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Fourfold tetraurea calix[4]arenes—potential cores for the formation of self-assembled dendrimers

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Wide rim tetraurea calix[4]arenes monofunctionalized at the narrow rim by COOH or NH_2 have been synthesized in five steps from *t*-butylcalix[4]arene tripropylether. Their covalent linkage *via* the narrow rim to a central calix[4]arene fixed in the 1,3-alternate conformation led to pentacalix[4]arenes **9** bearing four tetraurea derivatives in the cone conformation in a flexible tetrahedral arrangement. Their self-assembly *via* the formation of hydrogen bonded dimeric capsules has been studied under different conditions. A fourfold heterodimerisation of tetrakis-tetraurea derivatives of type **9** with tetratosylurea **10** has been confirmed by ^{1}H NMR-spectroscopy and dynamic light scattering.

Introduction

Self-organisation, a general principle in nature, is "copied" more and more by synthetic chemists to obtain sophisticated materials with novel properties.[1] Self-assembly processes that occur *via* reversible bonds have the advantage that incorrect links or connections can be corrected while building up larger structures. On the other hand, this strategy requires that all the information for the construction of a complex supramolecular assembly must be already present in the single building blocks.[2]

Numerous examples for the formation of oligomeric and polymeric aggregates in solution[3] using metal ion complexation,[4] hydrogen bonding,[5] or apolar forces, including π–π stacking,[6] have been reported during the last decade. For these purposes, the respective interacting groups or functions have been covalently attached to various molecular scaffolds. Among these potential skeletons or building blocks, calixarenes[7] or resorcarenes are especially attractive, since they are not only easily available but also prone to nearly unlimited chemical modifications.[8]

Calix[4]arenes bearing four urea functions at their wide rim, for instance, form dimeric capsules in apolar solvents in the presence of suitable guests (*e.g.* the solvent itself).[9] Various dimeric[10] to hexameric[11] capsules of calixarenes and resorcarenes held together by hydrogen bonds have been described subsequently, while dimeric assemblies have been found also for triurea derivatives of tribenzylamines[12] and triphenylmethanes.[13] Polymeric assemblies have been formed from dimers in which tetraurea calix[4]arenes are covalently connected *via* their narrow rim,[14] while the only published example for a bis-tetraurea with a covalent link between the urea residues formed a "unimolecular capsule".[15]

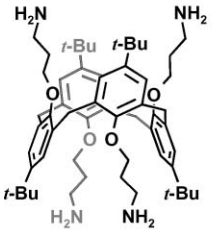
It should be possible to use the dimerisation of tetraurea calix[4]arenes, to build up not only linear polymers *via* self-assembly, but also definitely branched or dendritic structures. This would require oligomers in which tetraurea calix[4]arenes or similar self-complementary units are covalently linked. Proper use of selectivities observed for the dimerisation process, or more general of self-sorting processes[16] should allow their combination in a controlled way, leading to a single structure.

As a first step in this direction we have synthesized several novel pentacalix[4]arenes in which for the first time four tetraurea calix[4]arenes fixed in the cone conformation are covalently connected to a central calix[4]arene in the 1,3-alternate conformation.[17,18] Such pentacalix[4]arenes may serve as cores for self-assembled dendrimers.

Results and discussion

Syntheses

Amide links were chosen to attach four tetraurea calix[4]arenes to the central calix[4]arene fixed in the 1,3-alternate conformation. The synthesis of the necessary 1,3-alternate tetraamines (*e.g.* **1**) was recently described.[19] The corresponding tetraacid **2b** was synthesized in analogy by two subsequent *O*-alkylation steps with ethyl(δ-bromovaleriate) in the presence of K_2CO_3 (leading to the *syn*-1,3-diether[20] in 80%) and Cs_2CO_3 (to obtain the tetraether **2a** as the 1,3-alternate isomer in 42%), followed by alkaline hydrolysis of the ester functions.



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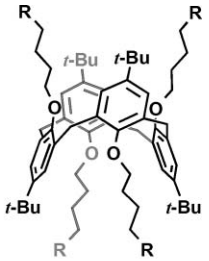

2 **a** R = COOEt
b R = COOH

The synthesis of the complementary tetraurea calix[4]arenes bearing one carboxyl or one amino group at the narrow rim is outlined in Scheme 1. The *syn-syn*-tripropylether **3**[21] was exhaustively *O*-alkylated by ethyl(δ-bromovaleriate), ethyl(ω-bromododecanoate), or *N*-(ω-bromododecyl)phthalimide with yields ≥80%. The alternative strategy to obtain **4**, monoalkylation by $Br(CH_2)_nR$ followed by exhaustive alkylation with propylbromide, was less advantageous in our hands. Usually the yields were lower since a purification by column chromatography was necessary after the monoalkylation step. The following steps, ipso-nitration (yielding **5** in 65–85%), reduction of the nitro groups (60–85% of tetraamine **6**) and acylation with the respective isocyanate (giving tetraureas **7** in 65–95% yield) follow well known procedures. In a final step the desired carboxyl compound was easily obtained by alkaline hydrolysis from **7a**–**e**. The yield of **8c**–**e** with the longer aliphatic chain was slightly higher (70–90%) than that of **8a**,**b** (60–65%).

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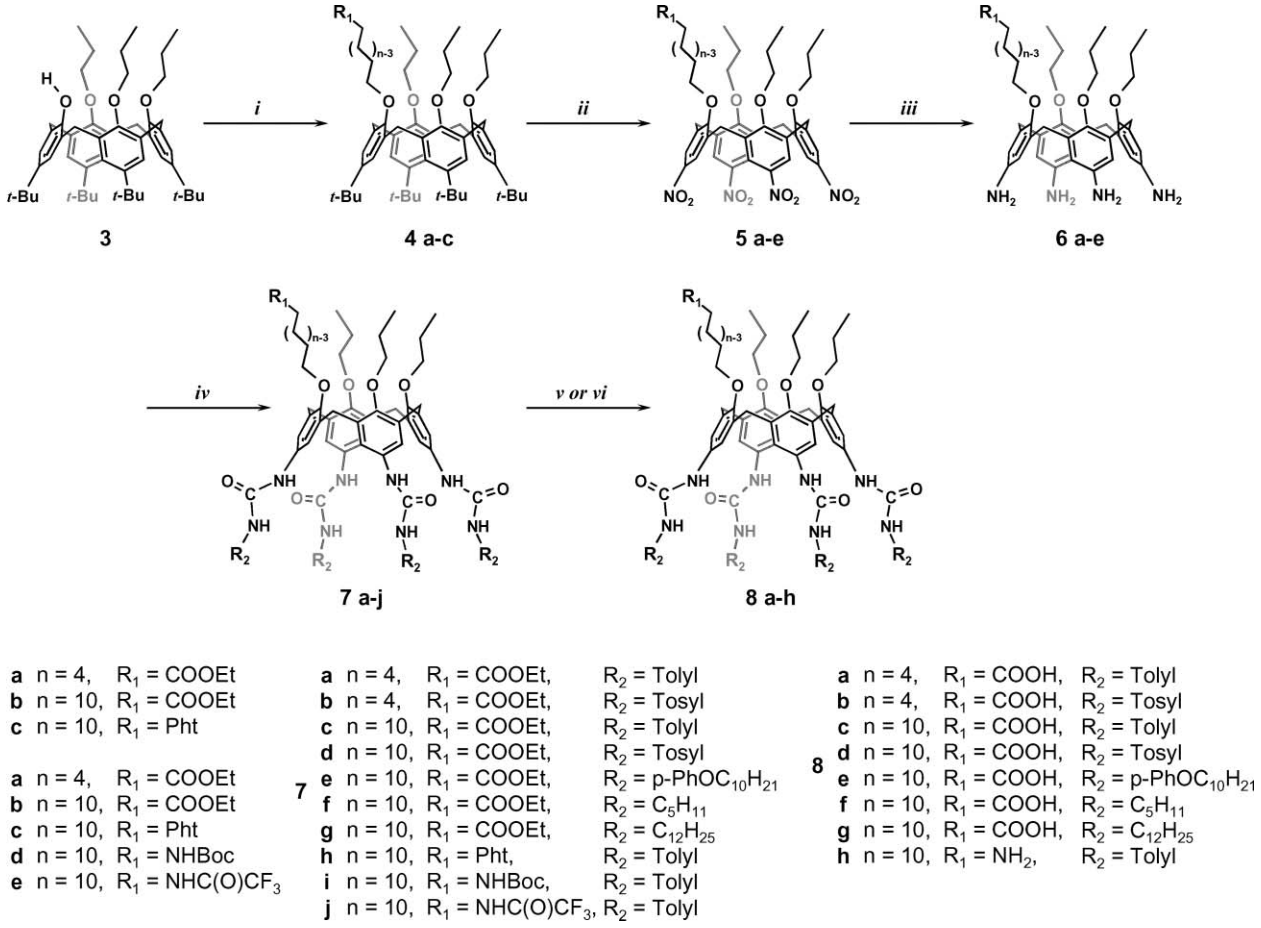
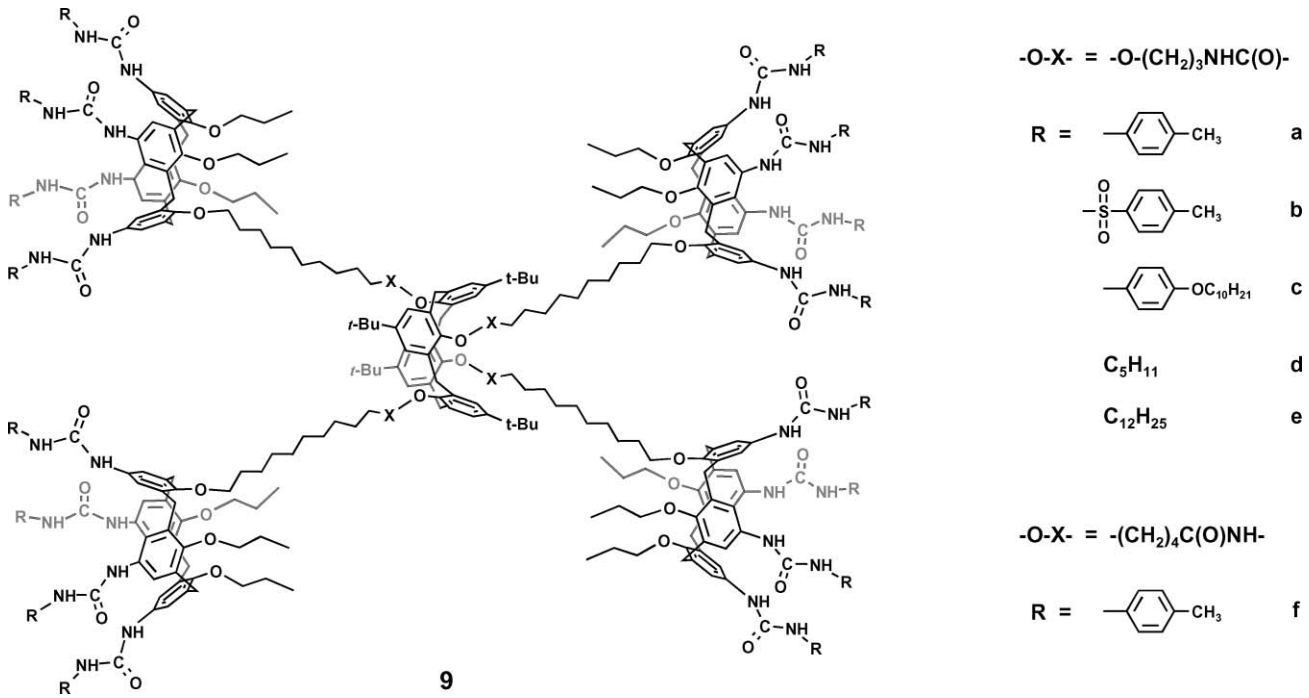


Scheme 1 Synthesis of tetraurea calixarenes bearing a single functional group R_1 at the narrow rim; (i) $Br(CH_2)_nR_1$, NaH, DMF; (ii) CH_3COOH, HNO_3, CH_2Cl_2; (iii) Raney–nickel, H_2, THF or toluene; (iv) R_2NCO, CH_2Cl_2; (v) MeOH–H_2O–NaOH(or LiOH), THF; (vi) N_2H_4, EtOH.

Cleavage of the phthalimide group by hydrazinolysis of **7h** was not possible, however, without attacking also the urea functions. To obtain **8h** with a single amino group, the phthalimide function in **4c** had to be replaced by Boc or by TFA, before the urea functions could be obtained by the reaction sequence described above. Now the deprotection to **8h** caused no problem.

Pentacalixarenes **9** were finally obtained by coupling of tetraamine **1** (or tetraacid **2b**) with four equivalents of the corresponding monoacid (or monoamine) **8** using PyBOP in up to 80% yield. Due to the difficulties faced with the phthalimide group, the strategy to obtain pentacalixarenes was finally based on tetraamine **1** rather than tetraacid **2**.



Characterization and self-assembly

All the single calix[4]arenes **1**–**8** were characterized by NMR and mass spectra. The confirmation of the structure of pentacalix[4]arenes **9** is mainly based on clear NMR spectra and will be discussed in connection with dimerization studies.

The four tetraurea units in **9** are C_S-symmetric (the whole molecules **9** have dynamic D_{2d}-symmetry) and all signals should be found therefore in the respective ratio. However, the apparent spectra are (often) more simple. Fig. 1 shows the aromatic part of the ^{1}H NMR spectrum of pentacalixarene **9a** in DMSO. Four signals of equal intensity for NH protons and two equal singlets for Ar–H of the tetraurea parts can be explained by a (time averaged) pinched cone conformation of the mentioned unit, which obviously does not "feel" the difference between the substituents at the narrow rim. Important is the singlet for Ar–H of the central calixarene and even more a single singlet for *t*-butyl groups which evidence in addition to the correct integration ratios the complete substitution of all four arms.

In benzene or chloroform compounds **9a** and **9f** have limited solubility, which is not sufficient to record the ^{1}H NMR spectra. We were able to get clear solutions of **9a** and **9f** in $CHCl_3$ only in the presence of 4 equivalents of tetratosyl urea **10**, which breaks the polymeric assemblies of **9** by the well known heterodimerization between tetraaryl- and tetratosylureas.[22] Usually the formation of the tetrakis-heterodimer is complete within 1 d, the long time being due to the low solubility of the components. In contrast, compound **9b** could not be dissolved in all solvents suitable for dimerization, neither alone nor after the addition of 4 equivalents or even of an excess of tetratolyl urea calix[4]arene **11**. It is unclear for the moment, if this is (only) a kinetic effect.

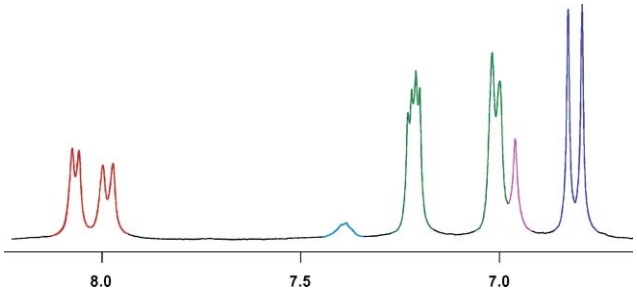
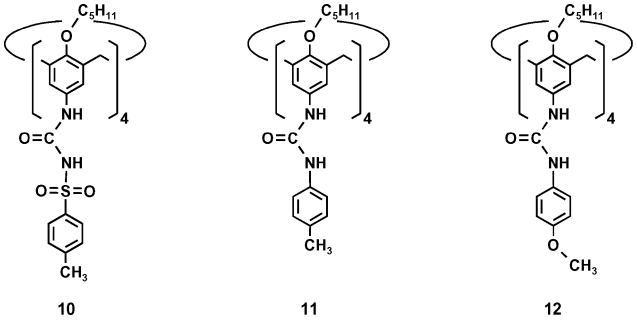


Fig. 1 Section of the ^{1}H NMR spectrum of **9a** in DMSO. Colour code: NH_{urea} = red; NH_{amide} = light blue; tolyl ArH = green; ArH of core-calixarene = pink; ArH of urea calixarenes = dark blue.



Calixarenes **9c**–**e** were soluble in chloroform, but clear solutions were only obtained for **9c** and **9e**. Not entirely unexpectedly, the ^{1}H NMR spectra do not show any well defined structures for both. Since the exclusive formation of heterodimers occurs only between aryl and arylsulfonyl ureas, this heterodimerization was studied just for **9c**.

The aromatic part of the spectrum of the tetrakis-heterodimer **9c**·**10**$_4$ in $CDCl_3$ is shown in Fig. 2a in comparison to the spectrum of the heterodimer **10**·**12** as a model (Fig. 2b).

According to the C_4-symmetry of a heterodimer the four phenolic units of each calixarene (**10** and **12**) are identical. Thus, four signals for aromatic protons are observed which show two cross peaks in the ^{1}H COSY-gs spectrum. Four singlets for NH urea protons are found and two pairs of (pseudo) doublets corresponding to the aromatic protons of the tolyl and tosyl residues. One of the pseudo doublets of the tolyl rings is actually overlapped with one NH signal.

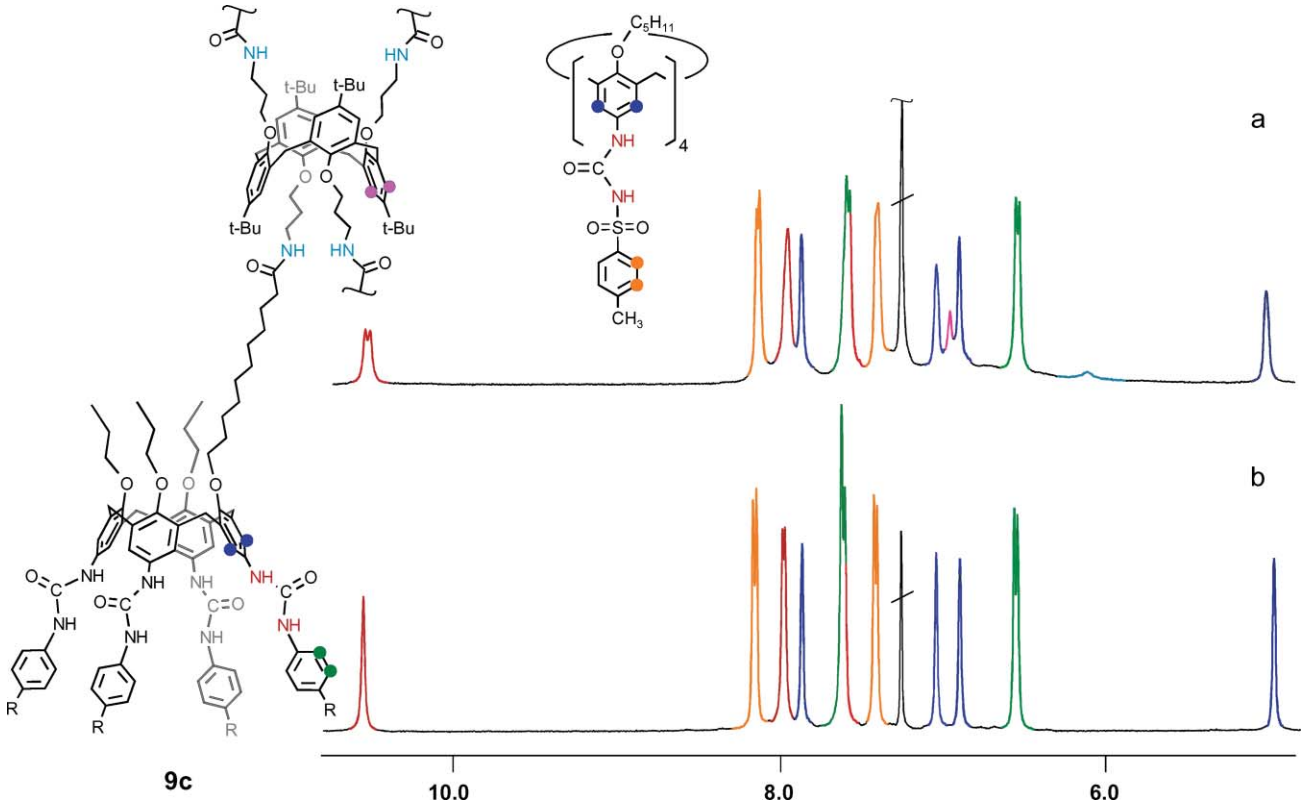


Fig. 2 Sections of the ^{1}H NMR spectra of tetrakis-heterodimer **9c**·**10**$_4$ (a) and heterodimer **10**·**12** (b). Colour code: NH_{urea} = red; NH_{amide} = light blue; ArH of urea calixarenes = dark blue; ArH of core-calixarene = pink; tolyl ArH = green; tosyl ArH = orange.

The chemical shifts of the signals attributed to the "dimeric parts" of **9c**·$\mathbf{10}_4$ are totally in accordance with those from the heterodimer **10**·**12**. Small differences are found only for the number of signals. The downfield shifted signal for NH protons splits into two signals ($\Delta\delta = 0.03$ ppm), while the two next signals for NH protons are now overlapping. The two additional signals in the spectrum were assigned to the aromatic protons of the core-calixarene and to amide NH protons.

This close analogy of the two spectra provides strong evidence for the self-assembled fourfold dimer **9c**·$\mathbf{10}_4$.

Light scattering

Dynamic light scattering measurements were performed to obtain an additional proof for the aggregation and the extend of structural control on self-assembly in solution. Fundamentals of dynamic light scattering are given elsewhere[23] and the results are summarized in Table 1.

In solvents which break hydrogen bonds[24] (*e.g.* DMSO, pyridine, HFIP) the hydrodynamic radius of monomeric calix[4]arenes is typically within 20% in the order of 1 nm, the specific value depending on the substituents and on the degree of solvation. The field correlation function, as measured by dynamic light scattering of **11** in DMSO, shows an almost perfect monoexponential decay which proves the absence of unspecific aggregation and yields a hydrodynamic radius of 0.9 nm. The field correlation function of the pentacalixarene **9a** in DMSO exhibits a small, but significant deviation from a single exponential decay which indicates the presence of minor unspecific aggregation. Note that DLS is particularly sensitive even to traces of aggregates. Being formed by five calixarenes, **9a** has roughly the five-fold volume of a monomeric calix[4]arene. Assuming a strictly spherical shape and identical density the radius of **9a** may be estimated from the measured radius of **11** as $\sqrt[3]{5}$ nm = 1.7 nm. This value represents a lower limit because changes in density, shape, solvation and draining are not accounted for and cannot easily be quantified. In view of the long spacer groups present in **9a** the measured radius is at least reasonable.

As described before, **9a** is insoluble in chloroform indicating strong intermolecular interactions, which can easily be overcome by the well known heterodimer formation simply induced by cosolution of four equivalents of tetratosylurea **10**. An increase of R_h to 2.4 nm is monitored by light scattering, which is 0.23 nm larger as compared to **9a**. This increase is similar to the observed increase of the heterodimer **10**·**11** radius as compared to **11**.

In contrast to **9a**, the pentacalixarenes **9c** and **9e** are soluble in chloroform but due to hydrogen bonding and their tetrafunctional character, aggregation is to be expected resulting even in gelation in solvents which do not break hydrogen bonds. However, the experiments in chloroform reveal that the spatial extension of aggregation is quite limited even at high concentrations of about 20 g L^{-1}. From the strongly non exponentially decaying field autocorrelation function average hydrodynamic radii of 5.8 and 5.2 nm for **9c** and **9e**, respectively, are determined (Table 1). The average aggregation numbers were estimated to 20 and 15 respectively. This increase in radius and in polydispersity is expected from "condensation" products of the tetrafunctional monomers **9c** and **9e**. The large concentration dependence of the apparent average diffusion coefficient with a negative slope as shown in Fig. 3 for **9c** represents another indication for reversible aggregate formation.

Table 1 Hydrodynamic radii R_h from dynamic light scattering applying the Stokes–Einstein equation (c = 17 g L^{-1}, 20 °C, scattering angle $\theta = 30°$)

Compound/assembly	Solvent	R_h (nm)
Tetratolyl urea **11**	DMSO	0.90
Heterodimer (**10**·**11**)	$CHCl_3$	1.15[a]
Pentacalix[4]arene **9a**	DMSO	2.17
Tetrakis-heterodimer (**9a**·$\mathbf{10}_4$)	$CHCl_3$	2.40
Pentacalix[4]arene **9c**	$CHCl_3$	5.80[b]
Pentacalix[4]arene **9e**	$CHCl_3$	5.20

[a] $\theta = 20°$. [b] c = 20 g L^{-1}.

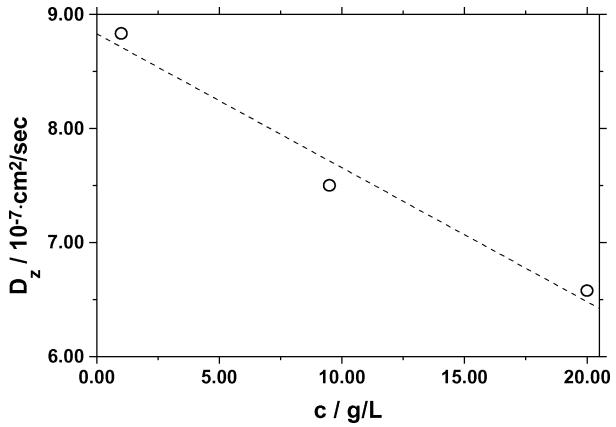


Fig. 3 Concentration dependence of the apparent z-average diffusion coefficient D_z of **9c** measured by dynamic light scattering in chloroform (the dashed line is only a guide for the eye).

Concerning the question why no gelation is observed, Stockmayer's[25] gelation theory should be considered. The growth of branched polycondensates of monomers with functionality f is described in terms of the conversion α by $P_w = (1 + \alpha)/(1 - \alpha/\alpha_c)$ and $\alpha_c = 1/(f - 1)$, thus with $f = 4$, $\alpha_c = 33\%$ at the gel point. The weight average degree of polymerization P_w strongly depends on conversion and reduces to only 13 at a conversion of 30%. In addition ring closure within the aggregates may efficiently reduce the effective functionality. In extreme cases even completely closed structures with no free functional groups left could result for aggregation numbers above 12, as suggested by CPK models. However, such structures are probably entropically disfavored and therefore seem to be unlikely. It is, however, well known from experimental and theoretical investigations[26,27] that dilution favours ring formation thus reducing the effective functionality and avoiding gel formation.

Experimental

Syntheses

Calix[4]arene 1. The corresponding tetraphthalimido calixarene[19] (0.62 g, 0.44 mmol) and hydrazine monohydrate (7.21 g (7.0 cm^3), 144 mmol) were refluxed in EtOH (45 cm^3) for 4 h. The reaction mixture was concentrated to *ca.* 10 cm^3 and water (30 cm^3) was added to the solution. A precipitate formed which was filtered off, washed with water and dried, to obtain **1** (0.32 g, 100%) as a white powder; mp > 246 °C (decomp.); (δ_H (400 MHz; $CDCl_3$) 6.99 (8H, s, Ar*H*), 3.80 (8H, s, ArCH_2Ar), 3.45 (8H, s, OCH_2), 2.50 (8H, s, NCH_2), 1.52–1.38 (16H, br s, NH_2, CH_2), 1.30 (18H, s, C(CH_3)$_3$), 1.29 (18H, s, C(CH_3)$_3$); (δ_C (100 MHz; $CDCl_3$) 154.9, 143.8, 133.0, 125.9, 68.8, 39.5, 39.2, 34.0, 33.2, 31.7; *m*/*z* (FD) 877.8 (100%) [M^+].

Calix[4]arene 2a. The corresponding 1,3-diether[20] (1.00 g, 1.10 mmol) was dissolved in CH_3CN (100 cm^3) and Cs_2CO_3 (5.40 g, 16.6 mmol) was added to the solution. The mixture was refluxed for 0.5 h, ethyl(5-bromovalerate) (3.50 g, 16.6 mmol) was added to the suspension, and the refluxing was continued for 6 d. The solvent was removed in vacuum and the residue dissolved in chloroform (100 cm^3). The organic solution was washed with 1 N HCl and water, dried over $MgSO_4$, filtered and evaporated. The crude product was crystallized from CH_3CN. **2a** was obtained as a white powder (0.53 g, 42%); mp 209–211 °C; (δ_H (200 MHz; $CDCl_3$) 6.93 (8H, s, Ar*H*), 4.15 (8H,

q, *J* 7.3, OCH_2CH$_3$), 3.69 (8H, s, ArCH_2Ar), 3.40 (8H, t, *J* 7.8, OCH_2CH$_2$), 2.21 (8H, t, *J* 8.30, C(O)CH_2), 1.55–1.43 (8H, m, CH_2), 1.31–1.21 (56H, m, CH_2, OCH$_2$CH_3, C(CH_3)$_3$); (δ_C (100 MHz; $CDCl_3$) 173.4, 154.6, 143.4, 133.0, 126.2, 70.3, 60.3, 38.8, 34.1, 33.8, 31.7, 29.2, 21.3, 14.2; *m/z* (FD) 1160.6 (100%) [M$^+$].

Calix[4]arene 2b. A solution of NaOH (0.25 g, 6.25 mmol) in MeOH (6 cm^3) and H_2O (2 cm^3) was added to the solution of calixarene **2a** (0.45 g, 0.39 mmol) in THF (30 cm^3). The reaction mixture was stirred 12 h at room temperature. 1 N HCl (5 cm^3) was added to neutralize the excess of NaOH and the mixture was concentrated to *ca.* 10 cm^3 under reduced pressure. After the addition of $CHCl_3$–THF = 2 : 1 (40 cm^3) the solution was washed with brine (3 × 15 cm^3), dried over $MgSO_4$, filtered and evaporated. **2b** (0.39 g, 95%) was obtained as a white powder; mp 280–282 °C; (δ_H (400 MHz; $CDCl_3$) 11.98 (4H, s, COO*H*), 6.94 (8H, s, Ar*H*), 3.71 (8H, s, ArCH_2Ar), 3.40 (8H, t, *J* 7.4, OCH_2), 2.06 (8H, t, *J* 7.8, C(O)CH_2), 1.37–1.32 (8H, m, CH_2), 1.22 (36H, s, C(CH_3)$_3$), 1.17–1.07 (8H, m, CH_2); (δ_C (100 MHz; $CDCl_3$),: 174.6, 154.7, 143.1, 133.2, 125.9, 69.9, 38.6, 34.1, 34.0, 31.9, 29.0, 21.4; *m/z* (FD) 1048.6 (100%) [M$^+$].

General procedure for the synthesis of calixarenes 4

A suspension of **3** (3.87 mmol) and NaH (5.03 mmol) in DMF (90 cm^3) was stirred for 1 h at room temperature. After addition of the alkylating agent (5.03 mmol) the stirring was continued for 72 h. The excess of NaOH was neutralized by acetic acid and water (120 cm^3) was added.

Calixarene 4a. was synthesized using ethyl(5-bromovaleriate). The precipitate was filtered off, washed with water and dried. The crude product was dissolved in $CHCl_3$ (100 cm^3), washed with water, dried over $MgSO_4$ and filtered. The filtrate was evaporated and the residue was recrystallized from CH_3CN. **4a** was obtained as a white powder (98%); mp 74–76 °C; δ_H (400 MHz; $CDCl_3$) 6.77 (4H, s, Ar*H*), 6.75 (4H, s, Ar*H*), 4.39 (2H, d, *J* 12.5, ArCH_2Ar), 4.37 (2H, d, *J* 12.5, ArCH_2Ar), 4.14 (2H, q, *J* 7.0, OCH_2CH$_3$), 3.86 (2H, t, *J* 7.4, OCH_2), 3.82–3.77 (6H, m, OCH_2CH$_2$), 3.10 (4H, d, *J* 12.5, ArCH_2Ar), 2.38 (2H, t, *J* 7.4, C(O)CH_2), 2.06–1.96 (8H, m, CH_2), 1.82–1.71 (2H, m, CH_2), 1.26 (3H, t, *J* 7.0, OCH$_2$CH_3), 1.07 (18H, s, C(CH_3)$_3$), 1.05 (18H, s, C(CH_3)$_3$), 0.98 (9H, t, *J* 7.3, CH$_2$CH_3); δ_C (100 MHz; $CDCl_3$) 173.6, 153.7, 144.3, 144.2, 133.9, 133.8, 133.7, 124.9, 74.6, 60.3, 34.4, 33.8, 31.5, 31.1, 29.7, 23.4, 21.7, 14.3, 10.3; *m/z* (FD) 902.9 (100%) [M$^+$].

Calixarene 4b. was synthsized using ethyl(ω-bromododecanoate). The product was extracted from the milky suspension with $CHCl_3$ (3 × 30 cm^3). The chloroform layer was separated, dried over $MgSO_4$ and evaporated. The residue was triturated three times with CH_3CN to extract the alkylating agent from the oily mass. The residue was dried in the vacuum of an oil pump. **4a** was obtained as a yellow oil (80%); δ_H (400 MHz; $CDCl_3$) 6.76 (8H, s, Ar*H*), 4.40 (4H, d, *J* 12.7, ArCH_2Ar), 4.11 (2H, q, *J* 7.3, OCH_2CH$_3$), 3.83–3.79 (8H, m, OCH_2CH$_2$), 3.10 (4H, d, *J* 12.7, ArCH_2Ar), 2.28 (2H, t, *J* 7.3, C(O)CH_2), 2.03–1.99 (8H, m, CH_2), 1.37–1.24 (14H, m, CH_2), 1.24 (3H, t, *J* 7.3, OCH$_2$CH_3), 1.07 (36H, s, C(CH_3)$_3$), 0.99 (9H, t, *J* 7.3, CH$_2$CH_3); δ_C (100 MHz; $CDCl_3$) 173.8, 153.8, 153.7, 144.1, 133.8, 124.9, 77.0, 75.4, 60.1, 34.4, 33.8, 31.5, 31.1, 30.3, 29.8, 29.5, 29.3, 29.2, 26.3, 25.0, 23.3, 23.3, 14.3, 10.4; *m/z* (FD) 988.4 (100%) [M$^+$].

Calix[4]arene 4c. was synthesized using *N*-(ω-bromododecyl)phthalimide. The solvents were poured off and the residual oil was dissolved in chloroform (100 cm^3), washed with water, dried over $MgSO_4$ and filtered. The filtrate was evaporated. **4c** was either purified by column chromatography (THF–hexane = 1 : 10) and obtained as a yellow oil (90%) or by treatment with CH_3CN (as described for **4b**) (50%); δ_H (200 MHz; $CDCl_3$) 7.85–7.82 (2H, m, ArH_{pht}), 7.71–7.67 (2H, m, ArH_{pht}), 6.77 (8H, s, Ar*H*), 4.41 (4H, d, *J* 12.2, ArCH_2Ar), 3.84–3.77 (8H, m, OCH_2), 3.68 (2H, t, *J* 7.3, NCH_2), 3.11 (4H, d, *J* 12.2, ArCH_2Ar), 2.07–1.95 (8H, m, CH_2), 1.70–1.66 (2H, m, CH_2), 1.34 (12H, br s, CH_2), 1.08 (36H, s, C(CH_3)$_3$), 0.99 (9H, t, *J* 7.3, CH_3); δ_C (100 MHz; $CDCl_3$) 168.4, 153.8, 153.7, 153.7, 144.1, 133.8, 132.2, 124.8, 123.1, 77.2, 76.9, 76.7, 75.4, 38.1, 33.8, 31.5, 31.1, 30.2, 29.8, 29.7, 29.5, 29.2, 28.6, 26.9, 26.2, 23.3, 23.2, 10.3, 10.3; *m/z* (FD) 1061.3 (100%) [M$^+$].

General procedure for the synthesis of 5a–c by ipso-nitration

Calix[4]arene **4** (2.44 mmol) was dissolved in CH_2Cl_2 (50 cm^3) and acetic acid (3.7 cm^3). Fuming HNO_3 (3 cm^3) was added with intensive stirring. The solution became dark immediately and stirring was continued for approximately 2 h at room temperature. The reaction mixture was diluted with water (40 cm^3), the organic layer was separated, washed with water (5 × 25 cm^3), dried over $MgSO_4$ and filtered.

Calix[4]arene 5a. The filtrate was concentrated to approximately 10–15 cm^3 and the product was precipitated with methanol. **5a** (85%) was obtained as a yellow powder; mp 230–232 °C; δ_H (400 MHz; $CDCl_3$) 7.60 (4H, s, Ar*H*), 7.52 (4H, s, Ar*H*), 4.51 (2H, d, *J* 14.1, ArCH_2Ar), 4.49 (2H, d, *J* 14.1, ArCH_2Ar), 4.13 (2H, q, *J* 6.8, OCH_2CH$_3$), 4.00–3.91 (8H, m, OCH_2CH$_2$), 3.40 (4H, d, *J* 14.1, ArCH_2Ar), 2.37 (2H, t, *J* 7.3, C(O)CH_2), 1.93–1.84 (8H, m, CH_2), 1.77–1.69 (2H, m, CH_2), 1.25 (3H, t, *J* 6.8, OCH$_2$CH_3), 1.04–0.97 (9H, m, CH$_2$CH_3); δ_C (100 MHz; $CDCl_3$) 172.8, 161.7, 161.6, 161.4, 142.9, 135.5, 135.4, 135.3, 124.1, 123.9, 77.7, 75.6, 60.5, 33.8, 31.1, 29.5, 23.2, 21.3, 14.2, 10.2, 10.1; *m/z* (FD) 858.5 (100%) [M$^+$].

Calix[4]arene 5b. The solvent was evaporated, the residue was triturated with methanol and filtered. **5b** (65%) was obtained as a yellow powder; mp 145–147 °C; δ_H (400 MHz; $CDCl_3$) 7.56 (8H, s, Ar*H*), 4.51 (4H, d, *J* 13.7, ArCH_2Ar), 4.10 (2H, q, *J* 7.0, OCH_2CH$_3$), 3.99–3.92 (8H, m, OCH_2CH$_2$), 3.39 (4H, d, *J* 13.7, ArCH_2Ar), 2.27 (2H, t, *J* 7.4, C(O)CH_2), 1.95–1.86 (8H, m, CH_2), 1.60–1.51 (2H, m, CH_2), 1.34–1.25 (12H, m, CH_2), 1.24 (3H, t, *J* 7.0, OCH$_2$CH_3), 1.00 (9H, t, *J* 7.4, CH$_2$CH_3); δ_C (100 MHz; $CDCl_3$) 173.8, 161.7, 142.8, 135.4, 123.9, 77.7, 76.2, 60.1, 34.3, 31.1, 30.1, 29.6, 29.5, 29.3, 29.2, 29.1, 25.9, 24.9, 23.2, 14.2, 10.1; *m/z* (FD) 944.0 (100%) [M$^+$].

Calix[4]arene 5c. The filtrate was evaporated, the residue was triturated with methanol and filtered. **5c** (65–75%) was obtained as a yellow powder; mp 127–129 °C; δ_H (200 MHz; $CDCl_3$) 7.85–7.82 (2H, m, ArH_{pht}), 7.71–7.69 (2H, m, ArH_{pht}), 7.55 (8H, s, Ar*H*), 4.50 (4H, d, *J* 14.1, ArCH_2Ar), 4.00–3.90 (8H, m, OCH_2), 3.65 (2H, t, *J* 7.3, NCH_2), 3.39 (4H, d, *J* 14.1, ArCH_2Ar), 1.94–1.84 (8H, m, CH_2), 1.63 (2H, br s, CH_2), 1.29 (12H, br s, CH_2), 1.00 (9H, t, *J* 7.3, CH$_2$CH_3); δ_C (100 MHz; $CDCl_3$) 168.5, 161.7, 142.9, 135.4, 133.9, 132.1, 124.0, 123.1, 77.7, 76.2, 38.0, 31.6, 31.1, 30.1, 29.5, 29.5, 29.4, 29.1, 28.6, 26.8, 25.9, 23.2, 22.6, 14.1, 10.1; *m/z* (FD) 1015.7 (100%) [M$^+$].

Deprotection of calix[4]arene 5c

Calix[4]arene **5c** (2.00 g, 1.96 mmol) was dissolved in EtOH (80 cm^3) and hydrazine monohydrate (18.7 g (18.1 cm^3), 0.36 mol) was added. The solution was refluxed for 4 h and concentrated to 50 cm^3. A product started to precipitate and the solution was cooled to 30 °C. The precipitate was filtered off, washed with water (3 × 10 cm^3) and ethanol (2 × 10 cm^3) and dried. The desired monoamine (1.30 g, 75%) was obtained as an orange powder; mp 227–229 °C; δ_H (400 MHz; $CDCl_3$) 7.57 (4H, s, Ar*H*), 7.55 (4H, s, Ar*H*), 4.51 (4H, d, *J* 14.2, ArCH_2Ar), 3.99–3.92 (8H, m, OCH_2), 3.39 (4H, d, *J* 14.2, ArCH_2Ar), 2.68 (2H, t, *J* 6.8, NCH_2), 1.92–1.87 (8H, m, CH_2), 1.43–1.29 (14H, br s, CH_2), 1.01 (9H, t, *J* 7.3, CH$_2$CH_3); δ_C (100 MHz; $CDCl_3$) 161.6, 161.6, 142.9, 135.4, 135.8, 124.0, 124.0, 77.7, 76.2, 42.1,

33.5, 31.1, 30.1, 29.6, 29.5, 29.4, 26.9, 25.9, 23.2, 23.2, 10.3; *m/z* (FD) 886.9 (54.8%) [M$^+$], 1771 (100%) [2M$^+$].

Calix[4]arene 5d

The monoamine obtained after deprotection of **5c** (1.30 g, 1.47 mmol) was dissolved in $CHCl_3$ (50 cm^3) and Boc-anhydride (0.42 g, 1.91 mmol) was added. The solution was refluxed for 8 h, concentrated to 5 cm^3 and hexane (25 cm^3) was added. The precipitate was filtered off, washed with hexane and dried. **5d** (1.29 g, 89%) was obtained as a yellow powder; mp 105–107 °C; δ_H (400 MHz; $CDCl_3$) 7.57 (4H, s, Ar*H*), 7.56 (4H, s, Ar*H*), 4.52 (1H, br s, N*H*), 4.52 (2H, d, *J* 14.2, ArCH_2Ar), 4.50 (2H, d, *J* 14.2, ArCH_2Ar), 3.99–3.92 (8H, m, OCH_2), 3.39 (4H, d, *J* 14.2, ArCH_2Ar), 3.10–3.06 (2H, m, NHCH_2), 1.93–1.86 (8H, m, CH_2), 1.44–1.28 (14H, m, CH_2), 1.43 (9H, s, OC(CH_3)$_3$), 1.01 (9H, t, *J* 7.4, CH_2CH_3); δ_C (100 MHz; $CDCl_3$) 161.7, 161.7, 161.6, 142.9, 135.4, 124.0, 77.7, 76.2, 40.6, 31.1, 30.1, 29.6, 29.5, 29.5, 29.2, 28.4, 27.4, 26.8, 25.9, 23.3, 23.2, 10.2, 10.1; *m/z* (FD) 986.7 [M$^+$].

Calix[4]arene 5e

The monoamine obtained from **5c** (1.17 g, 1.46 mmol) was dissolved in THF (25 cm^3) and trifluoroacetic acid anhydride (0.034 g (0.022 cm^3), 0.16 mmol) was added to the solution. The reaction mixture was stirred at room temperature for 2 h and then concentrated to 5 cm^3 in vacuum. The residue was precipitated with Et_2O. **5e** (1.10 g, 85%) was obtained as a light yellow powder; mp 104–106 °C; δ_H (400 MHz; $CDCl_3$) 7.54 (4H, s, Ar*H*), 7.53 (4H, s, Ar*H*), 6.43 (1H, s, N*H*), 4.51 (4H, d, *J* 14.1, ArCH_2Ar), 4.00–3.93 (8H, m, OCH_2), 3.39 (4H, d, *J* 14.1, ArCH_2Ar), 3.34 (2H, dt, *J* 7.0, *J* 7.0, NHCH_2), 1.92–1.87 (8H, m, CH_2), 1.60–1.55 (2H, m, CH_2), 1.37–1.28 (12H, m, CH_2), 1.00 (9H, t, *J* 7.4, CH_2CH_3); δ_C (100 MHz; $CDCl_3$) 161.7, 157.1 (q, *J* 37.0), 142.8, 135.4, 123.9, 115.8 (q, *J* 287.6), 77.7, 76.2, 39.9, 31.1, 30.0, 29.5, 29.3, 29.1, 28.9, 26.6, 25.9, 23.2, 10.1; *m/z* (FD) 981.5 (100%) [M$^+$].

General procedure for the synthesis of 6

Calix[4]arene **5** (1.16 mmol) was dissolved in the mixture of toluene–ethanol = 5 : 1 (30 cm^3) (for **6a** THF was used instead) and hydrogenated in the presence of Raney-Ni during 14 h at room temperature under normal pressure. The progress of the reaction was monitored by TLC in THF. Finally the catalyst was filtered off, washed with THF (2 × 10 cm^3), and the combined organic solution was evaporated under reduced pressure.

Calix[4]arene 6a. The residue was triturated with hexane and filtered; **5** (65%) was obtained as a brown powder; mp 170–172 °C (decomp.); δ_H (200 MHz; $CDCl_3$) 6.04 (8H, s, Ar*H*), 4.29 (2H, d, *J* 13.2, ArCH_2Ar), 4.26 (2H, d, *J* 13.2, ArCH_2Ar), 4.12 (2H, q, *J* 6.8, OCH_2CH$_3$), 3.77–3.66 (8H, m, OCH_2CH$_2$), 2.90 (4H, d, *J* 13.2, ArCH_2Ar), 2.73 (8H, br s, NH_2), 2.33 (2H, t, *J* 7.3, C(O)CH_2), 1.89–1.70 (10H, m, CH_2), 1.24 (3H, t, *J* 6.8, OCH$_2$CH$_3$), 0.93 (9H, t, *J* 7.3, CH_2CH_3); δ_C (100 MHz; $CDCl_3$) 173.5, 150.1, 150.0, 140.2, 140.0, 135.6, 115.9, 76.7, 74.3, 60.2, 34.3, 31.1, 29.5, 23.1, 21.7, 14.2, 10.3; *m/z* (FD) 738.7 (100%) [M$^+$].

Calix[4]arene 6b. The residue was crystallized from CH_3CN; **6b** (60%) was obtained as a brown powder; mp 150–152 °C; δ_H (400 MHz; $CDCl_3$) 6.07 (4H, s, Ar*H*), 6.05 (4H, s, Ar*H*), 4.28 (4H, d, *J* 13.2, ArCH_2Ar), 4.11 (2H, q, *J* 6.8, OCH_2CH$_3$), 3.73–3.68 (8H, m, OCH_2CH$_2$), 3.26 (8H, br s, NH_2), 2.90 (4H, d, *J* 13.2, ArCH_2Ar), 2.27 (2H, t, *J* 7.3, C(O)CH_2), 1.87–1.80 (8H, m, CH_2), 1.64–1.58 (2H, m, CH_2), 1.32–1.24 (12H, m, CH_2), 1.24 (3H, t, *J* 6.8, OCH$_2$CH$_3$), 0.93 (9H, t, *J* 7.3, CH_2CH_3); δ_C (100 MHz; $CDCl_3$) 173.9, 150.2, 140.1, 135.7, 135.6, 115.8, 76.7, 75.1, 60.1, 34.4, 31.1, 30.1, 29.7, 29.5, 29.3, 29.2, 26.2, 25.0, 23.1, 14.3, 10.4; *m/z* (FD) 822.7 (100%) [M$^+$].

Calix[4]arene 6c. (0.38 g, 85%) was obtained as a brown powder; mp > 240 °C (decomp.); δ_H (200 MHz; $CDCl_3$) 7.84–7.81 (2H, m, ArH_{pht}), 7.71–7.68 (2H, m, ArH_{pht}), 6.05 (4H, s, Ar*H*), 6.03 (4H, s, Ar*H*), 4.29 (4H, d, *J* 13.2, ArCH_2Ar), 3.74–3.62 (10H, m, OCH$_2$, NCH_2), 2.90 (4H, d, *J* 13.2, ArCH_2Ar), 1.90–1.79 (8H, m, CH_2), 1.69–1.63 (2H, m, CH_2), 1.29 (12H, br s, CH_2), 0.93 (9H, t, *J* 7.3, CH_2CH_3); *m/z* (FD) 896.1 (100%) [M$^+$].

Calix[4]arene 6d. The hydrogenation was carried out at 40 °C; **6d** (98%) was obtained as a brown powder; mp 115–117 °C; δ_H (400 MHz; $CDCl_3$) 6.06 (4H, s, Ar*H*), 6.03 (4H, s, Ar*H*), 4.47 (1H, br s, N*H*), 4.30 (4H, d, *J* 13.2, ArCH_2Ar), 3.77–3.68 (8H, m, OCH_2), 3.10–3.06 (2H, m, NHCH_2), 2.90 (4H, d, *J* 13.2, ArCH_2Ar), 2.71 (8H, br s, NH_2), 1.88–1.82 (8H, m, CH_2), 1.43 (9H, s, OC(CH_3)$_3$), 1.33 (4H, s, CH_2), 1.28 (10H, s, CH_2), 0.94 (9H, t, *J* 7.3, CH_2CH_3); δ_C (100 MHz; $CDCl_3$) 156.0, 150.2, 140.2, 135.7, 135.6, 115.8, 76.7, 75.0, 40.7, 31.2, 30.1, 29.7, 29.6, 29.3, 28.4, 26.8, 26.2, 23.1, 10.4; *m/z* (FD) 865.9 (100%) [M$^+$].

Calix[4]arene 6e. The hydrogenation was carried out at 40 °C; the residue was reprecipitated from toluene (3–5 cm^3) with hexane. **6e** (92%), was obtained as a white powder; mp 130–132 °C; δ_H (400 MHz; $CDCl_3$) 6.43 (1H, s, N*H*), 6.08 (4H, s, Ar*H*), 6.02 (4H, s, Ar*H*), 4.29 (4H, d, *J* 13.3, ArCH_2Ar), 3.75–3.68 (8H, m, OCH_2), 3.34–3.20 (10H, m, NH_2, NHCH_2), 2.90 (4H, d, *J* 13.3, ArCH_2Ar), 1.89–1.78 (8H, m, CH_2), 1.58–1.50 (2H, m, CH_2), 1.38–1.25 (12H, m, CH_2), 0.96–0.91 (9H, m, CH_2CH_3); δ_C (100 MHz; $CDCl_3$) 157.1 (q, *J* 37.0), 150.1, 140.0, 135.7, 135.5, 115.9 (q, *J* 287.8), 115.8, 76.6, 74.9, 39.9, 31.1, 30.0, 29.5, 29.3, 29.1, 28.9, 26.6, 26.1, 23.0, 10.3; *m/z* (FD) 863.3 (100%) [M$^+$].

General procedure for the synthesis of calixarenes 7

The tetraamine **6** (0.65 mmol) was dissolved in CH_2Cl_2 (25 cm^3). After addition of the respective isocyanate (5.24 mmol) the solution was stirred for 6 h.

Calix[4]arene 7a. After the addition of MeOH (30 cm^3) the solution was concentrated to *ca.* 15 cm^3. The precipitate formed was filtered, washed with MeOH and dried in air. **7a** (95%) was obtained as a white powder; mp > 290 °C (decomp.); δ_H (300 MHz; DMSO-d_6) 8.22 (4H, s, N*H*), 8.16 (4H, s, N*H*), 7.22 (8H, d, *J* 8.3, ArH_{Tol}), 7.02 (8H, d, *J* 8.3, ArH_{Tol}), 6.81 (4H, s, Ar*H*), 6.80 (4H, s, Ar*H*), 4.34 (2H, d, *J* 12.6, ArCH_2Ar), 4.31 (2H, d, *J* 12.6, ArCH_2Ar), 4.07 (2H, q, *J* 7.0, OCH_2CH$_3$), 3.84–3.74 (8H, m, OCH_2CH$_2$), 3.10 (4H, d, *J* 12.6, ArCH_2Ar), 2.37 (2H, t, *J* 7.0, C(O)CH_2), 2.21 (12H, s, ArCH_3), 1.96–1.85 (8H, m, CH_2), 1.73–1.65 (2H, m, CH_2), 1.19 (3H, t, *J* 7.0, OCH$_2$CH$_3$), 1.00–0.94 (9H, m, CH_2CH_3); δ_C (100 MHz; DMSO-d_6) 172.6, 152.4, 150.9, 137.2, 134.3, 133.4, 130.2, 129.0, 118.1, 118.0, 76.4, 74.3, 59.6, 33.5, 30.6, 29.0, 22.6, 21.2, 20.2, 14.1, 10.1; *m/z* (MALDI TOF) 1295.2 (100%) [M$^+$Na].

Calix[4]arene 7b. The reaction mixture was concentrated to 3 cm^3, MeOH was added, and the precipitate was filtered off and washed with MeOH. **7b** (80%) was obtained as a white powder; mp 225–227 °C; δ_H (300 MHz; DMSO-d_6) 10.19 (4H, s, N*H*), 8.43 (4H, s, N*H*), 7.82 (8H, d, *J* 8.4, ArH_{Tos}), 7.42 (8H, d, *J* 8.4, ArH_{Tos}), 6.61 (4H, s, Ar*H*), 6.60 (4H, s, Ar*H*), 4.21 (2H, d, *J* 12.5, ArCH_2Ar), 4.18 (2H, d, *J* 12.5, ArCH_2Ar), 4.02 (2H, q, *J* 7.0, OCH_2CH$_3$), 3.74–3.64 (8H, m, OCH_2CH$_2$), 3.10 (4H, d, *J* 12.5, ArCH_2Ar), 2.40 (12H, s, ArCH_3), 2.31 (2H, t, *J* 7.4, C(O)CH_2), 1.86–1.74 (8H, m, CH_2), 1.65–1.55 (2H, m, CH_2), 1.16 (3H, t, *J* 7.0, OCH$_2$CH$_3$), 0.92–0.86 (9H, m, CH_2CH_3); δ_C (100 MHz; DMSO-d_6) 172.5, 151.9, 151.8, 148.9, 143.7, 137.1, 134.3, 131.6, 129.4, 127.4, 118.9, 76.3, 74.2, 59.6, 33.3, 30.2, 28.8, 22.5, 21.1, 21.0, 14.0, 10.0.

Calix[4]arene 7c. was obtained by the procedure described for **7a** as a light brown powder (95%); mp 193–195 °C; δ_H

(400 MHz; DMSO-d_6) 8.22 (2H, s, N*H*), 8.19 (2H, s, N*H*), 8.17 (2H, s, N*H*), 8.13 (2H, s, N*H*), 7.23–7.19 (8H, m, ArH_{Tol}), 7.02 (8H, d, *J* 6.9, ArH_{Tol}), 6.81 (4H, s, Ar*H*), 6.75 (4H, s, Ar*H*), 4.33 (4H, d, *J* 12.7, ArCH_2Ar), 4.04 (2H, q, *J* 6.8, OCH_2CH$_3$), 3.82–3.75 (8H, m, OCH_2CH$_2$), 3.10 (4H, d, *J* 12.7, ArCH_2Ar), 2.26 (2H, t, *J* 6.8, C(O)CH_2), 2.21 (12H, s, ArCH_3), 1.96–1.85 (8H, m, CH_2), 1.52–1.35 (14H, m, CH_2), 1.17 (3H, t, *J* 6.8, OCH$_2$CH_3), 0.96 (9H, t, *J* 7.3, CH$_2$CH_3); δ_C (100 MHz; DMSO-d_6) 172.8, 152.4, 151.1, 150.9, 150.8, 137.2, 134.4, 134.1, 133.4, 133.4, 130.1, 129.0, 118.1, 117.9, 76.4, 76.3, 74.8, 59.5, 33.4, 30.6, 29.5, 29.0, 28.9, 28.8, 28.5, 28.3, 25.6, 24.4, 22.7, 22.6, 20.2, 14.0, 10.2, 10.0; *m/z* (ESI) 1377.9 (100%) [M$^+$Na].

Calix[4]arene 7d. was obtained by the procedure described for **7b** as a white powder (80%); mp 211–213 °C; δ_H (400 MHz; DMSO-d_6) 10.18 (4H, s, N*H*), 8.44 (2H, s, N*H*), 8.40 (2H, s, N*H*), 7.82 (4H, d, *J* 8.2, ArH_{Tos}), 7.81 (4H, d, *J* 8.2, ArH_{Tos}), 7.43 (8H, d, *J* 8.2, ArH_{Tos}), 6.64 (4H, s, Ar*H*), 6.58 (4H, s, Ar*H*), 4.21 (4H, d, *J* 12.9, ArCH_2Ar), 4.03 (2H, q, *J* 7.0, OCH_2CH$_3$), 3.72–3.64 (8H, m, OCH_2CH$_2$), 3.02 (4H, d, *J* 12.9, ArCH_2Ar), 2.40 (12H, s, ArCH_3), 2.24 (2H, t, *J* 7.0, C(O)CH_2), 1.82–1.77 (8H, m, CH_2), 1.46 (2H, br s, CH_2), 1.27–1.21 (12H, m, CH_2), 1.12 (3H, t, *J* 7.0, OCH$_2$CH_3), 0.89–0.84 (9H, m, CH$_2$CH_3); δ_C (100 MHz; DMSO-d_6) 173.3, 152.5, 152.3, 149.5, 144.2, 137.7, 135.0, 134.7, 132.2, 129.9, 127.9, 126.1, 119.4, 76.9, 76.7, 75.3, 60.0, 33.9, 31.1, 30.8, 29.9, 29.5, 29.4, 29.2, 29.0, 28.8, 26.0, 24.9, 23.1, 23.0, 21.5, 14.6, 10.6, 10.5; *m/z* (ESI) 1633.7 (100%) [M$^+$Na].

Calix[4]arene 7e. The tetraamine **6b** (0.16 g, 0.20 mmol) was dissolved in THF (25 cm^3). The corresponding active urethane (0.35 g, 0.84 mmol) and Et$_3$N (0.2 cm^3) were added to the solution and the reaction mixture was refluxed for 12 h. After cooling methanol was added to form a precipitate which was filtered off and washed with Et$_2$O. **7e** (0.30 g, 79%) was obtained as white powder; mp 162–164 °C; δ_H (400 MHz; DMSO-d_6; 75 °C) 7.92 (2H, s, N*H*), 7.91 (2H, s, N*H*), 7.88 (2H, s, N*H*), 7.86 (2H, s, N*H*), 7.22 (4H, d, *J* 9.0, ArH_{Ph}), 7.21 (4H, d, *J* 9.0, ArH_{Ph}), 6.84–6.77 (16H, m, ArH_{Ph}, Ar*H*), 4.40 (4H, d, *J* 12.9, ArCH_2Ar), 4.07 (2H, q, *J* 7.1, OCH_2CH$_3$), 3.95–3.82 (16H, m, OCH_2), 3.10 (4H, d, *J* 12.9, ArCH_2Ar), 2.26 (2H, t, *J* 7.2, C(O)CH_2), 1.96–1.87 (8H, m, CH_2), 1.72–1.65 (8H, m, CH_2), 1.60–1.55 (2H, m, CH_2), 1.43–1.38 (8H, m, CH_2), 1.29 (60H, br s, CH_2), 1.19 (3H, t, *J* 7.1, OCH$_2$CH_3), 1.03–0.98 (9H, m, (CH$_2$)$_2$CH_3), 0.89–0.86 (12H, m, O(CH$_2$)$_9$CH_3); δ_C (100 MHz; DMSO-d_6; 75 °C) 172.3, 153.4, 152.2, 150.7, 150.7, 133.8, 133.7, 133.0, 132.5, 119.7, 119.5, 118.1, 114.3, 75.8, 75.7, 74.1, 67.6, 58.9, 33.1, 30.6, 30.3, 29.0, 28.4, 28.3, 28.3, 28.1, 28.0, 25.1, 24.9, 23.9, 22.1, 22.0, 21.3, 13.4, 13.1, 9.6, 9.5; *m/z* (ESI) 1947.1 (20%) [M$^+$Na].

Calix[4]arene 7f. MeOH was added to the solution and the solvents were evaporated. The residue was triturated with hexane and filtered off. **7f** (65%) was obtained as a white powder; mp 230–232 °C; δ_H (400 MHz; DMSO-d_6; 100 °C) 7.91 (2H, s, N*H*), 7.88 (2H, s, N*H*), 6.73 (4H, s, Ar*H*), 6.68 (4H, s, Ar*H*), 5.80–5.74 (4H, m, N*H*), 4.28 (4H, d, *J* 11.0, ArCH_2Ar), 4.03 (2H, q, *J* 7.0, OCH_2CH$_3$), 3.76–3.70 (8H, m, OCH_2CH$_2$), 3.01–2.98 (12H, m, ArCH_2Ar, NHCH_2), 2.25 (2H, t, *J* 7.2, C(O)CH_2), 1.91–1.85 (8H, m, CH_2), 1.54–1.51 (2H, m, CH_2), 1.36–1.27 (36H, m, CH_2), 1.16 (3H, t, *J* 7.0, OCH$_2$CH_3), 0.97–0.91 (9H, m, (CH$_2$)$_2$CH_3), 0.88–0.85 (12H, m, (CH$_2$)$_{11}$CH_3); δ_C (100 MHz; DMSO-d_6; 100 °C) 172.7, 155.1, 150.5, 150.3, 150.3, 134.1, 134.0, 133.9, 117.8, 76.3, 76.2, 74.7, 59.5, 38.9, 33.4, 30.6, 29.4, 29.0, 28.9, 28.8, 28.5, 28.3, 25.6, 24.3, 22.6, 22.5, 21.8, 14.0, 13.8, 10.1, 10.0; *m/z* (ESI) 1297.9 (100%) [M$^+$Na].

Calix[4]arene 7g. The product was precipitated directly from the reaction mixture with CH$_3$CN, filtered, washed twice with CH$_3$CN, and dried in air. **7h** (85%) was obtained as a yellow powder; mp 193–195 °C; δ_H (400 MHz; DMSO-d_6; 100 °C) 7.50 (4H, m, N*H*), 6.71 (4H, s, Ar*H*), 6.69 (4H, s, Ar*H*), 5.55 (4H, m, N*H*), 4.37 (4H, d, *J* 12.9, ArCH_2Ar), 4.08 (2H, q, *J* 7.0, OCH_2CH$_3$), 3.87–3.80 (8H, m, OCH_2CH$_2$), 3.07–3.01 (12H, m, ArCH_2Ar, NHCH_2), 2.26 (2H, t, *J* 7.2, C(O)CH_2), 1.93–1.84 (8H, m, CH_2), 1.61–1.56 (2H, m, CH_2), 1.42 (8H, m, CH_2), 1.27 (84H, m, CH_2), 1.20 (3H, t, *J* 7.0, OCH$_2$CH_3), 1.01–0.97 (9H, m, (CH$_2$)$_2$CH_3), 0.90–0.87 (12H, m, (CH$_2$)$_{11}$CH_3); δ_C (100 MHz; DMSO-d_6; 100 °C) 171.8, 154.7, 150.3, 133.5, 133.4, 118.1, 75.5, 75.4, 73.8, 58.6, 38.6, 33.0, 30.5, 30.3, 29.3, 28.8, 28.2, 28.0, 27.8, 27.7, 25.7, 25.0, 23.7, 21.9, 21.8, 21.1, 13.2, 12.8, 9.3; *m/z* (ESI) 1691.4 (100%) [M$^+$Na].

Calix[4]arene 7h. MeOH (30 cm^3) was added to the solution and the solvents were evaporated. The crude product was reprecipitated from CHCl$_3$–hexane and then from CHCl$_3$–MeOH. **7h** (85%) was obtained as a yellow powder; mp 175–177 °C; δ_H (200 MHz; DMSO-d_6) 8.24 (2H, s, N*H*), 8.21 (2H, s, N*H*), 8.18 (2H, s, N*H*), 8.16 (2H, s, N*H*), 7.85–7.82 (4H, m, ArH_{pht}), 7.22 (4H, d, *J* 8.3, ArH_{Tol}), 7.21 (4H, d, *J* 8.3, ArH_{Tol}), 7.02 (8H, d, *J* 8.3, ArH_{Tol}), 6.84 (4H, s, Ar*H*), 6.77 (4H, s, Ar*H*), 4.33 (4H, d, *J* 13.2, ArCH_2Ar), 3.80–3.70 (8H, m, OCH_2), 3.56 (2H, t, *J* 6.8, NHCH_2), 3.10 (4H, d, *J* 13.2, ArCH_2Ar), 2.21 (12H, s, ArCH_3), 1.95–1.84 (8H, m, CH_2), 1.61–1.56 (2H, m, CH_2), 1.29 (12H, br s, CH_2), 0.99–0.92 (9H, m, CH$_2$CH_3); δ_C (100 MHz; DMSO-d_6) 168.4, 153.0, 151.6, 151.4, 137.7, 134.9, 134.8, 134.7, 134.0, 133.9, 132.1, 130.7, 129.5, 123.4, 118.6, 118.5, 77.0, 76.8, 75.3, 37.8, 31.9, 30.0, 29.5, 29.4, 29.3, 29.0, 28.3, 26.7, 26.1, 23.2, 23.1, 20.8, 10.7, 10.6; *m/z* (FD) 1428.6 (5.6%) [M$^+$].

Calix[4]arene 7i. MeOH (30 cm^3) was added to the solution and the solvents were evaporated. The crude product was reprecipitated from CHCl$_3$–MeOH. **7i** (87%) was obtained as a yellow powder; mp > 247 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 8.22 (2H, s, N*H*), 8.19 (2H, s, N*H*), 8.16 (2H, s, N*H*), 8.12 (2H, s, N*H*), 7.22 (4H, d, *J* 7.3, ArH_{Tol}), 7.20 (4H, d, *J* 7.3, ArH_{Tol}), 7.02 (8H, d, *J* 7.3, ArH_{Tol}), 6.84 (4H, s, Ar*H*), 6,78 (4H, s, Ar*H*), 6.71 (1H, s, N*H*Boc), 4.34 (4H, d, *J* 11.7, ArCH_2Ar), 3.81–3.75 (8H, m, OCH_2), 3.10 (4H, d, *J* 11.7, ArCH_2Ar), 2.90–2.87 (2H, m, NCH_2), 2.21 (12H, s, ArCH_3), 1.95–1.86 (8H, m, CH_2), 1.40–1.26 (23H, m, CH_2, OC(CH_3)$_3$), 1.01–0.95 (9H, m, CH$_2$CH_3); δ_C (100 MHz; DMSO-d_6) 155.5, 152.4, 151.1, 150.9, 150.9, 137.2, 134.4, 134.2, 133.5, 133.4, 130.2, 129.0, 118.1, 117.9, 77.1, 76.4, 76.3, 74.8, 30.6, 29.5, 29.4, 29.1, 29.0, 28.7, 28.2, 26.2, 25.6, 22.7, 22.6, 20.2, 10.2, 10.0.

Calix[4]arene 7j. The tetraamine **6e** (0.64 g, 0.74 mmol) was dissolved in CH$_2$Cl$_2$ (30 cm^3) and THF (5 cm^3). Tolyl isocyanate (0.79 g (0.74 cm^3), 6.00 mmol) was added to the solution and the reaction mixture was stirred for 6 h and then evaporated. Reprecipitation of the product with MeOH from THF (5 cm^3) yielded compound **7j** (90%) as a white powder; mp 202–204 °C; δ_H (400 MHz; DMSO-d_6) 9.36 (1H, s, CF$_3$C(O)N*H*), 8.22 (2H, s, N*H*), 8.19 (2H, s, N*H*), 8.16 (2H, s, N*H*), 8.12 (2H, s, N*H*), 7.24–7.20 (8H, m, ArH_{Tol}), 7.04–6.99 (8H, m, ArH_{Tol}), 6.84 (4H, s, Ar*H*), 6,78 (4H, s, Ar*H*), 4.34 (4H, d, *J* 12.5, ArCH_2Ar), 3.83–3.74 (8H, m, OCH_2), 3.17 (2H, dt, *J* 6.7, *J* 6.7, NHCH_2), 3.10 (4H, d, *J* 12.5, ArCH_2Ar), 2.21 (12H, s, ArCH_3), 1.97–1.86 (8H, m, CH_2), 1.52–1.28 (14H, m, CH_2), 1.00–0.95 (9H, m, CH$_2$CH_3); *m/z* (ESI) 1416.7 (100%) [M$^+$Na].

General procedure for synthesis of 8a,c,e–h

A solution of NaOH (4.6 mmol) in MeOH–H$_2$O = 3 : 1 (8 cm^3) was added to the solution of calixarene **7** (0.46 mmol) in THF (30 cm^3). The reaction mixture was stirred 6 h at room temperature and acetic acid was added to neutralize the excess of NaOH. The reaction mixture was concentrated to *ca.* 5–10 cm^3 and then water was added.

Calix[4]arene 8a. The precipitate was filtered off and washed with MeOH (5 cm^3); **8a** (65–90%) was obtained as a white powder; mp > 230 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 12.07

(1H, s, COO*H*), 8.22 (4H, s, N*H*), 8.16 (4H, s, N*H*), 7.22 (8H, d, *J* 8.2, ArH_{Tol}), 7.02 (8H, d, *J* 8.2, ArH_{Tol}), 6.81 (4H, s, Ar*H*), 6.80 (4H, s, Ar*H*), 4.34 (2H, d, *J* 12.6, ArCH_2Ar), 4.32 (2H, d, *J* 12.6, ArCH_2Ar), 3.82–3.72 (8H, m, OCH_2), 3.10 (4H, d, *J* 12.6, ArCH_2Ar), 2.30 (2H, t, *J* 7.4, C(O)CH_2), 2.21 (12H, s, ArCH_3), 1.96–1.85 (8H, m, CH_2), 1.73–1.65 (2H, m, CH_2), 0.97 (9H, t, *J* 7.4, CH_2CH_3); δ_C (100 MHz; DMSO-d_6) 174.2, 152.4, 151.0, 137.2, 134.3, 133.4, 130.2, 129.0, 118.1, 118.0, 76.4, 74.4, 33.6, 30.6, 29.1, 22.6, 21.2, 20.2, 10.1; *m/z* (MALDI TOF) 1267.4 (100%) [M^+Na].

Calix[4]arene 8c. Initially an oil was formed. MeOH was added and the mixture was left for 30 min in an ultrasonic bath to form a solid precipitate, which was filtered off, washed with MeOH (5 cm^3) and dried in air. **8c** (90%) was obtained as a white powder; mp > 190 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 12.07 (1H, s, COO*H*), 8.22 (2H, s, N*H*), 8.19 (2H, s, N*H*), 8.16 (2H, s, N*H*), 8.12 (2H, s, N*H*), 7.23–7.19 (8H, m, ArH_{Tol}), 7.02 (8H, d, *J* 6.9, ArH_{Tol}), 6.84 (4H, s, Ar*H*), 6.77 (4H, s, Ar*H*), 4.33 (4H, d, *J* 12.6, ArCH_2Ar), 3.82–3.71 (8H, m, OCH_2), 3.10 (4H, d, *J* 12.6, ArCH_2Ar), 2.21 (12H, s, ArCH_3), 2.18 (2H, t, *J* 7.2, C(O)CH_2), 1.96–1.85 (8H, m, CH_2), 1.49–1.25 (14H, m, CH_2), 1.00–0.95 (9H, m, CH_2CH_3); δ_C (100 MHz; DMSO-d_6) 174.9, 152.9, 157.6, 151.4, 137.7, 134.9, 134.6, 133.9, 133.9, 130.6, 129.5, 118.6, 118.4, 76.9, 76.8, 75.3, 34.1, 33.7, 31.1, 30.0, 29.5, 29.2, 29.0, 26.1, 24.9, 23.2, 20.7, 10.7, 10.5; *m/z* (ESI) 1349.8 (100%) [M^+Na].

Calix[4]arene 8e. The precipitate was filtered off and washed with MeOH. **8e** (70%) was obtained as a white powder; mp 171–173 °C; δ_H (400 MHz; DMSO-d_6; 75 °C) 8.01 (4H, br s, N*H*), 7.95 (4H, br s, N*H*), 7.23 (8H, m, ArH_{Ph}), 6.78 (16H, m, ArH_{Ph}, Ar*H*), 4.39 (4H, d, *J* 12.5, ArCH_2Ar), 3.90 (16H, m, OCH_2), 3.10 (4H, d, *J* 12.5, ArCH_2Ar), 1.19 (2H, m, C(O)CH_2), 1.90 (8H, m, CH_2), 1.68 (8H, m, CH_2), 1.55 (2H, m, CH_2), 1.28 (68H, m, CH_2), 1.00 (9H, m, $(CH_2)_2CH_3$), 0.87 (12H, m, $O(CH_2)_9CH_3$); δ_C (100 MHz; DMSO-d_6; 75 °C) 173.8, 153.4, 152.2, 150.7, 150.6, 133.8, 133.7, 133.0, 132.6, 119.6, 119.4, 118.1, 114.3, 75.8, 75.7, 67.5, 33.5, 30.6, 30.3, 29.0, 28.4, 28.3, 28.1, 28.0, 25.1, 24.9, 24.1, 22.1, 21.4, 13.1, 9.6, 9.5; *m/z* (ESI) 1919.1 (54%) [M^+Na].

Calix[4]arene 8f. The precipitate was filtered off and washed with acetone. **8f** (70%) was obtained as a light beige powder; mp 199–201 °C; δ_H (400 MHz; DMSO-d_6) 7.92 (2H, s, N*H*), 7.88 (2H, s, N*H*), 6.73 (4H, s, Ar*H*), 6.67 (4H, s, Ar*H*), 5.79–5.75 (4H, m, N*H*), 4.28 (4H, d, *J* 12.1, ArCH_2Ar), 3.77–3.69 (8H, m, OCH_2CH$_2$), 3.01–2.97 (12H, m, ArCH_2Ar, NHCH_2), 2.18 (2H, t, *J* 7.8, C(O)CH_2), 1.91–1.86 (8H, m, CH_2), 1.49–1.25 (38H, m, CH_2), 0.97–0.92 (9H, m, $(CH_2)_2CH_3$), 0.88–0.85 (12H, m, $(CH_2)_{11}CH_3$); δ_C (100 MHz; DMSO-d_6) 174.4, 155.1, 150.5, 150.4, 150.3, 134.2, 134.0, 133.9, 117.9, 76.4, 76.2, 74.7, 39.4, 33.6, 30.6, 29.4, 29.1, 29.0, 28.8, 28.7, 28.5, 25.6, 24.4, 22.6, 22.5, 21.8, 13.9, 10.2, 10.0; *m/z* (ESI) 1269.9 (100%) [M^+Na].

Calix[4]arene 8g. The precipitate was filtered off and washed with acetone. **8g** (85%) was obtained as a light beige powder; mp 158–160 °C; δ_H (400 MHz; DMSO-d_6) 7.68 (2H, s, N*H*), 7.66 (2H, s, N*H*), 6.71 (4H, s, Ar*H*), 6.68 (4H, s, Ar*H*), 5.67 (4H, m, N*H*), 4.33 (4H, d, *J* 12.9, ArCH_2Ar), 3.84–3.76 (8H, m, OCH_2CH$_2$), 3.02 (12H, m, ArCH_2Ar, NHCH_2), 2.18 (2H, t, *J* 7.2, C(O)CH_2), 1.91–1.85 (8H, m, CH_2), 1.53 (2H, m, CH_2), 1.40 (8H, m, CH_2), 1.27 (84H, m, CH_2), 0.99–0.94 (9H, m, $(CH_2)_2CH_3$), 0.89–0.85 (12H, m, $(CH_2)_{11}CH_3$); δ_C (100 MHz; DMSO-d_6) 174.7, 155.5, 151.3, 151.2, 134.7, 134.5, 118.9, 76.8, 76.4, 75.1, 39.7, 34.5, 31.7, 31.4, 30.3, 29.9, 29.4, 29.3, 29.2, 29.1, 29.0, 26.9, 26.2, 25.1, 23.1, 23.0, 22.4, 14.1, 10.6, 10.5; *m/z* (ESI) 1663.3 (100%) [M^+Na].

General procedure for the synthesis of tetratosylureas 8b,d

A solution of LiOH × H_2O (2.56 mmol) in MeOH–H_2O (8.5 : 2.5 cm^3) was added to the solution of calixarene **7** (0.41 mmol) in THF (25 cm^3). The reaction mixture was stirred for 12 h and acetic acid was added to neutralize the excess of LiOH.

Calix[4]arene 8b. $CHCl_3$ (40 cm^3) and H_2O (40 cm^3) were added to the solution; the organic layer was separated, washed with water (2 × 15 cm^3) and evaporated. The residue was triturated with water, and a solid was filtered off and washed with MeOH (5 cm^3). **8b** (60%) was obtained as a white powder; mp 217–219 °C; δ_H (400 MHz; DMSO-d_6) 12.00 (1H, br s, COO*H*), 10.13 (4H, br s, N*H*), 8.42 (4H, s, N*H*), 7.82 (8H, d, *J* 8.2, ArH_{Tos}), 7.42 (8H, d, *J* 8.2, ArH_{Tos}), 6.61 (4H, s, Ar*H*), 6.60 (4H, s, Ar*H*), 4.20 (4H, d, *J* 12.9, ArCH_2Ar), 3.72–3.67 (8H, m, OCH_2), 3.02 (4H, d, *J* 12.9, ArCH_2Ar), 2.40 (12H, s, ArCH_3), 2.31 (2H, t, *J* 7.1, C(O)CH_2), 1.83–1.77 (8H, m, CH_2), 1.62–1.55 (2H, m, CH_2), 0.89 (9H, t, *J* 7.1, CH_2CH_3).

Calix[4]arene 8d. The reaction mixture was concentrated to *ca.* 5 cm^3 and the product was precipitated with water and dried in air. **8d** (80%) was obtained as a white powder; mp > 230 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 11.95 (1H, br s, COO*H*), 10.15 (4H, s, N*H*), 8.43 (2H, s, N*H*), 8.39 (2H, s, N*H*), 7.82 (4H, d, *J* 7.8, ArH_{Tos}), 7.81 (4H, d, *J* 7.8, ArH_{Tos}), 7.42 (8H, d, *J* 7.8, ArH_{Tos}), 6.64 (4H, s, Ar*H*), 6.57 (4H, s, Ar*H*), 4.21 (4H, d, *J* 12.9, ArCH_2Ar), 3.72–3.64 (8H, m, OCH_2), 3.02 (4H, d, *J* 12.9, ArCH_2Ar), 2.40 (12H, s, ArCH_3), 2.16 (2H, t, *J* 7.4, C(O)CH_2), 1.83–1.77 (8H, m, CH_2), 1.46 (2H, br s, CH_2), 1.27–1.21 (12H, m, CH_2), 0.92–0.86 (9H, m, CH_2CH_3); δ_C (100 MHz; DMSO-d_6) 174.4, 151.7, 151.7, 149.6, 143.3, 137.6, 134.4, 134.1, 131.9, 131.8, 129.3, 127.3, 118.9, 76.3, 76.2, 74.7, 33.6, 30.3, 29.4, 29.0, 28.9, 28.8, 28.6, 28.4, 25.5, 24.4, 22.6, 22.5, 21.0, 10.1, 9.9; *m/z* (ESI) 1605.7 (9%) [M^+Na], 1408.7 (13%) [M^+–C(O)NHTos + Na], 1211.7 (3%) [M^+-2 C(O)NHTos +Na], 1015.7 (100%) [M^+-3 C(O)NHTos +Na].

Calix[4]arene 8h. (A) The tetratolylurea **7i** (0.30 g, 0.21 mmol) was dissolved in CH_2Cl_2 (15 cm^3) and trifluoroacetic acid (15 cm^3) was added to the solution. The reaction mixture was stirred for 2 h at room temperature and evaporated to dryness. Et_2O (15 cm^3) was added and the precipitate was filtered off. **8h** × CF_3COOH (0.27 g, 89%) was obtained as a yellow powder; mp > 247 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 8.31 (2H, s, N*H*), 8.28 (2H, s, N*H*), 8.24 (2H, s, N*H*), 8.20 (2H, s, N*H*), 7.68 (3H, br s, NH_3^+), 7.22 (8H, m, ArH_{Tol}), 7.01 (8H, m, ArH_{Tol}), 6.83 (4H, s, Ar*H*), 6.80 (2H, s, Ar*H*), 6.78 (2H, s, Ar*H*), 4.34 (4H, d, *J* 12.5, ArCH_2Ar), 3.81–3.75 (8H, m, OCH_2), 3.10 (4H, d, *J* 12.5, ArCH_2Ar), 2.81–2.75 (2H, m, NH_2CH_2), 2.21 (12H, s, ArCH_3), 1.97–1.89 (8H, m, CH_2), 1.52–1.28 (14H, m, CH_2), 1.01–0.95 (9H, m, CH_2CH_3); δ_C (100 MHz; DMSO-d_6) 158.3 (q, *J* 32), 152.4, 151.1, 150.9, 137.2, 134.4, 134.2, 133.5, 133.4, 130.2, 129.0, 118.1 117.9, 76.4, 76.3, 74.8, 30.6, 29.5, 29.1, 29.0, 28.8, 28.5, 26.9, 25.7, 25.6, 22.7, 22.6, 20.2, 10.2, 10.1.

(B) The tetratolylurea **7j** (0.52 g, 0.37 mmol) was dissolved in MeOH–THF (10 : 15 cm^3) and the solution of NaOH (0.073 g, 1.8 mmol) in water (3 cm^3) was added. The reaction mixture was stirred for 12 h and acetic acid was added to neutralize the excess of NaOH. Then the solvents were removed in vacuum and the residue was triturated with MeOH. **8h** (0.29 g, 60%) was obtained as a white powder; mp > 215 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 8.58–8.42 (8H, m, N*H*), 7.25 (4H, d, *J* 8.2, ArH_{Tol}), 7.23 (4H, d, *J* 8.2, ArH_{Tol}), 7.00 (8H, d, *J* 8.2, ArH_{Tol}), 6.80 (4H, s, Ar*H*), 6.77 (4H, s, Ar*H*), 4.33 (4H, d, *J* 12.5, ArCH_2Ar), 3.83–3.75 (8H, m, OCH_2), 3.08 (4H, d, *J* 12.5, ArCH_2Ar), 2.69 (2H, t, *J* 7.2, NH_2CH_2), 2.21 (12H, s, ArCH_3), 1.95–1.85 (8H, m, CH_2), 1.47–1.28 (14H, m, CH_2), 1.01–0.97 (9H, m, CH_2CH_3); δ_C (100 MHz; DMSO-d_6) 174.6, 152.5, 151.0, 150.9, 137.4, 134.2, 134.1, 133.5, 129.9, 128.9, 118.3, 117.9, 76.3, 76.2, 74.6, 30.6, 29.4, 29.0, 28.9, 28.8, 28.6, 28.6, 25.9, 25.6, 23.5,

22.7, 22.6, 20.2, 10.2, 10.1; *m/z* (MALDI TOF) 1322.7 (100%) [M^+Na].

General procedure for the synthesis of 9a–e

The acid **8** (0.069 mmol) and PyBOP (0.069 mmol) were dissolved in DMF (peptide synthesis grade, 2 cm^3). The solution was stirred 1 h at room temperature and then tetraamine **1** (0.017 mmol) and triethylamine (0.15 mmol) in DMF (1 cm^3) were added. The stirring was continued for 12 h at room temperature and 2 h at 30 °C. After that the reaction mixture was diluted with water (7 cm^3), the precipitate was filtered off, washed with MeOH and dried.

Pentacalixarene 9a. **9a** was obtained as a white powder (0.065 g, 62%); mp > 335 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 8.22 (8H, s, N*H*), 8.19 (8H, s, N*H*), 8.16 (8H, s, N*H*), 8.13 (8H, s, N*H*), 7.65 (4H, s, N*H*), 7.21 (32H, m, ArH_{Tol}), 7.01 (32H, m, ArH_{Tol}), 6.94 (8H, s, ArH_{alt}), 6.83 (16H, s, Ar*H*), 6.78 (16H, s, Ar*H*), 4.31 (16H, br s, ArCH_2Ar), 3.73 (40H, br s, OCH_2, ArCH_2Ar$_{alt}$), 3.20 (8H, br s, OC$H_{2\,alt}$), 3.09 (16H, br s, ArCH_2Ar), 2.90 (8H, br s, NHCH_2), 2.21 (48H, s, ArCH_3), 2.05 (8H, br s, C(O)CH_2), 1.91 (32H, br s, CH_2), 1.49 (8H, br s, CH_2), 1.36–1.27 (56H, m, CH_2), 1.19 (36H, s, C(CH_3)$_3$), 0.94 (36H, br s, CH_2CH_3).

Pentacalixarene 9b. **9b** was obtained as a white powder (70%); mp > 270 °C (decomp.); δ_H (400 MHz; DMSO-d_6; 50 °C) 7.91 (16H, s, N*H*), 7.75 (32H, m, ArH_{Tos}), 7.51 (4H, br s, N*H*), 7.20 (32H, m, ArH_{Tos}), 6.95–6.88 (40H, m, ArH_{alt}, Ar*H*), 4.24 (16H, br s, ArCH_2Ar), 3.68 (40H, br s, OCH_2, ArCH_2Ar$_{alt}$), 3.20 (8H, under the signal of water, OC$H_{2\,alt}$), 2.93–2.86 (24H, m, ArCH_2Ar, NHCH_2), 2.34 (48H, s, ArCH_3), 2.04 (8H, br s, C(O)CH_2), 1.87 (32H, br s, CH_2), 1.48–1.26 (64H, m, CH_2), 1.19 (36H, s, C(CH_3)$_3$), 0.93 (36H, m, CH_2CH_3).

Pentacalixarene 9c. The residue was additionally washed with Et_2O. **9c** (80%) was obtained as a white powder; mp > 240 °C (decomp.); δ_H (400 MHz; DMSO-d_6; 100 °C) 7.87 (16H, s, N*H*), 7.82 (16H, s, N*H*), 7.23–7.20 (32H, m, ArH_{Tol}), 7.20 (4H, br s, N*H*), 6.97 (8H, s, ArH_{alt}), 6.81–6.76 (64H, br s, ArH_{Tol}, Ar*H*), 4.04 (16H, d, *J* 12.1, ArCH_2Ar), 3.91–3.81 (64H, m, OCH_2), 3.67 (8H, s, ArCH_2Ar$_{alt}$), 3.41 (8H, br s, OC$H_{2\,alt}$), 3.09 (16H, d, *J* 12.1, ArCH_2Ar), 3.02 (8H, br s, NHCH_2), 2.07 (8H, br s, C(O)CH_2), 1.92–1.88 (32H, m, CH_2), 1.68 (32H, br s, CH_2), 1.53 (16H, m, CH_2), 1.41–1.29 (272H, m, CH_2), 1.23 (36H, s, C(CH_3)$_3$), 0.99 (36H, br s, (CH$_2$)$_2$CH_3), 0.94 (48H, br s, O(CH$_2$)$_9$CH_3).

Pentacalixarene 9d. **9d** was obtained as a white powder (70%); mp 196–198 °C; δ_H (400 MHz; DMSO-d_6; 75 °C) 7.65–7.63 (16H, m, N*H*), 7.32 (4H, br s, N*H*), 6.96 (8H, s, ArH_{alt}), 6.71 (16H, s, Ar*H*), 6.68 (16H, s, Ar*H*), 5.63–5.62 (16H, m, N*H*), 4.33 (16H, d, *J* 12.1, ArCH_2Ar), 3.81–3.76 (32H, m, OCH_2), 3.67 (8H, s, ArCH_2Ar$_{alt}$), 3.38 (8H, m, OC$H_{2\,alt}$), 3.01 (56H, m, ArCH_2Ar, C(O)NHCH_2, NHCH_2), 2.07 (8H, t, *J* 7.0, C(O)CH_2), 2.06–1.86 (32H, m, CH_2), 1.52 (16H, m, CH_2), 1.41–1.28 (144H, m, CH_2), 1.22 (36H, s, C(CH_3)$_3$), 0.96 (36H, m, (CH$_2$)$_2$CH_3), 0.87 (48H, m, (CH$_2$)$_4$CH_3).

Pentacalixarene 9e. **9e** was obtained as a white powder (66%); mp 180–183 °C; δ_H (400 MHz; DMSO-d_6; 100 °C) 7.47 (16H, br s, N*H*), 7.09 (4H, br s, N*H*), 6.98 (8H, s, ArH_{alt}), 6.70–6.68 (32H, m, Ar*H*), 5.55 (16H, br s, N*H*), 4.36 (16H, d, *J* 12.1, ArCH_2Ar), 3.83–3.80 (32H, m, OCH_2), 3.69 (8H, s, ArCH_2Ar$_{alt}$), 3.44 (8H, m, OC$H_{2\,alt}$), 3.04 (56H, m, ArCH_2Ar, C(O)NHCH_2, NHCH_2), 2.07 (8H, t, *J* 7.4, C(O)CH_2), 1.88–1.76 (32H, m, CH_2), 1.54 (16H, m, CH_2), 1.41–1.28 (368H, m, CH_2), 1.24 (36H, s, C(CH_3)$_3$), 0.98 (36H, m, (CH$_2$)$_2$CH_3), 0.88 (48H, m, (CH$_2$)$_{11}$CH_3).

Pentacalixarene 9f. The amine **8** (0.106 mmol) and PyBOP (0.106 mmol) were dissolved in DMF (peptide synthesis grade, 2.5 cm^3) and stirred for 1 h at room temperature. Tetraacid **2b** (0.026 mmol) and triethylamine (0.15 mmol) in DMF (1 cm^3) were added and the stirring was continued for 12 h at room temperature and 2 h at 30 °C. After that the reaction mixture was diluted with water (10 cm^3), the precipitate was filtered off, washed with MeOH and dried. **9g** (73%) was obtained as a white powder; mp > 270 °C (decomp.); δ_H (400 MHz; DMSO-d_6) 8.22 (8H, s, N*H*), 8.19 (8H, s, N*H*), 8.15 (8H, s, N*H*), 8.12 (8H, s, N*H*), 7.70 (4H, s, N*H*), 7.21 (32H, m, ArH_{Tol}), 7.01 (32H, m, ArH_{Tol}), 6.90 (8H, s, ArH_{alt}), 6.83 (16H, s, Ar*H*), 6.78 (16H, s, Ar*H*), 4.33 (16H, br s, ArCH_2Ar), 3.76 (32H, br s, OCH_2) 3.64 (8H, br s, ArCH_2Ar$_{alt}$), 3.20 (8H, br s, OC$H_{2\,alt}$), 3.06 (24H, m, ArCH_2Ar, NHCH_2), 2.20 (48H, s, ArCH_3), 2.05 (8H, br s, C(O)CH_2), 1.91 (32H, br s, CH_2), 1.37–1.25 (72H, m, CH_2), 1.19 (36H, s, C(CH_3)$_3$), 0.96 (36H, br s, CH_2CH_3).

Dimerisation

In a typical experiment pentacalixarene **9a** (0.86 μmol) and tetratosylurea **10** (3.43 μmol) were mixed together, chloroform (0.7 cm^3) was added and the solution formed (sometimes with the help of ultrasonic bath) was transferred into a NMR tube and ^{1}H NMR spectra were recorded. All other heterodimers were prepared analogously. ^{1}H NMR spectra of typical heterodimers are given below.

Pentacalixarene 9a + 4 × calixarene 10

(δ_H (400 MHz; $CDCl_3$) N*H*: 10.52 (16H, s), 8.03 (16H, s), 8.02 (16H, s), 7.62 (16H, s); ArH_{Tos}: 8.12 (32H, m), 7.39 (32H, m); ArH_{Tol}: 7.57 (32H, d, *J* 7.9), 6.79 (32H, d, *J* 7.9); ArH_{cal}: 7.87 (16H, s), 7.04 (16H, s), 6.86 (16H, s), 4.88 (16H, s); Ar$H_{1,3alt}$: 6.94 (8H, s); ArCH_2Ar: 4.54 (16H, d, *J* 11.2), the next 16H are overlapped with a broad signal at 3.88, the next 16H are overlapped with a multiplet at 3.68–3.34, 2.53–2.42 (16H, m); ArCH_2Ar$_{1,3alt}$: 8H are overlapped with broad signal at 3.88; OCH_2: 3.88 (56H, br s, (from them 32H belong to the described group), 3.68–3.34 (48H, m (from them 32H belong to the described group)); OCH$_{2\,1,3\,alt}$: 3.19 (8H, br s); NHCH_2: 2.93 (8H, br s); C(O)CH_2: 8H are overlapped with a singlet at 2.05; ArCH_{3Tos}: 2.48 (48H, s); ArCH_{3Tol}: 2.05 (56H, s (from them 48H belong to the described group); CH_2: 1.64 (100H, br s), 1.32–1.21 (92H, m); C(CH_3)$_3$: 1.23 (36H, s); CH_2CH_3: 1.00 (36H, t, *J* 7.3), 0.88 (48H, t, *J* 7.3).

Pentacalixarene 9c + 4 × calixarene 10

(δ_H (400 MHz; $CDCl_3$) N*H*: 10.54 (8H, s), 10.51 (8H, s), 7.95 (32H, s), the next 16H are overlapped with a multiplet at 7.58; ArH_{Tos}: 8.13 (32H, d, *J* 7.4), 7.39 (32H, br s); ArH_{Tol}: 7.58 (48H, m, from them 32H belong to the described group), 6.54 (32H, d, *J* 7.8); ArH_{cal}: 7.86 (16H, s), 7.03 (16H, s), 6.89 (16H, s), 5.01 (16H, s); Ar$H_{1,3alt}$: 6.95 (8H, s); ArCH_2Ar: 4.55 (16H, d, *J* 11.0), the next 16H are overlapped with a multiplet at 3.95–3.80, 3.36 (16H, d, *J* 11.0), 2.57 (16H, d, *J* 11.0); ArCH_2Ar$_{1,3alt}$: 8H are overlapped with a multiplet at 3.95–3.80; OCH_2: 3.95–3.80 (56H, m, from them 32H belong to the described group), 3.68–3.62 (32H, m), 3.47–3.44 (32H, m); OCH$_{2\,1,3\,alt}$: 3.17 (8H, br s); NHCH_2: 2.93 (8H, br s); C(O)CH_2: 2.15 (8H, br s); ArCH_{3Tos}: 2.46 (48H, s); CH_2: 2.04 (24H, br s), 1.76 (32H, br s), 1.60 (64H, br s), 1.26 (364H, br s, (from them 328H belong to the described group)); C(CH_3)$_3$: 36H are overlapped with a broad signal at 1.26; CH_2CH_3: 1.01 (36H, t, *J* 6.7), 0.91–0.86 (96H, m).

Light scattering

0.3 cm^3 of solution was filtered through 4 mm 0.2 μm LG-filters (Millipore) into dust free cylindrical 1 cm cuvettes (540.110 QS Hellma) in a dust-free flow cabinet (Bleymehl). Dynamic light scattering measurements were carried out using a Uniphase He/Ne laser ($\lambda = 632.8$ nm, 22 mW), a ALV SP-86 goniometer, a ALV/High QE APD Avalanche photodiode with fibre optic

detection, a ALV3000 correlator (all components ALV Langen), and a Lauda RC 6 thermostat (20 °C ± 0.1). Diffusion coefficients were determined by non linear fitting (Simplex algorithm) of the field autocorrelation function applying mono- or biexponential fit functions and the polydispersity was evaluated by cumulant analysis in terms of the normalized second cumulant μ_2. Hydrodynamic radii were calculated applying the Stokes–Einstein equation.

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