion of tosyl AA′BB′ system); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 21.6 (tosyl CH_3), 68.7, 69.3, 69.5, 70.5, 70.6 [×3], 70.7 [×3], (all OCH_2), 72.9 (C-α,α′), 127.0 (C-2,2′), 128.0, 129.8 (tosyl aromatic CH), 128.2 (C-3,3′), 133.1 (tosyl aromatic CCH_3), 137.3 (C-4,4′), 140.2 (C-1,1′), 144.8 (tosyl aromatic CSO_2). Anal. calcd for $C_{48}H_{66}S_2O_{16}$: C, 59.8; H, 6.91. Found: C, 59.6; H, 7.21.

The ditosylate (2.8 g, 2.9 mmol) was treated with potassium phthalimide (1.2 g, 6.4 mmol) in anhydrous DMF (20 mL) to afford the corresponding diphthalimide in 72% yield (1.9 g) as a colourless oil after column chromatography (SiO_2, EtOAc). CIMS (NH_3): *m/z* 930 $[M + NH_4]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.51–3.67 (32H, m, OCH_2), 3.68 (4H, t, ^3J_H = 5.5 Hz, OCH_2CH_2N), 3.83 (4H, t, ^3J_H = 5.5 Hz, NCH_2), 4.54 (4H, s, H-α,α′), 7.35 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.50 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′), 7.64 (4H, m, phthaloyl H_m), 7.76 (4H, m, phthaloyl H_o); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 37.5 (NCH_2), 67.9, 69.5, 70.1, 70.5 [×3], 70.6 [×3] (all OCH_2), 72.9 (C-α,α′), 123.2 (phthaloyl CH_o), 127.0 (C-2,2′), 128.2 (C-3,3′), 132.1 (phthaloyl CC=O), 133.9 (phthaloyl CH_m), 137.4 (C-4,4′), 140.2 (C-1,1′), 168.2 (C=O). Anal. calcd for $C_{50}H_{60}N_2O_{14}$: C, 65.8; H, 6.62; N, 3.07. Found: C, 65.5; H, 6.71; N, 3.26.

Treatment of the diphthalimide (1.72 g, 1.9 mmol) in MeOH (20 mL) with hydrazine hydrate (0.25 mL, 4.5 mmol) gave diamine **14** in 97% yield (1.2 g) as a colourless oil after purification by column chromatography (SiO_2, $CHCl_3$:MeOH:concentrated aqueous NH_3 solution 80:18:2). CIMS (NH_3): *m/z* 653 $[M + H]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.64 (4H, brs, NH_2), 2.81 (4H, brt, ^3J_H = 5.5 Hz, NCH_2), 3.48 (4H, t, ^3J_H = 5.5 Hz, OCH_2CH_2N), 3.55–3.70 (32H, m, OCH_2), 4.57 (4H, s, H-α,α′), 7.38 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.53 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 41.5 (NCH_2), 69.5, 70.2, 70.4, 70.5 [×3], 70.6 [×2], 72.4 (all OCH_2), 73.0 (C-α,α′), 127.1 (C-2,2′), 128.3 (C-3,3′), 137.3 (C-4,4′), 140.3 (C-1,1′).

4-{1,1-[2-(2-(2-(2-(2-Aminoethoxy)ethoxy)ethoxy)ethoxy)ethoxy]methylene}-4′-{1,1-[2-(2-(2-aminoethoxy)ethoxy)ethoxy]methylene}biphenyl (17) was prepared according to method A. Diol **16** (1.5 g, 2.65 mmol) in THF/20% aqueous NaOH (20 mL, 1/1 v/v) was treated with toluene-*p*-sulfonyl chloride (1.15 g, 6.05 mmol) in THF (10 mL) to afford the corresponding ditosylate in 88% yield (2.05 g) as a colourless oil after column chromatography (SiO_2, EtOAc). FABMS: *m/z* 897 $[M + Na]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.42 (3H, s, tosyl CH_3), 2.43 (3H, s, tosyl CH_3), 3.56–3.72 (28H, m, OCH_2), 4.12–4.18 (4H, m, $TsOCH_2$), 4.59 (2H, s, H-α or H-α′), 4.60 (2H, s, H-α or H-α′), 7.31 (2H, m, $^3J_{AB}$ = 8.2 Hz, AA′ portion of tosyl AA′BB′ system), 7.33 (2H, m, $^3J_{AB}$ = 8.2 Hz, AA′ portion of tosyl AA′BB′ system), 7.40 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.41 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.56 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portions of biphenyl AA′BB′ systems, H-2,2′), 7.79 (4H, m, $^3J_{AB}$ = 8.2 Hz, BB′ portions of tosyl AA′BB′ systems); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 21.6 [×2] (tosyl CH_3), 68.7 [×2], 69.3 [×2], 69.5, 70.5 [×2], 70.6 [×2], 70.7 [×4], 70.8 [×3], (all OCH_2), 73.0 [×2] (C-α,α′), 127.1 [×2] (C-2,2′), 128.0 [×2], 129.8 [×2] (tosyl aromatic CH), 128.2 [×2] (C-3,3′), 133.1 [×2] (tosyl aromatic CCH_3), 137.3, 137.4 (C-4,4′), 140.3 [×2] (C-1,1′), 144.8 [×2] (tosyl aromatic CSO_2). Anal. calcd for $C_{44}H_{58}S_2O_{14}$: C, 60.4; H, 6.68. Found: C, 59.1; H, 6.48.

The ditosylate (1.25 g, 1.43 mmol) was treated with potassium phthalimide (0.56 g, 3.02 mmol) in anhydrous DMF (15 mL) to afford the corresponding diphthalimide in 75% yield (0.89 g) as a colourless oil. FABMS: *m/z* 825 and 847 ($[M + H]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.56–3.70 (24H, m, OCH_2), 3.71–3.77 (4H, m, OCH_2CH_2N), 3.87–3.93 (4H, m, NCH_2), 4.57 (2H, s, H-α or H-α′), 4.61 (2H, s, H-α or H-α′), 7.39 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.41 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.55 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′), 7.56 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′), 7.66–3.72 (4H, m, phthaloyl H_m), 7.80–3.86 (4H, m, phthaloyl H_o); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 37.3 [×2] (NCH_2), 67.9 [×2], 69.5, 69.6, 70.1, 70.2, 70.6 [×4], 70.7 [×4] (all OCH_2), 72.9, 73.0 (C-α,α′), 123.2 [×2] (phthaloyl CH_o), 127.1 [×2] (C-2,2′), 128.2 [×2] (C-3,3′), 132.2 [×2] (phthaloyl CC=O), 133.9 [×2] (phthaloyl CH_m), 137.4 [×2] (C-4,4′), 140.2 [×2] (C-1,1′), 168.2 [×2] (C=O). Anal. calcd for $C_{46}H_{52}N_2O_{12}$: C, 67.0; H, 6.35; N, 3.35. Found: C, 67.3; H, 6.21; N, 3.29.

Treatment of the diphthalimide (0.85 g, 1.03 mmol) in MeOH (15 mL) with hydrazine hydrate (0.2 mL, 3.6 mmol) gave diamine **17** in 79% yield (0.46 g) as a colourless oil after purification by column chromatography (SiO_2, $CHCl_3$:MeOH:concentrated aqueous NH_3 solution 80:18:2). FABMS: *m/z* 565 $[M + H]^+$; ^{13}C NMR (300 MHz, $CDCl_3$) δ = 2.13 (4H, brs, NH_2), 2.84 (4H, brs, NCH_2), 3.51 (2H, t, ^3J_H = 5.5Hz, OCH_2CH_2N), 3.52 (2H, t, ^3J_H = 5.5Hz, OCH_2CH_2N), 3.62–3.72 (24H, m, OCH_2), 4.61 (4H, s, H-α,α′), 7.41 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.56 (4H, m, $^3J_{2,3}$ = 8.2Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 41.7 [×2] (NCH_2), 69.5, 69.6, 70.2, 70.3, 70.4 [×4], 70.7 [×4], 72.5, 73.4 (all OCH_2), 73.0 (C-α,α′), 127.1 [×2] (C-2,2′), 128.2, 128.3 (C-3,3′), 137.3, 137.4 (C-4,4′), 140.2 and 140.3 (C-1,1′).

4-{1,1-[2-(2-(2-(Toluene-*p*-sulfonyl)ethoxy)ethoxy)ethoxy]methylene}-4′-{1,1-[2-(2-(2-hydroxyethoxy)ethoxy)ethoxy]methylene}biphenyl (15) was prepared in 65% yield (2.7 g) as a colourless oil according to the procedure used for the preparation of ditosylate **9** from diol **8** (3.2 g, 6.7 mmol) in THF/20% aqueous NaOH (120 mL, 1/1 v/v) and toluene-*p*-sulfonyl chloride (1.3 g, 6.8 mmol) in THF (60 mL). FABMS: *m/z* 655 and 669 ($[M + Na]^+$ and $[M + K]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 2.35 (1H, brs, OH), 2.42 (3H, s, tosyl CH_3), 3.59–3.76 (22H, m, OCH_2) 4.13–4.19 (2H, m, $TsOCH_2$), 4.59 (2H, s, H-α,α′), 4.61 (2H, s, H-α,α′), 7.32 (2H, m, $^3J_{AB}$ = 8.2 Hz, AA′ portion of tosyl AA′BB′ system), 7.40 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.41 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.56 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′), 7.57 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′), 7.79 (2H, m, $^3J_{AB}$ = 8.2 Hz, BB′ portion of tosyl AA′BB′ system); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 21.6 (tosyl CH_3), 61.8 ($HOCH_2$), 68.7, 69.3, 69.5, 70.4, 70.6 [×2], 70.7 [×2], 70.8, 72.5 [×2] (all OCH_2), 73.0 [×2] (C-α,α′), 127.1 [×2] (C-2,2′), 128.0 (tosyl aromatic CH), 128.2, 128.3 (C-3,3′), 129.8 (tosyl aromatic CH), 133.1 (tosyl aromatic CCH_3, 137.3, 137.4 (C-4,4′), 140.3 [×2] (C-1,1′), 144.8 (tosyl aromatic CSO_2). Anal. calcd for $C_{33}H_{44}SO_{10}$: C, 62.6; H, 7.01. Found: C, 62.4; H, 6.76.

4,4′-Bis{1,1-[2-(2-(2-(2-aminoethoxy)ethoxy)ethoxy)ethylamino]carbonyl}-biphenyl (18): A solution of biphenyl-4,4′-dicarbonyl dichloride (1.8 g, 7 mmol) in anhydrous CH_2Cl_2 (100 mL) was added dropwise over 4 h to a solution of 1,11-diamino-3,6,9-trioxaundecane (5.4 g, 28 mmol) and triethylamine (9 mL) in anhydrous CH_2Cl_2 (100 mL). An atmosphere of dry nitrogen, room temperature and vigorous stirring were the conditions maintained during the whole reaction procedure. The reaction mixture was then stirred for another 12 h. The resulting suspension was washed with 1 N aqueous NaOH solution (2 × 75 mL). The organic phase was dried ($MgSO_4$) before being evaporated to dryness in vacuo. The residue was suspended in 0.1 N aqueous NaOH solution (100 mL), sonicated for 10 min and filtered through Celite. The solid material was washed with 0.1 N aqueous NaOH solution (2 × 25 mL), and the filtrate and washings were extracted with $CHCl_3$ (3 × 75 mL). The organic extracts were dried ($MgSO_4$) and evaporated to dryness in vacuo to yield a colourless solid which was subjected to column chromatography (SiO_2, $CHCl_3$:MeOH:concentrated aqueous NH_3 solution 82:16:2). Collection of the appropriate fractions afforded pure **18** (1.3 g, 31%). M.p. 107–108 °C; FABMS: *m/z* 591, 613 and 631 ($[M + H]^+$, $[M + Na]^+$ and $[M + K]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.96 (4H, brs, NH_2), 2.82 (4H, brs, H_2NCH_2), 3.48 (4H, t, ^3J_H 5.5 Hz, $OCH_2CH_2NH_2$), 3.59–3.72 (24H, m, OCH_2 and CON-

HCH_2), 7.66 (4H, m, $^3J_{2,3}$ = 8.4 Hz, AA' portion of biphenyl AA'BB' system, H-2,2'), 7.69 (2H, brt, NHCO), 7.95 (4H, m, $^3J_{2,3}$ = 8.4 Hz, BB' portion of biphenyl AA'BB' system, H-3,3'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.9 (CONHCH$_2$), 41.6 (H_2NCH_2), 70.0, 70.1, 70.3, 70.5, 70.6, 73.2 (all OCH_2), 127.1 (C-2,2'), 127.9 (C-3,3'), 134.1 (C-4,4'), 142.1 (C-1,1'), 167.1 (C=O). Anal. calcd for $C_{30}H_{46}N_4O_8$: C, 61.0; H, 7.85; N, 9.48. Found: C, 60.4; H, 7.56; N, 9.09.

1,4-Bis[1,1-(2-methoxyethylamino)carbonyl]benzene (3): A solution of terephthaloyl chloride (2 g, 9.8 mmol) in anhydrous CH_2Cl_2 (50 mL) was added dropwise to a solution of 2-methoxyethylamine (1.6 g, 21.3 mmol) and triethylamine (2 g, 20 mmol) in 50 mL CH_2Cl_2 at 0 °C under nitrogen. After completion of the addition, the reaction mixture was allowed to warm up to room temperature before being stirred for 12 h. The resulting suspension was washed with aqueous 2N HCl (2 × 50 mL) and H_2O (50 mL). The organic phase was then dried ($MgSO_4$) before being evaporated to dryness. The crude material was recrystallized from Me_2CO/Et_2O to afford **3** as a colourless solid (2.3 g, 85%): m.p. 171–172 °C; EIMS: *m/z* 281 $[M + H]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.36 (6H, s, OCH_3), 3.51–3.57 (4H, m, OCH_2), 3.59–3.65 (4H, m, OCH_2), 6.74 (2H, brt, NHCO), 7.78 (4H, s, aromatic protons); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.8 (NCH_2) d 58.8, 71.0 (OCH_2), 127.2 (aromatic CH), 137.1 (aromatic CC), 166.7 (C=O). Anal. calcd for $C_{14}H_{20}N_2O_4$: C, 59.98; H, 7.19; N, 10.00. Found: C, 59.99; H, 7.10; N, 9.97.

General Procedure for the Preparation of Catenated Cyclodextrins 25, 26, 27, 28, 29a/29b, 30a/30b, 36 and 38 from DM-β-CD, Terephthaloyl Chloride or Biphenyl-4,4'-dicarbonyl Dichloride, and Diamines 10, 12, 14 and 18: A solution of diamine (1 equiv), **DM-β-CD** (1 equiv) and NaOH in H_2O was sonicated for 2 h at room temperature. The reaction mixture was cooled down to 5 °C and powdered aromatic diacid chloride (1 equiv) was then added. The suspension was sonicated at 0–5 °C. After 2 h, more NaOH and powdered diacid chloride (1 equiv) were added. The reaction mixture was sonicated for a further 2 h at room temperature before being extracted with $CHCl_3$ (3 × 100 mL). The organic extracts were washed with aqueous 1N NaOH solution (100 mL) followed by H_2O (100 mL) and dried ($MgSO_4$). Removal of the solvent in vacuo gave a colourless solid, which was purified by column chromatography (SiO_2).

12,19-Dioxo-2,5,8,23,26,29-hexaoxa-11,20-diaza-[12.12.0]paracyclophane (19) and 12,19,55,61-Tetraoxo-2,5,8,23,26,29,44,47,50,65,68,71-dodecaoxa-11,20,53,-62-tetraaza-[12.12.0.12.12.0]paracyclophane (22): Reaction of diamine **10** (0.42 g, 0.88 mmol), NaOH (2 × 100 mg, 5 mmol) and **DM-β-CD** (1.2 g, 0.90 mmol) in H_2O (200 mL) with terephthaloyl chloride (2 × 182 mg, 1.8 mmol) afforded a colourless solid, which was purified by column chromatography (SiO_2, $CHCl_3$:2-propanol 9:1) to afford three fractions: Fraction 1, **DM-β-CD**.

Fraction 2, macrocycle **19** (85 mg, 16%): colourless powder; m.p. 205–207 °C; CIMS (NH_3): *m/z* 606 $[M]^+$; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.58–3.75 (24H, m, OCH_2 and NCH_2), 4.58 (4H, s, H-α,α'), 6.98 (2H, brt, NHCO), 7.34 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.38 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'), 7.56 (4H, s, H-ω,ω'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 40.1 (NCH_2), 69.5, 70.0, 70.4, 70.8 [× 2] (all OCH_2), 73.0 (C-α,α'), 126.9 (C-ω,ω'), 127.0 (C-2,2'), 128.3 (C-3,3'), 136.5 (C-v,v'), 137.1 (C-4,4'), 139.9 (C-1,1'), 166.5 (C=O), Anal. calcd for $C_{34}H_{42}N_2O_8$: C, 67.30; H, 6.98; N, 4.62. Found: C, 67.26; H, 6.93; N, 4.60.

Fraction 3, macrocycle **22** (15 mg, 2.8%): colourless powder; m.p. 204–205 °C; FABMS: *m/z* 1213 and 1235 $([M + H]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.57–3.70 (48H, m, NCH_2 and OCH_2), 4.51 (8H, s, H-α,α'), 7.03 (4H, brt, NHCO), 7.32 (8H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.47 (8H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'), 7.79 (8H, s, H-ω,ω'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.9 (NCH_2), 69.4, 69.8, 70.3, 70.6 [× 2] (all OCH_2), 72.9 (C-α,α'), 127.0 (C-2,2'), 127.2 (C-ω,ω'), 128.2 (C-3,3'), 137.0 (C-v,v'), 137.1 (C-4,4'), 140.2 (C-1,1'), 166.6 (C=O). Anal. calcd for $C_{68}H_{84}N_4O_{16}$: C,67.30; H, 6.98; N, 4.62. Found: C, 67.60; H, 6.98; N, 4.63. No catenanes were isolated from the reaction mixture.

15,22-Dioxo-2,5,8,11,26,29,32,35-octaoxa-14,23-diaza-[15.15.0]paracyclophane (20), 15,22,63,70-Tetraoxo-2,5,8,11,26,29,32,35,50,53,56,59,74,77,80,83-hexadodecaoxa-14,23,62,71-tetraaza-[15.15.0.15.15.0]paracyclophane (23), [2][15,22-Dioxo-2,5,8,11,26,29,32,35-octaoxa-14,23-diaza-[15.15.0]paracyclophane]||heptakis(2,6-di-O-methyl)-β-cyclodextrin|catenane (25), [2][15,22,63,70-Tetraoxo-2,5,8,11,26,29,32,35,50,53,56,59,74,77,80,83-hexadodecaoxa-14,23,62,71-tetraaza-[15.15.0.15.15.0]paracyclophane]||heptakis(2,6-di-O-methyl)-β-cyclodextrin|catenane (27), [3][15,22,63,70-Tetraoxo-2,5,8,11,26,29,32,35,50,53,56,59,74,77,80,83-hexadodecaoxa-14,23,62,71-tetraaza-[15.15.0.15.15.0]paracyclophane]||heptakis(2,6-di-O-methyl)-β-cyclodextrin]||heptakis(2,6-di-O-methyl)-β-cyclodextrin|catenane (Head-to-Tail Isomer) (29a) and [3][15,22,63,70-Tetraoxo-2,5,8,11,26,29,32,-35,50,53,56,59,74,77,80,83-hexadodecaoxa-14,23,62,71-tetraaza-[15.15.0.15.15.0]paracyclophane]||heptakis(2,6-di-O-methyl)-β-cyclodextrin]||heptakis(2,6-di-O-methyl)-β-cyclodextrin|catenane (Head-to-Head Isomer) (29b): Reaction of diamine **12** (1 g, 1.8 mmol), NaOH (2 × 200 mg, 10 mmol) and **DM-β-CD** (2.5 g, 1.9 mmol) in H_2O (500 mL) with terephthaloyl chloride (2 × 405 mg, 4 mmol) afforded a colourless solid, which was purified by column chromatography (SiO_2, $CHCl_3$:MeOH 92:8) to afford four fractions: Fraction 1, **DM-β-CD**.

Fraction 2, the macrocycle **20** (150 mg, 12%): colourless powder; m.p. 134–135 °C; FABMS: *m/z* 695 and 717 $([M + H]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.58–3.72 (32H, m, OCH_2 and NCH_2), 4.55 (4H, s, H-α,α'), 7.24 (2H, brt, NHCO), 7.35 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.41 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'), 7.70 (4H, s, H-ω,ω'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 40.0 (NCH_2), 69.4, 69.8, 70.2, 70.5, 70.6, 70.7 [× 2] (all OCH_2), 72.9 (C-α,α'), 126.9 (C-ω,ω'), 127.2 (C-2,2'), 128.3 (C-3,3'), 136.8 (C-v,v'), 137.2 (C-4,4'), 140.0 (C-1,1'), 166.5 (C=O). Anal. calcd for $C_{38}H_{50}N_2O_{10}$: C, 65.6; H, 7.25; N, 4.03. Found: C, 65.5; H, 7.23; N, 3.89.

Fraction 3, which was purified further by preparative thin layer chromatography (SiO_2, CH_2Cl_2:MeOH 91:9) to afford: 1) A dimeric macrocycle **23** (45 mg, 3.5%): colourless powder; m.p. 148–149 °C; FABMS: *m/z* 1390 and 1412 $([M + H]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.56–3.68 (64H, m, OCH_2 and NCH_2), 4.52 (8H, s, H-α,α'), 7.31 (4H, brs, NHCO), 7.34 (8H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3,3'), 7.48 (8H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2,2'), 7.84 (8H, s, H-ω,ω'); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.9 (NCH_2), 69.4, 69.8, 70.2, 70.5 [× 2], 70.6 [× 2] (all OCH_2), 72.9 (H-α,α'), 127.0 (C-ω,ω'), 127.3 (C-2,2'), 128.3 (C-3,3'), 137.1 (C-v,v'), 137.2 (C-4,4'), 140.2 (C-α,α'), 166.7 (C=O). Anal. calcd for $C_{76}H_{100}N_4O_{20}$: C, 65.69; H, 7.25; N, 4.03. Found: C, 65.45; H, 7.41; N, 3.99.

2) [2]Catenane **25** (105 mg, 3%): colourless crystals after recrystallization from EtOH/diisopropyl ether; m.p. 175–176 °C; $[\alpha]_D$ +76 (*c*, 0.47 in $CHCl_3$). FABMS: *m/z* 695, 1353 and 2049 $([M-$**DM-β-CD** $+ H]^+$, $[M-$**20** $+ Na]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.02 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.6 Hz, H-2 of the **DM-β-CD** component), 3.20–3.85 (53H, m, OCH_2 and NCH_2 of component **20**, H-4, H-6a and H-6b of the **DM-β-CD** component), 3.37 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.44 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.89 (7H, ddd, $^3J_{4,5}$ = 10.0 Hz, $^3J_{5,6a}$ = 1.5 Hz, $^3J_{5,6b}$ = 4.6 Hz, H-5 of the **DM-β-CD** component), 4.18 (7H, t, $^3J_{2,3}$ = and $^3J_{3,4}$ = 9.3 Hz, H-3 of the **DM-β-CD** component), 4.41 and 4.45 (2H, AB system, $^2J_{AB}$ = 12.5 Hz, H-α' of component **20**), 4.54 and 4.55 (2H, AB system, $^2J_{AB}$ = 12.5 Hz, H-α of component **20**), 4.81 (7H, d, $^3J_{1,2}$ = 3.7 Hz, H-1 of the **DM-β-CD** component), 5.30 (7H, s, 3-O*H* of the **DM-β-CD** component), 7.46 (1H, brt, NHCO of component **20**), 7.59 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portions of biphenyl AA'BB' systems, H-3,3' of component **20**), 7.82 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2 of component **20**), 7.86 (1H, brt, NHCO of component **20**), 7.87 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2' of component **20**), 8.00 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, AA' portion of terephthaloyl AA'BB' system, H-ω of component **20**), 8.11 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, BB' portion of terephthaloyl AA'BB' system, H-ω' of component **20**); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 59.0 (6-*O*-Me), 60.3 (2-*O*-Me), 70.4 (C-5), 70.7 (C-6), 73.3 (C-3), 81.9 (C-2), 83.3 (C-4), 101.2 (C-1) for the **DM-β-CD** component and 40.1, 40.3 (NCH_2), 72.5, 72.9 (C-α,α'), 126.0, 126.4 (C-ω,ω'), 127.5, 127.7 (C-2,2'), 127.9, 128.0 (C-3,3'), 137.1, 137.5 (C-v,v'), 138.6 [× 2] (C-4,4'), 138.9, 140.1 (C-1,1'), 167.0, 168.0 (C=O) for component **20** excluding the 14 OCH_2 signals which overlap in the region 69.8–70.6. Anal. calcd for $C_{94}H_{148}N_2O_{45}$: C, 55.72; H, 7.37; N, 1.38. Found: C, 54.55; H, 7.36; N, 1.25.

Fraction 4 was purified further by preparative thin layer chromatography (SiO_2, CH_2Cl_2:MeOH 9:1) to afford two fractions: Fraction 4a, [2]catenane **27** (20 mg, 0.8%): colourless amorphous solid; $[\alpha]_D$ + 59 (*c*, 0.31 in $CHCl_3$); FABMS: *m/z* 1353, 1389, 2721 and 2743 $([M-$**23** $+ Na]^+$, $[M-$**DM-β-CD**$]^+$, $[M]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.12 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.6 Hz, H-2 of the **DM-β-CD** component), 3.25–3.85 (85H, m, OCH_2 and NCH_2 of component **23**, H-6a, H-6b, and H-4 of the **DM-β-CD** component), 3.36 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.45 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.93 (7H, ddd, $^3J_{4,5}$ = 10.0 Hz, $^3J_{5,6a}$ = 1.7 Hz, $^3J_{5,6b}$ = 3.8 Hz, H-5 of the **DM-β-CD** component), 4.21 (7H, t, $^3J_{2,3}$ = and $^3J_{3,4}$ = 9.3 Hz, H-3 of the **DM-β-CD** component), 4.47 (4H, s, H-α or H-α' of component **23**), 4.49 (4H, s, H-α or H-α' of component **23**), 4.86 (7H, d, $^3J_{1,2}$ = 3.7 Hz, H-1 of the **DM-β-CD** component), 5.31 (7H, s, 3-O*H* of the **DM-β-CD** component), 7.35 (2H, brt, NHCO of component **23**), 7.44 (2H, brt, NHCO of component **23**), 7.48 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3 or H-3' of component **23**), 7.49 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA' portion of biphenyl AA'BB' system, H-3 or H-3' of component **23**), 7.70 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2 or H-2' of component **23**), 7.71 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB' portion of biphenyl AA'BB' system, H-2 or H-2' of component **23**), and 8.06 (8H, s, Hω,ω' of component **23**); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 58.9 (6-*O*-Me), 60.3 (2-*O*-Me), 70.3 (C-5), 70.6 (C-6), 73.3 (C-3), 82.1 (C-2), 83.4 (C-4), 101.2 (C-1) for the **DM-β-CD** component and 39.9 [× 2] (NCH_2), 72.8, 72.9 (C-α,α'), 126.7, 126.8 (C-ω,ω'), 127.3, 127.4 (C-2,2'), 128.0, 128.1 (C-3,3'), 137.0, 137.2 (C-v,v'), 137.4, 137.8 (C-4,4'), 138.9, 140.2 (C-1,1'), 166.6 [× 2] (C=O) for component **23** excluding the 14 OCH_2 signals which overlap in the region 69.8–70.6. Anal. calcd for $C_{132}H_{198}N_4O_{55}$: C, 58.26; H, 7.33; N, 2.06. Found: C, 59.01; H, 6.84; N, 2.21.

Fraction 4b was purified further by preparative HPLC (reverse-phase column: Dynamax-60A C_{18} 83-221-C, gradient elution from MeCN:H_2O 30:70 to 37:63 over 40 min with a flow rate of 20 mL min^{-1}) to afford: 1) [3]Catenane **29a** as an amorphous solid, which was recrystallized from EtOH/diisopropyl ether to give colourless crystals (16 mg, 0.4%). M.p. 198–200 °C; $[\alpha]_D$ + 85 (*c*, 0.14 in $CHCl_3$); FABMS: *m/z* 1353, 1389, 2742 and 4072 $([M-$**27** $+ Na]^+$, $[M-2\times$**DM-β-CD**$]^+$, $[M-$**DM-β-CD** $+ Na]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6)

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δ = 3.17 (14H, dd, $^3J_{1,2}$ = 3.6 Hz, $^3J_{2,3}$ = 9.5 Hz, H-2 of the **DM-β-CD** components), 3.37–3.87 (106H, m, OCH_2 and NCH_2 of component **27**, H-4, H-6a and H-6b of the **DM-β-CD** components), 3.40 (42H, s, 6-*O*-Me of the **DM-β-CD** components), 3.48 (42H, s, 2-*O*-Me of the **DM-β-CD** components), 3.97 (14H, br m, H-5 of the **DM-β-CD** components), 4.24 (14H, t, $^3J_{2,3}$ = and $^3J_{3,4}$ = 9.2 Hz, H-3 of the **DM-β-CD** components), 4.56 (8H, s, H-α,α′ of component **23**), 4.91 (14H, d, $^3J_{1,2}$ = 3.6 Hz, H-1 of the **DM-β-CD** components), 5.34 (14H, s, 3-O*H* of the **DM-β-CD** components), 7.36 (2H, br t, N*H*CO of component **23**), 7.56 (2H, br t, N*H*CO of component **23**), 7.56 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **23**), 7.58 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **23**), 7.80 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **23**), 7.81 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **23**), 8.11 (4H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **23**), 8.15 (4H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **23**); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 59.0 (6-*O*-Me), 60.3 (2-*O*-Me), 70.4 (C-5), 70.7 (C-6), 73.3 (C-3), 82.1 (C-2), 83.4 (C-4), 101.2 (C-1) for the **DM-β-CD** components and 39.9, 40.0 (NCH_3), 72.7, 73.0 (C-α,α′), 126.3, 126.6 (C-ω,ω′), 127.2, 127.4 (C-2,2′), 127.8, 127.9 (C-3,3′), 136.9, 137.3 (C-ν,ν′), 137.5, 138.2 (C-4,4′), 139.4, 140.1 (C-1,1′), 166.6 [× 2] (*C*=O) for component **23** excluding the 14 OCH_2 signals which overlap in the region 68.4–70.8.

2) [3]Catenane **29b** as an amorphous solid (24 mg, 0.7%). $[\alpha]_D$ +71 (*c*, 0.27 in $CHCl_3$); FABMS: *m/z* 1353, 1389, 2742 and 4072 ($[M-27+Na]^+$, $[M-2\times$ **DM-β-CD**$]^+$, $[M-$**DM-β-CD** + Na$]^+$ and $[M+Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.18 (14H, dd, $^3J_{1,2}$ = 3.6 Hz, $^3J_{2,3}$ = 9.5 Hz, H-2 of the **DM-β-CD** components), 3.47–3.87 (106H, m, OCH_2 and NCH_2 of component **23**, and H-4, H-6a, and H-6b of the **DM-β-CD** components), 3.38 (42H, s, 6-*O*-Me), 3.50 (42H, s, 2-*O*-Me), 3.97 (14H, br m, H-5 of the **DM-β-CD** components), 4.55 (8H, s, H-α,α′ of component **23**), 4.92 (14H, d, $3J_{1,2}$ = 3.6 Hz, H-1 of the **DM-β-CD** components), 5.34 (14H, s, 3-O*H* of the **DM-β-CD** components) 7.51 (4H, br t, N*H*CO of component **23**), 7.58 (8H, m, $3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′ of component **23**), 7.82 (8H, m, $3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′ of component **23**), 8.13 (8H, s, H-ω,ω′ of component **23**); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 58.9 (6-*O*-Me), 60.4 (2-*O*-Me), 70.4 (C-5), 70.7 (C-6), 73.3 (C-3), 82.1 (C-2), 83.5 (C-4), 101.2 (C-1) for the **DM-β-CD** components and 40.0 (NCH_2), 72.8 (H-α,α′), 126.5 (C-ω,ω′), 127.3 (C-2,2′), 128.0 (C-3,3′), 137.1 (C-ν,ν′), 137.8 (C-4,4′), 139.8 (C-α,α′), 166.6 (*C*=O) for component **23** excluding the 14 OCH_2 signals which overlap in the region 68.4–70.8.

18,25-Dioxo-2,5,8,11,14,29,32,35,38,41-decaoxa-17,26-diaza-[18.18.0]paracyclophane (21), 18,25,72,79-Tetraoxo-2,5,8,11,14,29,32,35,38,41,53,56,59,62,68,83,-86,89,92,95-eicosaoxa-17,26,71,80-tetraaza-[18.18.0.18.18.0]paracyclophane (24), [2]|[18,25-Dioxo-2,5,8,11,14,29,32,35,38,41-decaoxa-17,26-diaza-[18.18.0]-paracyclophane]|heptakis(2,6-di-*O*-methyl)-β-cyclodextrin|catenane (26), [2]|[18,25,72,79-Tetraoxo-2,5,8,11,14,29,32,35,38,41,53,56,59,62,68,83,86,89,92,95-eicosaoxa-17,26,71,80-tetraaza-[18.18.0.18.18.0]paracyclophane]|heptakis(2,6-di-*O*-methyl)-β-cyclodextrin|catenane (28), [3]|[18,25,72,79-Tetraoxo-2,5,8,11,14,29,32,35,38,41,53,56,59,62,68,83,86,89,92,95-eicosaoxa-17,26,71,80-tetraaza-[18.18.0.18.18.0]paracyclophane]|heptakis(2,6-di-*O*-methyl)-β-cyclodextrin]|heptakis(2,6-di-*O*-methyl)-β-cyclodextrin|catenane (Head-to-Tail Isomer) (30a) and [3]|[18,25,72,79-Tetraoxo-2,5,8,11,14,29,32,-35,38,41,53,56,59,62,68,83,86,89,92,95-eicosaoxa-17,26,71,80-tetraaza-[18.18.0.18.18.0]paracyclophane]|heptakis(2,6-di-*O*-methyl)-β-cyclodextrin]|heptakis(2,6-di-*O*-methyl)-β-cyclodextrin|catenane (Head-to-Head Isomer) (30b): Reaction of diamine **14** (0.55 g, 0.84 mmol), NaOH (2 × 180 mg, 9 mmol) and **DM-β-CD** (2.5 g, 1.9 mmol) in H_2O (250 mL) with terephthaloyl chloride (2 × 175 mg, 1.74 mmol) afforded a colourless solid, which was purified by column chromatography (SiO_2, $CHCl_3$:MeOH 92:8) to afford four fractions: Fraction 1, **DM-β-CD**.

Fraction 2, the macrocycle **21** as a white powder (51 mg, 8%): m.p. 85–87 °C; FABMS: *m/z* 783, 805 and 821 ($[M+H]^+$, $[M+Na]^+$ and $[M+K]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.54–3.67 (40H, m, OCH_2 and NCH_2), 4.53 (4H, s, H-α,α′), 7.01 (2H, br t, N*H*CO), 7.33 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.49 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′), 7.78 (4H, s, H-ω,ω′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.9 (NCH_2), 69.4, 69.7, 70.3, 70.5, 70.6 [× 3], 70.7 [× 2] (all OCH_2), 72.8 (C-α,α′), 126.9 (C-ω,ω′), 127.3 (C-2,2′), 128.2 (C-3,3′), 137.0 (C-ν,ν′), 137.4 (C-4,4′), 140.1 (C-1,1′), 166.6 (*C*=O). Anal. calcd for $C_{42}H_{58}N_2O_{12}$: C, 67.30; H, 6.98; N, 4.62. Found: C, 66.62; H, 8.30; N, 2.73.

Fraction 3, which was purified further by preparative thin layer chromatography (SiO_2, CH_2Cl_2:MeOH 91:9) to afford: 1) Dimeric macrocycle **24** as a white powder (4 mg, 0.6%): m.p. 101–102 °C; FABMS: *m/z* 1564 and 1586 ($[M+H]^+$ and $[M+Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.57–3.70 (80H, m, OCH_2 and NCH_2), 4.54 (8H, s, H-α,α′), 7.26 (4H, br t, N*H*CO), 7.36 (8H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′), 7.52 (8H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′), 7.88 (8H, s, H-ω,ω′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.9 (NCH_2), 69.5, 69.8, 70.2, 70.5 [× 3], 70.6 [× 3] (all OCH_2), 72.9 (C-α,α′), 127.0 (C-ω,ω′), 127.3 (C-2,2′), 128.2 (C-3,3′), 137.1 (C-ν,ν′), 137.2 (C-4,4′), 140.2 (C-1,1′), 166.7 (*C*=O).

2) [2]Catenane **26** as colourless crystals after recrystallization from EtOH/diisopropyl ether (43 mg, 2.4%): m.p. 142–143 °C; FABMS: *m/z* 783, 1353, 2114, 2136 and 2150 ($[M-$**DM-β-CD** + H$]^+$, $[M-$**21** + Na$]^+$, $[M+H]^+$, $[M+Na]^+$ and $[M+K]^+$, respectively); $[\alpha]_D$ +78 (*c*, 0.31 in $CHCl_3$); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.07 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.6 Hz, H-2 of the **DM-β-CD** component), 3.19–3.79 (61H, m, OCH_2 and NCH_2 of component **21**, H-4, H-6a, and H-6b of the **DM-β-CD** component), 3.38 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.45 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.92 (7H, ddd, $^3J_{4,5}$ = 10.0 Hz, $^3J_{5,6a}$ = 1.5 Hz, $^3J_{5,6b}$ = 4.0 Hz, H-5 of the **DM-β-CD** component), 4.19 (7H, t, $^3J_{2,3}$ and $^3J_{3,4}$ = 9.2 Hz, H-3 of the **DM-β-CD** component), 4.50 (2H, s, H-α or H-α′ of component **21**), 4.56 (2H, s, H-α or H-α′ of component **21**), 4.84 (7H, d, $^3J_{1,2}$ = 3.7 Hz, H-1 of the **DM-β-CD** component), 5.30 (7H, s, 3-O*H* of the **DM-β-CD** component), 7.38 (1H, br t, N*H*CO of component **21**), 7.56 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **21**), 7.61 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **21**), 7.62 (1H, br t, N*H*CO of component **21**), 7.81 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **21**), 7.84 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **21**), 8.01 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **21**), 8.09 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **21**); ^{13}C NMR (100.6 MHz, C_6D_6) δ = 58.9 (6-*O*-Me), 60.3 (2-*O*-Me), 70.6 (C-5), 71.0 (C-6), 74.1 (C-3), 82.7 (C-2), 84.2 (C-4), 101.9 (C-1) for the **DM-β-CD** component and 40.4 [× 2] (NCH_2), 72.7, 73.1 (C-α,α′), 126.8, 127.2, 127.8, 127.9, 128.0, 128.2 (C-ω,ω′, C-2,2′, and C-3,3′), 137.7, 138.1 (C-ν,ν′), 138.5, 139.3 (C-4,4′), 139.5, 140.7 (C-1,1′), 166.6, and 166.7 (*C*=O) for component **21** excluding the 18 OCH_2 signals which overlap in the region 70.1–71.0. Anal. calcd for $C_{98}H_{156}N_2O_{47}$: C, 55.67; H, 7.43; N, 1.32. Found: C, 54.53; H, 7.00; N, 1.17.

Fraction 4 was purified further by preparative thin layer column chromatography on silica gel (SiO_2, CH_2Cl_2:MeOH 9:1) to afford two fractions: Fraction 4a, [2]catenane **28** as a colourless amorphous solid (8 mg, 0.3%). $[\alpha]_D$ + 56 (*c*, 0.29 in $CHCl_3$); FABMS: *m/z* 1353, 1587 and 2916 ($[M-$**24** + Na$]^+$, $[M-$**DM-β-CD** + Na$]^+$ and $[M+Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.13 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.5 Hz, H-2 of the **DM-β-CD** component), 3.31–3.83 (101H, m, OCH_2 and NCH_2 of component **24**, H-4, H-6a, and H-6b of the **DM-β-CD** component), 3.37 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.45 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.96 (7H, ddd, $^3J_{4,5}$ = 10.0 Hz, $^3J_{5,6a}$ = 1.7 Hz, $^3J_{5,6b}$ = 4.0 Hz, H-5 of the **DM-β-CD** component), 4.23 (7H, t, $^3J_{2,3}$ = and $^3J_{3,4}$ = 9.3 Hz, H-3 of the **DM-β-CD** component), 4.49 (8H, s, H-α,α′ of component **24**), 4.87 (7H, d, $^3J_{1,2}$ = 3.7 Hz, H-1 of the **DM-β-CD** component), 5.31 (7H, s, 3-O*H* of the **DM-β-CD** component), 7.42 (2H, br t, N*H*CO of component **24**), 7.47 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **24**), 7.48 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **24**), 7.54 (2H, br t, N*H*CO of component **24**), 7.67 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **24**), 7.68 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **24**), 8.08 (4H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **24**), 8.11 (4H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **24**); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 58.9 (6-*O*-Me), 60.3 (2-*O*-Me), 71.0 (C-5), 71.8 (C-6), 74.0 (C-3), 82.8 (C-2), 84.3 (C-4), 101.9 (C-1) for the **DM-β-CD** component and 40.7 [× 2] (NCH_2), 72.9, 73.0 (C-α,α′), 127.1, 127.3 (C-ω,ω′), 127.8, 127.9 (C-2,2′), 128.3, 128.4 (C-3,3′), 137.7, 137.8 (C-ν,ν′), 138.2, 138.6 (C-4,4′), 140.2, 140.6 (C-1,1′), 166.4 [× 2] (*C*=O) for component **24** excluding the 18 OCH_2 signals which overlap in the region 70.1–71.1.

Fraction 4b was purified further by preparative HPLC [reverse-phase column: Dynamax-60A C18 83-221-C, gradient elution from MeCN:H_2O 30:70 to 37:63 over 40 min with a flow rate of 20 mL min^{-1}] to afford: 1) [3]Catenane **30a** as an amorphous solid (7 mg, 0.2%). $[\alpha]_D$ + 72 (*c*, 0.24 in $CHCl_3$); FABMS: *m/z* 1354, 1588, 2918 and 4245 ($[M-$**28** + Na$]^+$, $[M-2\times$**DM-β-CD** + Na$]^+$, $[M-$**DM-β-CD** + Na$]^+$ and $[M+Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.18 (14H, dd, $^3J_{1,2}$ = 3.6 Hz, $^3J_{2,3}$ = 9.5 Hz, H-2 of the **DM-β-CD** components), 3.39–3.87 (122H, m, OCH_2 and NCH_2 of component **24**, H-4, H-6a, and H-6b of the **DM-β-CD** components), 3.41 (42H, s, 6-*O*-Me of the **DM-β-CD** components), 3.49 (42H, s, 2-*O*-Me of the **DM-β-CD** components), 3.98 (14H, br m, H-5 of the **DM-β-CD** components), 4.23 (14H, t, $^3J_{2,3}$ = and $^3J_{3,4}$ = 9.2 Hz, H-3 of the **DM-β-CD** components), 4.56 (8H, s, H-α,α′ of component **24**), 4.92 (14H, d, $^3J_{1,2}$ = 3.6 Hz, H-1 of the **DM-β-CD** components), 5.33 (14H, s, 3-O*H* of the **DM-β-CD** components), 7.45 (2H, br t, N*H*CO of component **24**), 7.55 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **24**), 7.58 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **24**), 7.72 (2H, br t, N*H*CO of component **24**), 7.78 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **24**), 7.79 (4H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **24**), 8.13 (4H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **24**), 8.19 (4H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **24**).

2) [3]Catenane **30b** as an amorphous solid (7 mg, 0.2%): $[\alpha]_D$ + 69 (*c*, 0.25 in $CHCl_3$); FABMS: *m/z* 1354, 1588, 2918 and 4245 ($[M-$**28** + Na$]^+$, $[M-2\times$**DM-β-CD** + Na$]^+$, $[M-$**DM-β-CD** + Na$]^+$ and $[M+Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.19 (14H, dd, $^3J_{1,2}$ = 3.6 Hz, $^3J_{2,3}$ = 9.5 Hz, H-2 of the **DM-β-CD** components), 3.49–3.87 (122H, m, OCH_2 and NCH_2 of component **24**, H-4, H-6a and H-6b of the **DM-β-CD** components), 3.40 (42H, s, 6-*O*-Me of the **DM-β-CD** components), 3.51 (42H, s, 2-*O*-Me of the **DM-β-CD** components), 3.98

(14H, br m, H-5 of the **DM-β-CD** components), 4.23 (14H, t, $^3J_{2,3}$ and $^3J_{3,4}$ = 9.2 Hz, H-3 of the **DM-β-CD** components), 4.58 (8H, s, H-α,α′ of component **24**), 4.92 (14H, d, $^3J_{1,2}$ = 3.6 Hz, H-1 of the **DM-β-CD** components), 5.33 (14H, s, 3-O*H* of the **DM-β-CD** components), 7.57 (8H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3,3′ of component **24**), 7.60 (4H, br t, N*H*CO of component **24**), 7.89 (8H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2,2′ of component **24**), 8.18 (8H, s, H-ω,ω′ of component **24**).

18,25-Dioxo-2,5,8,11,13,29,32,35-octaoxa-17,26-diaza-[18.12.0]paracyclo-phane (31), [2][18,25-Dioxo-2,5,8,11,13,29,32,35-octaoxa-17,26-diaza-[18.12.0]-paracyclophane][heptakis(2,6-di-*O*-methyl)-β-cyclodextrin]catenane (Isomer 1) (32) and [2][18, 25-Dioxo-2,5,8,11,13,29,32,35-octaoxa-17,26-diaza-[18.12.0]paracyclophane][hepta-kis(2,6-di-*O*-methyl)-β-cyclodextrin]catenane (Isomer 2) (33): Reaction of diamine **16** (0.55 g, 0.84 mmol), NaOH (2 × 180 mg, 9 mmol) and **DM-β-CD** (2.5 g, 1.9 mmol) in H_2O (250 mL) with terephthaloyl chloride (2 × 175 mg, 1.74 mmol) afforded a colourless solid, which was purified by column chromatography (SiO_2, $CHCl_3$:MeOH 92:8) to afford four fractions: Fraction 1, **DM-β-CD**.

Fraction 2, macrocycle **31** (32 mg, 6.5%): m.p. 131–132 °C; FABMS: *m/z* 695 and 717 ($[M + H]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.52–3.70 (32H, m, O*CH*$_2$), 4.52 (2H, s, H-α or H-α′), 4.56 (2H, s, H-α or H-α′), 6.96 (1H, br t, N*H*CO), 7.03 (1H, br t, N*H*CO), 7.30 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.34 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′), 7.41 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′), 7.43 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′), 7.65 (2H, m, $^3J_{\omega,\omega'}$ = 8.2 Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′), 7.68 (2H, m, $^3J_{\omega,\omega'}$ = 8.2 Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.9, 40.0 (N*C*H$_2$), 69.4 [× 2], 69.7, 69.8, 70.3 [× 2], 70.5, 70.6, 70.7 [× 3], 70.8 [× 3] (all O*C*H2), 72.9, 73.00 (C-α,α′), 126.9, 127.0 (C-ω,ω′), 127.2 (C-2,2′), 128.2 [× 2] (C-3,3′), 136.8, 137.0 (C-ν,ν′), 137.0, 137.4 (C-4,4′), 139.8, 140.1 (C-1,1′), 166.5, 166.6 (*C*=O). Anal. calcd for $C_{38}H_{50}N_2O_{10}$: C, 65.7; H, 7.25; N, 4.03. Found: C, 65.4; H, 7.20; N, 4.02.

Fraction 3, which was purifed further by preparative thin layer chromatography (SiO_2, CH_2Cl_2:MeOH 91:9) to afford (a) an equimolar mixture of the isomeric non-catenated macrocyclic dimers of **31**, the separation of which was not attempted (5 mg, 1%): FABMS: *m/z* 1389 and 1411 ($[M + H]^+$ and $[M + Na]^+$, respectively); and (b) an equimolar mixture of two compounds which were separated by preparative HPLC [reverse-phase column: Dynamax-60A C18 83-221-C, gradient elution from MeCN:H_2O 20:80 to 35:65 over 30 min with a flow rate of 20 mL min^{-1}] to afford: 1) [2]Catenane **32** as colourless crystals after recrystallization from EtOH/diisopropyl ether (12 mg, 0.8%): m.p. 166-167 °C; $[\alpha]_D$ + 68 (*c*, 0.21 in $CHCl_3$); FABMS: *m/z* 695, 1354 and 2049 ($[M-$**DM-β-CD**$]^+$, $[M-$**31** + Na$]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.02 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.6 Hz, H-2 of the **DM-β-CD** component), 3.20-3.82 (53H, m, O*CH*$_2$ and N*CH*$_2$ of component **31**, H-4, H-6a, and H-6b of the **DM-β-CD** component), 3.39 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.42 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.84-3.96 (7H, br m, H-5 of the **DM-β-CD** component), 4.17 (7H, t, $^3J_{2,3}$ and $^3J_{3,4}$ = 9.3 Hz, H-3 of the **DM-β-CD** component), 4.30 and 4.36 (2H, AB system, $^2J_{AB}$ = 12.5 Hz, H-α or H-α′ of component **31**), 4.56 (2H, s, H-α or H-α′ of component **31**), 4.83 (7H, d, $^3J_{1,2}$ = 3.7 Hz, H-1 of the **DM-β-CD** component), 5.30 (7H, s, 3-O*H* of the **DM-β-CD** component), 7.47 (1H, br t, N*H*CO of component **31**), 7.55 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **31**), 7.57 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **31**), 7.71 (1H, br t, N*H*CO of component **31**), 7.83 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **31**), 7.85 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **31**), 8.01 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **31**), 8.11 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **31**); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 59.0 (6-*O*-Me), 60.2 (2-*O*-Me), 70.4 (C-5), 70.7 (C-6), 73.2 (C-3), 81.9 (C-2), 83.2 (C-4), 101.1 (C-1) for the **DM-β-CD** component and 40.1, 40.3 (N*C*H$_2$), 72.5, 72.9 (C-α,α′), 126.1, 126.4 (C-ω,ω′), 127.5, 127.7 (C-2,2′), 127.8, 128.0 (C-3,3′), 137.0, 137.3 (C-ν,ν′), 138.2, 138.5 (C-4,4′), 138.8, 140.2 (C-1,1′), 166.9, 167.8 (*C*=O) for component **31** excluding the 14 O*C*H$_2$ signals which overlap in the region 69.8–70.6.

2) [2]Catenane **33** as colourless crystals after recrystallization from EtOH/diisopropyl ether (10 mg, 0.7%); m.p. 196–197 °C; $[\alpha]_D$ + 52 (*c*, 0.26 in $CHCl_3$); FABMS: *m/z* 695, 1354 and 2049 ($[M-$**DM-β-CD**$]^+$, $[M-$**31** + Na$]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.01 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.6 Hz, H-2 of the **DM-β-CD** component), 3.20–3.92 (53H, m, O*CH*$_2$ and N*CH*$_2$ of component **31**, H-4, H-6a, and H-6b of the **DM-β-CD** component), 3.35 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.45 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.82–3.94 (7H, br m, H-5 of the **DM-β-CD** component), 4.17 (7H, t, $^3J_{2,3}$ and $^3J_{3,4}$ = 9.3 Hz, H-3 of the **DM-β-CD** component), 4.49 (2H, s, H-α or H-α′ of component **31**), 4.53 (2H, s, H-α or H-α′ of component **31**), 4.90 (7H, d, $^3J_{1,2}$ = 3.7 Hz, H-1 of the **DM-β-CD** component), 5.29 (7H, s, 3-O*H* of the **DM-β-CD** component), 7.58 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **31**), 7.59 (1H, br t, N*H*CO), 7.61 (2H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **31**), 7.73 (1H, br t, N*H*CO of component **31**), 7.81 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **31**), 7.86 (2H, m, $^3J_{2,3}$ = 8.2 Hz, BB′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **31**), 7.93 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **31**), 8.12 (2H, m, $^3J_{\omega,\omega'}$ = 8.4 Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **31**); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 58.9 (6-*O*-Me), 60.3 (2-*O*-Me), 70.3 (C-5), 70.7 (C-6), 73.2 (C-3), 81.9 (C-2), 83.3 (C-4), 101.2 (C-1) for the **DM-β-CD** component and 40.3 [× 2] (N*C*H$_2$), 72.5, 72.9 (C-α,α′), 126.0, 126.4 (C-ω,ω′), 127.6 [× 2] (C-2,2′), 127.9, 128.1 (C-3,3′), 137.1, 137.6 (C-ν,ν′), 138.3, 138.6 [× 2] (C-4,4′), 138.9, 140.1 (C-1,1′), 167.1, 168.0 (*C*=O) for component **31** excluding the 14 O*C*H$_2$ signals which overlap in the region 69.8–70.6.

15,28-Dioxo-2,5,8,11,32,35,38,41-octaoxa-14,29-diaza-[15.0.15.0]paracyclophane (34), 15,28,69,82-Tetraoxo-2,5,8,11,32,35,38,41,56,59,62,65,86,89,92,95-hexadodecaoxa-14,29,68,83-tetraaza-[15.0.15.0.15.0.15.0]paracyclophane (35) and [2][15,28-Dioxo-2,5,8,11,32,35,38,41-octaoxa-14,29-diaza[15.0.15.0]paracyclophane][hepta-kis(2,6-di-*O*-methyl)-β-cyclodextrin]catenane (36): Reaction of diamine **12** (0.2 g, 0.35 mmol), NaOH (2 × 40 mg, 2 mmol) and **DM-β-CD** (0.5 g, 0.35 mmol) in H_2O (100 mL) with biphenyl-4,4′-dicarbonyl dichloride (2 × 100 mg, 0.72 mmol) afforded a colourless solid, which was purified by column chromatography (SiO_2, CH_2Cl_2:Me$_2$CO:MeOH 75:18:7) to afford three fractions: Fraction 1, **DM-β-CD**.

Fraction 2, which was purified further by column chromatography (SiO_2, $CHCl_3$:MeOH 93:7) to afford: 1) Macrocycle **34** as a white powder (113 mg, 41%): m.p. 214–216 °C; FABMS: *m/z* 771, 793 and 809 ($[M + H]^+$, $[M + Na]^+$ and $[M + K]^+$, respectively); ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.62–3.72 (32H, m, O*CH*$_2$ and N*CH*$_2$), 4.53 (4H, s, H-α,α′), 7.29 (4H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of bitolyl AA′BB′ system, H-3,3′), 7.35 (4H, m, $^3J_{2,3}$ = 8.3 Hz, BB′ portion of bitolyl AA′BB′ system, H-2,2′), 7.39 (4H, m, $^3J_{\mu,\nu}$ = 8.4 Hz, AA′ portion of biphenyldicarbonyl AA′BB′ system, H-ν,ν′), 7.46 (2H, br t, N*H*CO), 7.83 (4H, m, $^3J_{\mu,\nu}$ = 8.4 Hz, BB′ portion of biphenyldicarbonyl AA′BB′ system, H-μ,μ′); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ = 39.9 (N*C*H$_2$), 69.5, 70.0, 70.2, 70.5, 70.6, 70.7 [× 2] (all O*C*H$_2$), 72.9 (C-α,α′), 126.9, 127.0, 127.7, 128.1 (aromatic *C*H), 133.7 (C-4,4′), 137.2 (C-j,j′), 139.9 (C-1,1′), 142.7 (C-ω,ω′). Anal. calcd for $C_{44}H_{54}N_2O_{10}$: C, 68.55; H, 7.06; N, 3.63. Found: C, 68.26; H, 6.90; N, 3.71.

2) Dimeric macrocycle **35** (6 mg, 2.2%): white powder, m.p. 223–224 °C; FABMS: *m/z* 1563 $[M + Na]^+$. ^{13}C NMR (300 MHz, $CDCl_3$) δ = 3.52–3.72 (64H, m, O*CH*$_2$ and N*CH*$_2$), 4.51 (8H, s, H-α,α′), 7.30 (8H, m, $^3J_{2,3}$ = 8.2 Hz, AA′ portion of bitolyl AA′BB′ system, H-3,3′), 7.39 (4H, br t, N*H*CO), 7.43 (8H, m, $^3J_{2,3}$ = 8.3 Hz, BB′ portion of bitolyl AA′BB′ system, H-2,2′), 7.53 (8H, m, $^3J_{\mu,\nu}$ = 8.4 Hz, AA′ portion of biphenyldicarbonyl AA′BB′ system, H-ν,ν′), 7.88 (8H, m, $^3J_{\mu,\nu}$ = 8.4 Hz, BB′ portion of biphenyldicarbonyl AA′BB′ system, H-μ,μ′).

Fraction 3, [2]catenane **36** as colourless crystals after recrystallization from EtOH/diisopropyl ether (20 mg, 2.7%): m.p. 152–153 °C; $[\alpha]_D$ + 94 (*c*, 0.37 in $CHCl_3$); FABMS: *m/z* 771, 1353, 2101, 2123 and 2140 ($[M-$**DM-β-CD** + H$]^+$, $[M-$**34** + Na$]^+$, $[M + H]^+$, $[M + Na]^+$ and $[M + K]^+$, respectively); ^{1}H NMR (400 MHz, C_6D_6) δ = 3.07 (7H, dd, $^3J_{1,2}$ = 3.7 Hz, $^3J_{2,3}$ = 9.6 Hz, H-2 of the **DM-β-CD** component), 3.18–3.84 (53H, m, O*CH*$_2$ and N*CH*$_2$ of component **34**, H-4, H-6a, and H-6b of the **DM-β-CD** component), 3.38 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.44 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.91 (7H, dt, $^3J_{4,5}$ = 10.0 Hz, $^3J_{5,6a}$ and $^3J_{5,6b}$ = 3.4 Hz, H-5 of the **DM-β-CD** component), 4.16 (7H, t, $^3J_{2,3}$ and $^3J_{3,4}$ = 9.3 Hz, H-3 of the **DM-β-CD** component), 4.37 and 4.42 (2H, AB system, $^2J_{AB}$ = 12.6 Hz, H-α of component **34**), 4.53 (2H, s, H-α′ of component **34**), 4.81 (7H, d, $^3J_{1,2}$ = 3.7 Hz, H-1 of the **DM-β-CD** component), 5.27 (7H, s, 3-O*H* of the **DM-β-CD** component), 7.05 (1H, br t, N*H*CO of component **34**), 7.50 (1H, br t, N*H*CO of component **34**), 7.53 (4H, m, $^3J_{2,3}$ = 8.0 Hz, AA′ portions of bitolyl AA′BB′ systems, H-3,3′ of component **34**), 7.60 (2H, m, $^3J_{\mu',\nu'}$ = 8.4 Hz, AA′ portion of biphenyldicarbonyl AA′BB′ system, H-ν′ of component **34**), 7.66 (2H, m, $^3J_{\mu,\nu}$ = 8.4 Hz, AA′ portion of biphenyldicarbonyl AA′BB′ system, H-n of component **34**), 7.79 (2H, m, $^3J_{2,3}$ = 8.0 Hz, BB′ portion of bitolyl AA′BB′ system, H-2 of component **34**), 7.81 (2H, m, $^3J_{2',3'}$ = 8.0 Hz, BB′ portion of bitolyl AA′BB′ system, H-2′ of component **34**), 8.07 (2H, m, $^3J_{\mu',\nu'}$ = 8.4 Hz, BB′ portion of biphenyldicarbonyl AA′BB′ system, H-μ′ of component **34**), 8.16 (2H, m, $^3J_{\mu,\nu}$ = 8.4 Hz, BB′ portion of biphenyldicarbonyl AA′BB′ system, H-μ of component **34**); ^{13}C NMR (100.6 MHz, C_6D_6) δ = 58.9 (6-*O*-Me), 6.03 (2-*O*-Me), 70.5 (C-5), 71.4 (C-6), 74.1 (C-3), 82.3 (C-2), 83.9 (C-4), 101.6 (C-1) for the **DM-β-CD** component and 40.2, 40.4 (N*C*H$_2$), 72.6, 73.2 (C-α,α′), 126.6, 126.9, 127.3, 127.4, 127.7 [× 2], 128.0 [× 2] (aromatic *C*H), 133.8, 135.1, 137.9, 139.1, 139.5, 140.8, 143.0, 143.5 (aromatic *C*C), 166.7, 166.9 (*C*=O) for component **34** excluding the 14 O*C*H$_2$ signals which overlap in the region 60.0–71.0. Anal. calcd for $C_{100}H_{152}N_2O_{45}$: C, 57.13; H, 7.28; N, 1.33. Found: C, 55.01; H, 7.06; N, 1.16.

1,15,22,36-Tetraoxo-5,8,11,26,29,32-hexaoxa-2,14,23,35-tetraaza-[15.15.0]-paracyclophane (37) and [2][1,15,22,36-Tetraoxo-5,8,11,26,29,32-hexaoxa-2,14,-23,35-tetraaza-[15.15.0]paracyclophane][heptakis(2,6-di-*O*-methyl)-β-cyclo-dextrin]catenane (38): Reaction of diamine **18** (0.2 g, 0.34 mmol), NaOH (2 × 40 mg, 2 mmol) and **DM-β-CD** (0.54 g, 0.41 mmol) in H_2O (100 mL) with terephthaloyl chloride (2 × 81 mg, 0.8 mmol) afforded a colourless solid, which was purified by column chromatography (SiO_2, $CHCl_3$:MeOH 93:7) to afford three fractions: Fraction 1, **DM-β-CD**.

Fraction 2, [2]catenane **38** as a colourless solid (5 mg, 0.7%): m.p. 232–234 °C, $[\alpha]_D$ + 52 (*c*, 0.11 in $CHCl_3$); *m/z* FABMS: 721, 1353 and 2074 ($[M-$**DM-β-CD** + H$]^+$, $[M-$**37** + Na$]^+$ and $[M + Na]^+$, respectively); ^{1}H NMR (400 MHz,

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C_6D_6) $\delta = 3.03$ (7H, dd, $^3J_{1,2} = 3.7$ Hz, $^3J_{2,3} = 9.6$ Hz, H-2), 3.20–3.85 (53H, m, OCH_2 and NCH_2 of component **37** and H-4, H-6a, and H-6b of the **DM-β-CD** component), 3.38 (21H, s, 6-*O*-Me of the **DM-β-CD** component), 3.44 (21H, s, 2-*O*-Me of the **DM-β-CD** component), 3.91 (7H, dt, $^3J_{4,5} = 10.0$ Hz, $^3J_{5,6a}$ and $^3J_{5,6b} = 4.0$ Hz, H-5 of the **DM-β-CD** component), 4.17 (7H, $^3J_{2,3}$ and $^3J_{3,4} = 9.3$ Hz, H-3 of the **DM-β-CD** component), 4.83 (7H, $^3J_{1,2} = 3.7$ Hz, H-1 of the **DM-β-CD** component), 5.27 (7H, s, 3-O*H* of the **DM-β-CD** component), 6.83 (1H, br t, N*H*CO), 7.28 (1H, br t, N*H*CO of component **37**), 7.42 (1H, br t, NHCO of component **31**), 7.63 (1H, br t, N*H*CO), 7.75 (2H, m, $^3J_{2,3} = 8.4$ Hz, AA′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **37**), 7.79 (2H, m, $^3J_{2,3} = 8.4$ Hz, AA′ portion of biphenyl AA′BB′ system, H-2 or H-2′ of component **37**), 7.96 (2H, m, $^3J_{\omega,\omega'} = 8.4$ Hz, AA′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **37**), 8.06 (2H, m, $^3J_{2,3} = 8.4$ Hz, BB′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **37**), 8.07 (2H, m, $^3J_{2,3} = 8.4$ Hz, BB′ portion of biphenyl AA′BB′ system, H-3 or H-3′ of component **37**), 8.21 (2H, m, $^3J_{\omega,\omega'} = 8.4$ Hz, BB′ portion of terephthaloyl AA′BB′ system, H-ω or H-ω′ of component **37**); ^{13}C NMR (100.6 MHz, C_6D_6) $\delta = 59.0$ (6-*O*-Me), 60.3 (2-*O*-Me), 71.0 (C-5), 71.8 (C-6), 74.1 (C-3), 82.6 (C-2), 84.1 (C-4), 101.9 (C-1) for the **DM-β-CD** component excluding the signals for component **37** which were too weak to be assigned.

Fraction 3, macrocycle **37** as a colourless solid (63 mg, 26%): m.p. 260–261 °C; FABMS: *m/z* 721, 743 and 759 ($[M + H]^+$, $[M + Na]^+$ and $[M + K]^+$, respectively); ^1H NMR (300 MHz, $CDCl_3$) $\delta = 3.54$–3.81 (32H, m, OCH_2 and NCH_2), 6.78 (2H, br t, N*H*CO), 7.18 (2H, br t, N*H*CO), 7.56 (4H, m, $^3J_{2,3} = 8.4$ Hz, AA′ portion of biphenyl AA′BB′ system, H-2,2′), 7.67 (4H, s, H-ω,ω′), 7.86 (4H, m, $^3J_{2,3} = 8.4$ Hz, BB′ portion of biphenyl AA′BB′ system); ^{13}C NMR (75.5 MHz, $CDCl_3$) $\delta = 39.9$ [×2] (NCH_2), 69.8, 70.0, 70.2, 70.3, 70.5, 70.6 (OCH_2), 127.0 (C-ω,ω′), 127.1 (C-2,2′), 127.8 (C-3,3′), 133.8 (C-4,4′), 136.4 (C-μ,μ′), 142.0 (C-1,1′), 165.9, 166.8 (*C*=O). Anal calcd for $C_{38}H_{48}N_4O_{10}$: C, 63.32; H, 6.71; N, 7.77. Found: C, 63.46; H, 6.81; N, 7.56.

NMR Spectroscopy: The two-dimensional rotating frame Overhauser experiment (ROESY) was performed according to the pulse sequence: D1 – 90° – D0 – spin-lock – FID (D1 is a relaxation delay and D0 is the incremental delay). The experiment was performed in phase-sensitive mode using time-proportional phase incrementation (TPPI), and full regulated power was used for excitation (1 db attenuation). The attenuation employed for the cw spin-lock field was 19 db, and this corresponded to a spin-lock field of 2 kHz. This relatively low value was used to minimize the effect of homonuclear Hartmann–Hahn (HOHAHA) cross-coupling. The solvent was presaturated before the start of the main sequence by slighlty modifying the standard Bruker pulse program. A spin-lock time of 300 ms was used when the experiment was carried out in C_6H_6 and increased to 500 ms when it was carried out in D_2O. The experimental parameters used were S1 = 2 s, Δd0 = 3 us, SW = 7 ppm. In the F1 domain, TD1 = S1 = 1 K data points. In the F2 domain, TD = SI = 2 K data points. NS = 16 and DS = 2. The data was processed with a sine-bell window function shifted by π/2 in both domains and phased so that the ROE cross-peaks were anti-phase with the diagonal (HOHAHA cross-peaks appear in phase with the diagonal). Automatic base-line correction was applied in both frequency domains and maximum spectral clarity was achieved by the careful subtraction of typical "background" noise from all the row and column data after Fourier transformation.

Stability Constant Determinations by ^1H NMR Spectroscopy: This method is based on the change in chemical shift differences for a probe proton of either host or guest upon varying the relative concentration (e.g., the guest) with respect to the other component (e.g., the CD host). All experiments were carried out in either D_2O or in 0.1 N NaOD/D_2O at 298 K. The CD hosts were dried in a drying pistol at 100 °C for 12 h under high vacuum (0.1 mbar) in the presence of phosphorus pentoxide before use. The guests were dried in a similar manner but at 40 °C. Two methods of association constant determination were employed, namely, a titration and a dilution procedure.

In a typical titration experiment, a stock solution of the CD host was made up by dissolving a weighed sample of host in a weighed amount of deuteriated solvent. The concentration of the stock solutions were in the range 2×10^{-3}–3×10^{-3} M. Accurately weighed aliquots of the host stock solution were then added to a range of accurately weighed guest samples. This procedure provided a series of solutions of varying guest concentrations but of constant host concentration. The molar ratios of guest-to-host were in the range 0.5:1 to 10:1.

In the dilution method, an equimolar or a 2:1 molar ratio (guest:host) stock solution of host and guest (5×10^{-3} M) was prepared by dissolving a weighed equimolar or 2:1 molar ratio (guest:host) amount of guest and host in a weighed amount of deuterated solvent. Approximately 6–8 solutions were then prepared from a single stock solution by adding different weighed amounts of D_2O to weighed aliquots of the stock solution. Thus, the final concentrations, ranging from 10^{-4} to 5×10^{-3} M, were readily determined.

For the Job method, which provides the stoichiometry of CD complexes, a stock solution of host and a stock solution of guest having identical molarities (3×10^{-3} M) were prepared in the first instance by using, in each case, the same weighed amount of deuterated solvent and the same weighed *molar* amount of solute. Approximately 6–8 solutions were then prepared by mixing the two stock solutions so that the total mass of solution was approximately identical for all samples, but with a different ratio of host-to-guest. Molarities (mol L^{-1}) were otained by mutiplying molalities (mol kg^{-1}) by the density of the solution of complex, which was approximated to the density of D_2O at 25 °C.

A Sartorius Analytic AC-120S balance with a precision of 10^{-4} g was used to weigh the samples. The ^1H NMR spectra were recorded on a Brucker AMX 400 spectrometer with an external reference of TSP in D_2O. In order to reduce the intensity of the large HDO signal present for each solution, the spectra were recorded with pre-irradiation of the HDO signal. The data were linearized and treated by the nonlinear regression analysis program Kaleidagraph 2.0 run on an Apple Macintosh SE/30 microcomputer, or by using an iterative nonlinear curve fitting program running on an Apple Macintosh LC microcomputer.

Absorption and Luminescence: The solvent used for absorption and luminescence spectroscopy was MeCN Merck Uvasol, without further purification. The concentrations of the solutions studied were in the range 5×10^{-6}–5×10^{-5} M. Absorption spectra were recorded with a Perkin-Elmer 16 spectrophotometer. Uncorrected emission spectra and corrected excitation spectra were obtained with a Perkin-Elmer LS 50 spectrofluorimeter. An Edinburgh single-photon counting apparatus was used to obtain emission lifetimes. For more details, see ref. [17d].

Crystallographic Measurements: Crystal data for **25**: single crystals suitable for X-ray crystallography were obtained by vapour diffusion of *i*Pr_2O into an ethanolic solution of the [2]catenane. $C_{94}H_{148}N_2O_{45} \cdot H_2O$, $M = 2044.2$, orthorhombic, $a = 14.989(2)$, $b = 23.147(8)$, $c = 31.254(7)$ Å, $V = 10843(5)$ Å^3, space group $P2_12_12_1$, $Z = 4$, $D_c = 1.253$ g cm^{-3}, $\mu(Cu_{K\alpha}) = 8.4$ cm^{-1}, $F(000) = 4416$. Data for a crystal of dimensions $0.03 \times 0.21 \times 0.43$ mm^3 were measured on a Siemens P3/PC diffractometer ($2\theta < 116°$) with $Cu_{K\alpha}$ radiation (graphite monochromator) using ω scans. 8002 independent reflections were measured and of these 4159 had $|F_o| > 3\sigma(|F_o|)$ and were considered to be observed. The data were corrected for Lorentz and polarization factors; no absorption correction was applied. The structure was solved by direct methods and the non-hydrogen atoms were refined isotropically (there were too few observed data to permit meaningful anisotropic refinement). The lower phenyl ring of the bitolyl unit and the part of the polyether chain depicted by broken bonds in Figure 9a–c are disordered; the aromatic ring adopts two well-defined orientations each of 50% occupancy twisted by ca. ±40° with respect to the ordered upper phenyl ring. The geometry of this disordered polyether chain was optimized by distance and angle refinement. Hydrogen atoms were placed in calculated positions and assigned isotropic thermal parameters and allowed to ride on their parent C, N and O atoms. The hydrogen atoms of the included H_2O molecule were not located. The refinement was by full-matrix least-squares to give $R = 0.143$, $R_w = 0.138$ ($w^{-1} = \sigma^2F + 0.0005F^2$), 594 refined parameters. The maximum and minimum residual electron densities in the final ΔF map were 0.65 and −0.53 e Å^{-3}. Computations were carried out on a 486 PC, with the SHELXTL-PC program system[158]. Further details of the crystal structure investigations are available on request from the Director of the Cambridge Crystallographic Data Centre, 12 Union Road, GB-Cambridge CB2 1EZ (UK), on quoting the full journal reference, namely, D. Armspach, P. R. Ashton, C. P. Moore, N. Spencer, J. F. Stoddart, T. J. Wear, D. J. Williams, *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 854–858.

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[37] In the case of the titration experiment, the values of K_a and $\Delta\delta_{max}$ (CIS values) were obtained after treatment of the binding data by an iterative nonlinear least-square curve fitting programm.

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$$\Delta\delta_o = \Delta\delta_{max} - \left(\frac{\Delta\delta_o \Delta\delta_{max}}{cK_a}\right)^{1/2} \quad (1)$$

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[44] The value of K'_a was obtained after linearization of the binding data according to Equation (2), where $\Delta\delta_{max}$ is the difference in chemical shifts of CD probes between the pure 2:1 adduct and the free CD, $\Delta\delta_o$ is the observed chemical shift difference between the 2:1 complex and the free CD, $2c'$ is the total concentration of guest, and c' is the total concentration of CD.

$$\Delta\delta_o = \Delta\delta_{max} - \left(\frac{\Delta\delta_o \Delta\delta^2_{max}}{4c'^2 K'_a}\right)^{1/3} \quad (2)$$

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[50] The [2]catenanes **27**/**28** are only sparingly soluble in H_2O or MeOH. However, all the catenanes, including **27**/**28**, are soluble in Me_2CO but not at all in Et_2O.
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