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Hydrogen Bonded Homo- and Heterodimers of Tetra Urea Derivatives of Calix[4]arenes

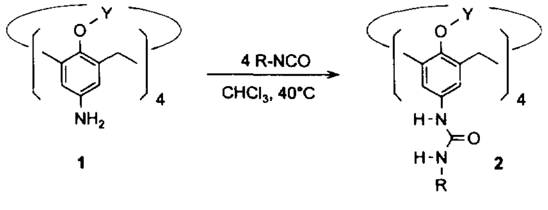
Oliver Mogck, Volker Böhmer*, and Walter Vogt

Institut für Organische Chemie, Johannes Gutenberg-Universität, J.-J.-Becher Weg 34 SB1
D-55099 Mainz, Germany

Abstract: Calix[4]arene ethers fixed in the cone conformation and substituted at the upper rim by various urea residues have been synthesized by reaction of the amino calix[4]arenes with isocyanates. Their dimerisation in apolar solvents has been established by the formation of mixed dimers consisting of two different urea derivatives. Copyright © 1996 Elsevier Science Ltd

Self-organisation is found as a general principle in nature, and the design and investigation of artificial molecules that are able to mimic this principle at least in part is a topic of current interest in supramolecular chemistry.[1] Various examples of self-complementary molecules which form definite dimers in solution have been reported.[2] If this dimerisation occurs between suitably curved molecules, molecular capsules may be formed with cavities large enough to include smaller guest molecules in a reversible manner.[3]

It has been shown, that N,N'-dialkyl or -diaryl urea derivatives are organized in the crystal lattice via hydrogen bonds between the HN- and O=C-functions.[4] Therefore the attachment of urea functions to a suitable molecular skeleton should lead to molecules which are able to associate via such hydrogen bonds. Calix[4]arenes bearing urea groups at the upper rim **2** are easily obtained by reaction of the corresponding p-amino derivatives **1** with isocyanates.[5]



1, 2
a-e $Y = C_5H_{11}$
f,g $Y = CH_2COOC_2H_5$
h $Y = CH_2C_6H_5$

2a $R = C_4H_9$
b $R = C_6H_5$
c $R = p\text{-}C_6H_4OCH_3$
d $R = p\text{-}C_6H_4CH_3$
e $R = p\text{-}C_6H_4NO_2$
f $R = p\text{-}C_6H_4CH_3$
g $R = p\text{-}C_6H_4OCH_3$
h $R = C_6H_5$

Scheme 1: Preparation of urea-calix[4]arenes **2**.

For such an urea derivative **2b**, initially prepared in order to characterize the amino calixarene,[6] we observed indeed rather surprising ^{1}H NMR spectra in apolar solvents. While in dmso-d_6 one singlet for the aromatic protons (6.81 ppm) and two closely adjoining singlets for the NH protons (8.35 and 8.21 ppm) were found,[6] the expected pattern consistent with apparent C_{4v} symmetry, these singlets for the NH protons were separated by 2.35 ppm in $CDCl_3$ (9.41/7.05 ppm), and, more surprising, the Ar-H protons of the calixarene part appeared as two strongly separated doublets (7.62 and 5.88 ppm) with a coupling constant of 2.1 Hz, typical for protons in meta-position. This means, that all four phenolic units are identical, while the ArH protons of a given unit are different. Obviously the calixarene has effective C_4 symmetry which rules out a "pinched" cone-conformation with intramolecular hydrogen bonds between opposite phenolic units.[7] While the NMR spectrum would be easily explained by ***intra***molecular hydrogen bonds of type **I** (Fig.1), molecular models show that the distance between adjacent urea functions is too large to make this a realistic explanation.

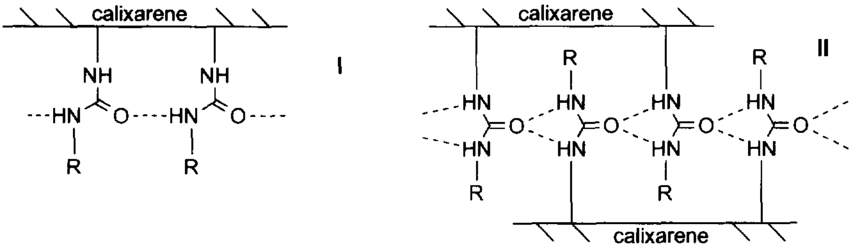


Figure 1. Schematic representation of hydrogen bonding in urea substituted calixarenes.

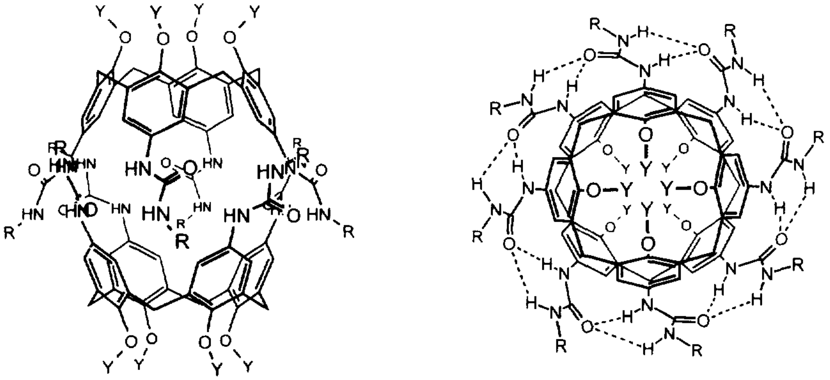


Figure 2. Side view and top view of the dimers held together by hydrogen bonds of type **II**.

A reasonable interpretation of the NMR-results discussed above was given by Rebek for a similar example (**2h**).[8] He proposed the association of two calix[4]arenes via their upper rim to dimers, which are held together by eight ***inter***molecular hydrogen bonds of type **II**.

Such a dimer,[9] having overall S_8 symmetry, is composed of two calix[4]arene moieties with C_4 symmetry.[10] While a proof of the dimerisation by the determination of the molecular weight in solution is still lacking, additional support has been found by Rebek et al. who were able to demonstrate by NMR spectroscopic studies the inclusion of suitable guest molecules in the cavity created by the two calixarene parts of the dimer.[8]

We present here an independent proof, which is based on the following simple consideration. Assuming that two different urea derivatives A and B form dimers AA and BB in an apolar solvent, then a mixture of these two derivatives should contain not only these homodimers but also the mixed or heterodimer AB. We therefore prepared various tetra-urea derivatives **2a-g** by reaction of the tetraamino calix[4]arenes[6, 11] with the appropriate isocyanates. These tetraamino calix[4]arenes fixed in the cone conformation are easily available in large quantities. The addition of isocyanates yields the analytical pure urea derivatives in 80-93% making these compounds also available on a large scale. All these derivatives show analogous NMR spectra which are consistent with a „monomeric" species in polar solvents like dmso-d_6. In apolar solvents like $CDCl_3$, toluene-d_8, CCl_4, tetrachlorethane-d_2 or benzene-d_6 the formation of dimers is indicated by the ArH and NH pattern discussed above. An additional proof for the formation of dimers is found for compounds **2f** and **2g** by the signal of the -O-CH_2- protons. In the monomeric form with effective C_{4v} symmetry these CH_2 groups are bisected by symmetry planes and the protons appear as a singlet. No symmetry plane exists in the S_8 symmetrical dimer. Thus the protons of the CH_2 group are diastereotopic and appear as a pair of doublets (AB-system) with geminal coupling. Significant differences are found for the chemical shift of a given proton of the dimer which seem to be characteristic for the solvent (compare Tab. 1). Interestingly no indication of the monomer is observed in all these solvents.[12, 13]

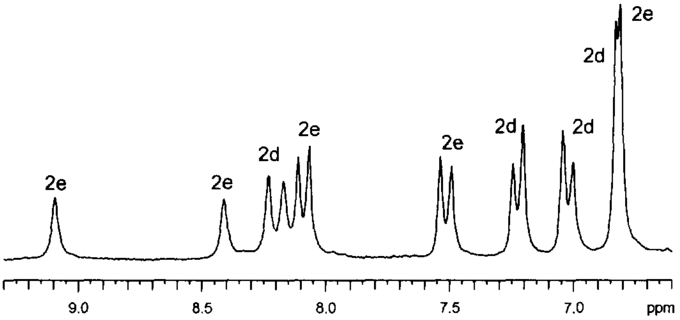


Figure 3: Section of the ^1H NMR spectrum (200 MHz, dmso-d_6) of a mixture of **2d** and **2e**. The origin of the signals is indicated.

As expected, the ^1H NMR spectrum of a mixture of two different urea derivatives in dmso-d_6 appears in all cases just as the superimposition of the spectra of the two pure compounds. An example is shown in Fig. 3. On the other hand, an analogous mixture in apolar solvents shows in addition to the signals of the pure compounds a series of signals which can be entirely understood by assuming, that in addition to the two homo-dimers AA and BB a heterodimer AB is formed.[14] Fig. 4 shows an example for the region of the aromatic and the NH protons. As indicated, all peaks can be assigned, assuming that one signal for the heterodimer is hidden by the solvent peak. For a different example the region of the methylene protons (and O-CH_2 / NH-CH_2 protons) is shown in Fig. 5. While each homodimer shows one pair of doublets for the Ar-CH_2-Ar protons the mixture shows in addition two pairs of doublets for the heterodimer (one pair for each calixarene part). Similar results are obtained for all combinations of the compounds **2a-g**. This is not only an additional strong indication of the dimerisation, it also demonstrates that this self-organisation to dimers is obviously a more or less general phenomenon for urea derivatives of this type in apolar solvents. A quantitative interpretation of the NMR-spectra allows (in principle) a determination of the equilibrium constant for the reaction AA + BB $\rightleftharpoons$ 2 AB. These studies which reveal a more or less statistical equilibrium for the present examples are in progress.

It should be possible, however, to influence the dimerisation equilibrium for instance by variation of the residues Y and R. Further studies will be devoted to such structural variations in order to obtain in this way a better understanding of the factors which govern this self-organisation process.

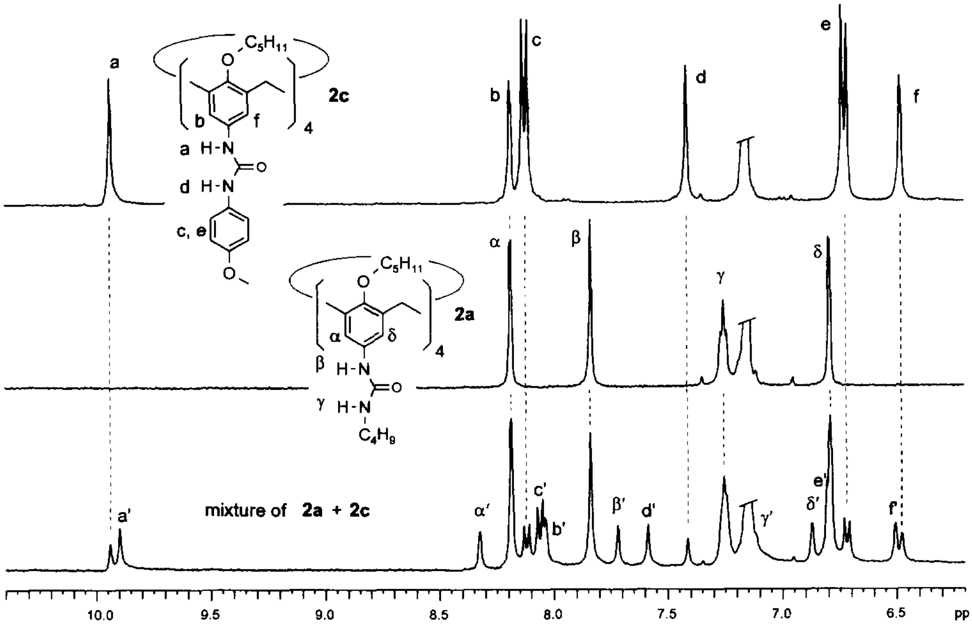
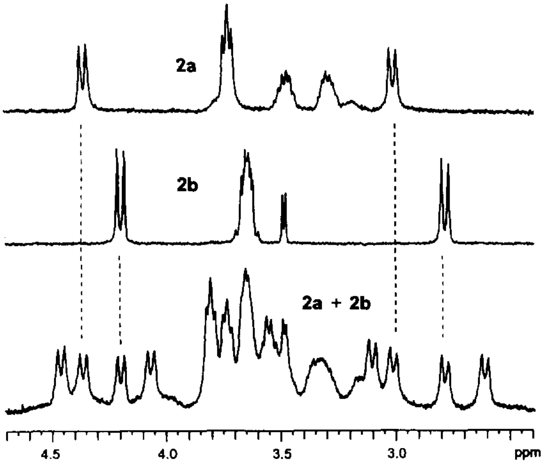


Figure 4: Section of the ^{1}H NMR spectrum (400 MHz, benzene-d_6) of **2a**, **2c**, and of their mixture. The signals for the heterodimer are tentatively assigned in analogy to those of the two homodimers.



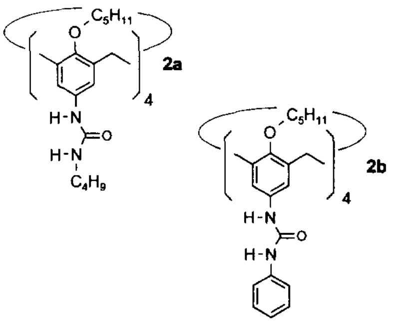


Figure 5: Section of the ^{1}H NMR spectrum (400 MHz, $CDCl_3$) of **2a**, **2b** and of their mixture.[15]

Table 1: Selected ^{1}H NMR data of **2a-g** in different solvents. Chemical shifts are given in ppm, coupling constants in Hz are indicated in brackets.

		NH[a]	NH[b]	ArH[c]	ArH[c]	ArCH$_2$Ar ax	ArCH$_2$Ar eq
2a	dmso-d_6*	7.92	5.78 t_{br}	6.69 [e]		4.27 (12.5)	2.99 (12.3)
	benzene-d_6*	8.19	7.26 t_{br}	7.84	6.79	4.89 (11.4)	3.17 (11.8)
	CDCl$_3$#	7.54	6.75 t_{br}	7.34	6.27	4.35 (11.7)	2.99 (11.5)
	CCl$_4$[d]*	7.67	6.93 t_{br}	7.50	6.35	4.53 (11.9)	3.17 (11.1)
2b	dmso-d_6*	8.35	8.21	6.81 [e]		4.34 (12.7)	3.12 (12.9)
	CDCl$_3$#	9.41	7.05	7.62 (2.1)	5.88 (2.1)	4.19 (11.8)	2.77 (11.8)
2c	dmso-d_6*	8.14	8.11	6.78 [e]		4.32 (12.5)	3.08 (12.3)
	benzene-d_6#	9.94	7.41	8.19	6.44	4.64 (11.7)	3.35 (11.7)
	CCl$_4$[d]*	9.47	7.15	7.79	5.99	4.38 (11.3)	2.97 (11.8)
2d	dmso-d_6*	8.22	8.15	6.79 [e]		4.32 (12.5)	3.09 (12.8)
	benzene-d_6#	9.97	7.38	8.16 (2.3)	6.40 (2.3)	4.59 (11.8)	3.31 (11.8)
	CDCl$_3$*	9.33	7.01	7.26	5.89	4.19 (11.7)	2.81 (11.8)
	CCl$_4$[d]*	9.54	7.10	7.79	5.91	4.33 (11.5)	2.93 (11.7)
	C$_2$D$_2$Cl$_4$*	9.29	6.59	7.20	5.74	4.17 (11.4)	2.82 (11.8)
	toluene-d_8*	9.95	6.88	8.11	6.20 (1.7)	4.57 (11.6)	3.28 (11.8)
2e	dmso-d_6*	9.07	8.39	6.81 [e]		4.34 (13.0)	3.14 (13.0)
2f	dmso-d_6*	8.25 [f]		6.84 [e]		4.73 (12.9)*	3.14 (13.3)
	benzene-d_6*	9.85	7.37	8.13	6.32 (1.8)	5.26 (12.3)	3.32 (12.4)
	CDCl$_3$*	9.27	7.09	7.66	5.89 (1.8)	4.78 (12.1)	2.89 (12.4)
	CCl$_4$[d]*	9.51	7.85	7.19	5.96	4.96 (11.8)	2.99 (12.3)
2g	dmso-d_6*	8.19	8.14	6.82 [e]		4.71 (11.9)	3.11 (11.7)
	benzene-d_6*	9.79	7.41	8.14	6.39	5.26 (12.4)	3.34 (11.8)
	CDCl$_3$*	9.16	7.13	7.65	5.95	4.78 (12.4)	2.90 (12.7)

* 200 MHz, # 400 MHz, [a] connected to the calixarene skeleton, [b] connected to the urea residue R, [c] ArH in calixarene, [d] external lock, [e] aromatic protons of the calixarene part are identical, [f] protons are coincident isochronous

EXPERIMENTAL

Melting points were determinated with a MEL TEMP 2 capillary melting point apparatus and are uncorrected. ^{1}H NMR (200 MHz) and ^{13}C NMR (50 MHz) spectra were recorded on a Bruker AC 200; ^{1}H NMR (400 MHz) spectra were recorded on a Bruker AM 400 spectrometer. Coupling constants J are given in Hz. ^{1}H NMR data are summarized in Table 1. In the following only those signals are given which are not included in Tab. 1. FD mass spectra were recorded with a Finnigan MAT 90 (5 kV/10 mA/min) spectrometer. The monomer peak M^+ was found in all cases although with difficulties, and in some cases even the dimer peak $2M^+$. Solvents of technical quality were distilled before use. The compounds **1** were prepared according to the literature.[6, 11]

General procedure for the preparation of 2a-g

To a solution of compound **1** (0.52 mmol) in $CHCl_3$ (40 ml) the isocyanate (2.2 mmol) is added and the mixture is kept under argon at 40°C for 5 h. The solution is then concentrated under reduced pressure. MeOH is added to precipitate **2**. The products thus obtained are mostly pure enough for further studies. For analytical purpose they may be purified by recrystallisation ($CHCl_3$/MeOH).

5,11,17,23-Tetra-[N'-(n-butyl)-ureido]-25,26,27,28-tetrapentyloxycalix[4]arene (2a)

82 % yield, white solid, m.p. 253-255°C. ^{1}H NMR δ: **(dmso-d$_6$)** Tab. 1 and 3.76 (t, 8H, J 6.9, O-CH_2), 3.49-3.29 (m, 4H, NH-CH_2), 2.98 (m$_{br}$, 4H, NH-CH_2), 1.88 (m$_{br}$, 8H, CH_2), 1.35 (m$_{br}$, 32H, CH_2), 0.92-0.83 (m, 24H, CH_3), **(benzene-d$_6$)** Tab. 1 and 4.04 (t, 8H, J 7.5, O-CH_2), 3.54 (m$_{br}$, 4H, NH-CH_2), 3.35 (m$_{br}$, 4H, NH-CH_2), 2.26 (m$_{br}$, 16H, CH_2), 1.61-1.26 (m, 24H, CH_2), 0.99 (t, 12H, J 6.5, CH_3), 0.79 (t, 12H, J 7.1, CH_3), **($CDCl_3$)** Tab. 1 and 4.04 (t, 8H, J 8, O-CH_2), 3.59-3.51 (m, 4H, NH-CH_2), 3.37-3.29 (m, 4H, NH-CH_2), 2.29-2.22 (m, 8H, CH_2), 1.62-1.5 (m, 8H, CH_2), 1.48-1.27 (m, 24H, CH_2), 0.99 (t, 12H, J 7.1, CH_3), 0.79 (t, 12H, J 7.3, CH_3), **(CCl_4)** Tab. 1 and 3.93 (t, 8H, J 8, O-CH_2), 3.84-3.69 (m, 4H, NH-CH_2), 3.58-3.41 (m, 4H, NH-CH_2), 2.25-2.1 (m, 8H, CH_2), 1.96-1.85 (m, 8H, CH_2), 1.79-1.49 (m, 24H, CH_2), 1.35-1.14 (m, 24H, CH_3). Anal. calcd. for $C_{68}H_{104}N_8O_8$: C, 70.31; H, 9.02; N, 9.65. Found: C, 70.37; H, 9.09; N, 9.55%. MS (FD) m/z 1163.4 (M^+, calcd. for $C_{68}H_{104}N_8O_8$ 1161.6); m/z 2327.1 ($2M^+$)

5,11,17,23-Tetra-[N'-(phenyl)-ureido]-25,26,27,28-tetrapentyloxycalix[4]arene (2b)

86 % yield, white solid, m.p. 273-275°C. ^{1}H NMR δ: **(dmso-d$_6$)** Tab. 1 and 7.33 (d, 8H, J 7.8, ArH), 7.21 (t, 8H, J 7.8, ArH), 6.91 (t, 4H, J 7.1, ArH), 3.82 (t, 8H, J 7.2, O-CH_2), 2.05-1.75 (m, 8H, CH_2), 1.55-1.35 (m, 16H, CH_2), 0.94 (t, 12H, J 6.7, CH_3), **($CDCl_3$)** Tab. 1 and 7.83 (d, 8H, J 8, ArH), 7.35 (t, 8H, J 7.9, ArH), 7.02 (t, 4H, J 7.9, ArH), 3.68-3.61 (m, 8H, O-CH_2), 1.93-1.85 (m, 8H, CH_2), 1.54-1.21 (m, 16H, CH_2), 0.92 (t, 12H, J 7.1, CH_3). Anal. calcd. for $C_{76}H_{88}N_8O_8 \cdot 1/4\ CHCl_3$: C, 72.03; H, 7.0; N, 8.81. Found: C, 72.1; H, 7.55; N, 8.83%. MS (FD) m/z 1241.7 (M^+, calcd. for $C_{76}H_{88}N_8O_8$ 1241.6); m/z 2482.9 ($2M^+$)

5,11,17,23-Tetra-[N'-(p-methoxyphenyl)-ureido]-25,26,27,28-tetrapentyloxycalix[4]arene (2c)

91 % yield, white solid, m.p. 201-204°C. ^{1}H NMR δ: **(dmso-d$_6$)** Tab. 1 and 7.23 (d, 8H, J 8.8, ArH), 7.6.8 (d, 8H, J 8.8, ArH), 3,7 (t$_{br}$, 8H, O-CH_2), 3.68 (s, 12H, Ar-O-CH_3), 1.9 (m$_{br}$, 8H, CH_2), 1.37 (m$_{br}$, 16H, CH_2), 0.92 (m$_{br}$, 12H, CH_3), **(benzene-d$_6$)** Tab. 1 and 7.23 (d, 8H, J 8.8, ArH), 6.8 (d, 8H, J 8.8, ArH), 3.84-3.72 (m, 8H, O-CH_2), 3.13 (s, 12H, Ar-O-CH_3), 2.15-2.07 (m, 8H, CH_2), 1.44-1.36 (m, 8H, CH_2), 1.29-1.24 (m, 8H, CH_2), 0.98 (t, 12H, J 7.2, CH_3), **(CCl_4)** Tab. 1 and 7.91 (d, 8H, J 8.7, ArH), 7.07 (d, 8H, J 8.7, ArH), 3.93 (s, 12 H, Ar-O-CH_3), 3.87 (t, 8H, J 7.6, O-CH_2), 2.21-2.05 (m, 8H, CH_2), 1.64-1.41 (m, 16H, CH_2), 1.17 (t, 12H, J 6.8, CH_3), ^{13}C NMR δ **(dmso-d$_6$)** 154.2, 152.6, 150.9, 134.4, 133.6, 132.9, 119.7, 118.2, 113.9, 74.9, 55.1, 30.7, 29.4, 27.9, 22.4, 13.9. Anal. calcd. for $C_{80}H_{96}N_8O_{12} \cdot 2/3\ CHCl_3$: C, 67.22; H, 6.76; N, 7.77.

Found: C, 67.27; H, 7.11; N, 7.78%. MS (FD) *m/z* 1361.7 (M^+, calcd. for $C_{80}H_{96}N_8O_{12}$ 1361.7); *m/z* 2724.4 ($2M^+$)

5,11,17,23-Tetra-[N'-(p-toluyl)-ureido]-25,26,27,28-tetrapentyloxycalix[4]arene (2d)

93 % yield, white solid, m.p. 211-214°C. ^{1}H NMR δ: **(dmso-d_6)** Tab. 1 and 7.21 (d, 8H, *J* 8.2, ArH), 7.01 (d, 8H, *J* 8.3, ArH), 3.79 (t, 8H, *J* 7, O-CH_2), 2.19 (s, 12H, ArCH_3), 1.89 (m_{br}, 8H, CH_2), 1.37 (m_{br}, 16H, CH_2), 0.954 (t_{br}, 12 H, CH_3), **(benzene-d_6)** Tab. 1 and 8.10 (d, 8H, *J* 8.3, ArH), 6.92 (d, 8H, *J* 8.3, ArH), 3.82-3.7 (m, 8H, O-CH_2), 2.13-2.05 (m, 8H, CH_2), 1.94 (s, 12H, ArCH_3), 1.44-1.35 (m, 8H, CH_2), 1.28-1.2 (m, 8H, CH_2), 0.97 (s, 12H, *J* 7.2 ,CH_3), **($CDCl_3$)** Tab. 1 and 7.71 (d, 8H, *J* 8.2, ArH), 7.14 (d, 8H, *J* 8.2, ArH), 3.71-3.62 (m, 8H, O-CH_2), 2.26 (s, 12H, ArCH_3), 1.99-1.82 (m, 8H, CH_2), 1.39-1.25 (m, 16H, CH_2), 0.93 (t, 12H, *J* 6.9, CH_3), **(CCl_4)** Tab. 1 and 7.88 (d, 8H, *J* 8.1, ArH), 7.33 (d, 8H, *J* 8.1, ArH), 3.84 (t, 8H, *J* 7.4, O-CH_2), 2.49 (s, 12H, ArCH_3), 2.18-2.04 (m, 8H, CH_2), 1.6-1.44 (m, 16H, CH_2), 1.15 (t, 12H, *J* 6.8, CH_3), **($C_2D_2Cl_4$)** Tab. 1 and 7.66 (d, 8H, *J* 8.2, ArH), 7.09 (d, 8H, *J* 8.2, ArH), 3.62 (t, 8H, *J* 7.5, O-CH_2), 2.19 (s, 12H, ArCH_3), 1.87 (m_{br}, 8H, CH_2), 1.25 (m_{br}, 16H, CH_2), 0.88 (t, 12H, *J* 6.5, CH_3), **(toluene-d_6)** Tab. 1 and 8.13 (d, 8H, ArH), 6.98 (d, 8H, ArH), 3.76 (t, 8H, *J* 7.3, O-CH_2), 2.14-1.99 (m, 8H, CH_2), 1.99 (s, 12H, ArCH_3), 1.46-1.24 (m, 16H, CH_2), 0.98 (t, 12H, *J* 7.1, CH_3), ^{13}C NMR δ **(benzene-d_6)** 155.1, 151.8, 137.8, 135.7, 135.3, 134.4, 132.5, 130.6, 118.6, 118.2, 117.7, 75.9, 31.3, 30.4, 28.5, 23.3, 20.6, 14.4. Anal. calcd. for $C_{80}H_{96}N_8O_8 \cdot 3/8\ CHCl_3$: C, 71.91; H, 7.24; N, 8.35. Found: C, 71.95; H, 7.73; N, 8.23%. MS (FD) *m/z* 1297.8 (M^+, calcd. for $C_{80}H_{96}N_8O_8$ 1297.7)

5,11,17,23-Tetra-[N'-(p-nitrophenyl)-ureido]-25,26,27,28-tetrapentyloxycalix[4]arene (2e)

79 % yield, yellow solid, m.p. >280°C (decomp.). ^{1}H NMR δ: **(dmso-d_6)** Tab. 1 and 8.07 (d, 8H, *J* 9.2, ArH), 7.49 (d, 8H, *J* 9.2, ArH), 3.81 (t, 8H, *J* 6.7, O-CH_2), 1.87 (m_{br}, 8H, CH_2), 1.38 (m_{br}, 16H, CH_2), 0.92 (t_{br}, 12H, CH_3). Anal. calcd. for $C_{76}H_{84}N_{12}O_8 \cdot 1/4\ CHCl_3$: C, 63.1; H, 5.85; N, 11.58. Found: C, 63.04; H, 6.32; N, 11.64%. MS (FD) *m/z* 1422.9 (M^+, calcd. for $C_{76}H_{84}N_{12}O_8$ 1421.6)

5,11,17,23-Tetra-[N'-(p-toluyl)-ureido]-25,26,27,28-tetraethoxycarbonylmethoxycalix[4]arene (2f)

89 % yield, white solid, m.p. 194-197°C. ^{1}H NMR δ: **(dmso-d_6)** Tab. 1 and 7.23 (d, 8H, *J* 8.4, ArH), 7.02 (d, 8H, *J* 8.4, ArH), 4.69 (s, 8H, Ar-O-CH_2), 4.14 (q, 8H, *J* 7.1, O-CH_2), 2.21 (s, 12H, ArCH_3), 1.24 (t, 12H, CH_3), **(benzene-d_6)** Tab. 1 and 8.05 (d, 8H, *J* 8.3, ArH), 6.88 (d, 8H, *J* 8.3, ArH), 4.99 (d, 4H, *J* 16.2, Ar-O-CH_2), 4.76 (d, 4H, *J* 16.2, Ar-O-CH_2), 3.93 (q, 8H, *J* 7.2, O-CH_2), 1.93 (s, 12H, ArCH_3), 0.94 (t, 12H, *J* 7.2, CH_3), **($CDCl_3$)** Tab. 1 and 7.68 (d, 8H, *J* 8.3, ArH), 7.13 (d, 8H, *J* 8.3, ArH), 4.8 (d, 4H, *J* 16.3, Ar-O-CH_2), 4.55 (d, 4H, *J* 16.3, Ar-O-CH_2), 4.14 (q, 8H, *J* 7.2, O-CH_2), 2.26 (s, 12H, ArCH_3), 1.24 (t, 12H, *J* 7.2, CH_3), **(CCl_4)** Tab. 1 and 7.88 (d, 8H, *J* 8.2, ArH), 7.35 (d, 8H, *J* 8.2, ArH), 4.88 (d, 4H, *J* 16.1, Ar-O-CH_2), 4.73 (d, 4H, *J* 16.1, Ar-O-CH_2), 4.34 (q, 8H, *J* 7.2, O-CH_2), 2.51 (s, 12H, ArCH_3), 1.48 (t, 12H, *J* 7.2, CH_3), ^{13}C NMR δ **(dmso-d_6)** 169.6, 152.4, 150.2, 137.2, 134.2, 130.1, 129.0, 118.3, 118.1, 71.11, 60.1, 31.3, 20.3, 13.9, ^{13}C NMR δ **($CDCl_3$)** 170.8, 154.4, 150.8, 136.7, 134.5, 134.0, 132.7, 130.3, 118.4, 117.9, 117.2, 116.6, 72.1, 60.5, 31.3, 20.8, 14.2. MS (FD) *m/z* 1361.6 (M^+, calcd. for $C_{76}H_{80}N_8O_{16}$ 1361.4); *m/z* 2722.9 ($2M^+$)

5,11,17,23-Tetra-[N'-(p-methoxyphenyl)-ureido]-25,26,27,28-tetraethoxycarbonylmethoxy-calix[4]arene (2g) 87 % yield, white solid, m.p. 178-181°C. ^{1}H NMR δ: **(dmso-d_6)** Tab. 1 and 7.23 (d, 8H, *J* 8.9, ArH), 7.02 (d, 8H, *J* 8.9, ArH), 4.68 (s, 8H, Ar-O-CH_2), 4.14 (q, 8H, *J* 7.1, O-CH_2), 2.49 (s, 12H, ArCH_3), 1.23 (t, 12H, *J* 7.1, CH_3), **(benzene-d_6)** Tab. 1 and 8.05 (d, 8H, *J* 8.6, ArH), 6.69 (d, 8H, *J* 8.6, ArH), 4.96 (d, 4H, *J* 16.1, Ar-O-CH_2), 4.78 (d, 4H, *J* 16.1, Ar-O-CH_2), 3.94 (q, 8H, *J* 7.1, O-CH_2), 3.14 (s, 12H, Ar-O-CH_3), 0.95 (t, 12H, *J* 12.1, CH_3), **($CDCl_3$)** Tab. 1 and 7.69 (d, 8H, *J* 8.9, ArH), 6.88 (d, 8H, *J* 8.9, ArH), 4.78 (d, 4H, *J* 16.3, Ar-O-CH$_2$), 4.58 (d, 4H, *J* 16.3, Ar-O-CH$_2$), 4.14 (q, 8H, *J* 7.1, O-CH$_2$), 3.75 (s, 12H, Ar-O-CH$_3$), 1.24 (t, 12H, *J* 7.1, CH$_3$). MS (FD) *m/z* 1425.3 (M$^+$, calcd. for $C_{76}H_{80}N_8O_{20}$ 1425.4); *m/z* 2850.3 (2M$^+$)

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12. The addition of 0.4 vol-% dmso-d$_6$ or acetone-d$_6$ leads to a complete destruction of the dimer, which can also be achieved by the addition of a simple dialkyl or diaryl urea.
13. In CD$_2$Cl$_2$ ^{1}H NMR spectra with very broad signals are observed.
14. The heterodimers are chiral, since the S$_8$-symmetry of the homodimers is reduced to C$_4$ due to the non-equivalence of A and B.
15. It is unclear from our results whether the signals around 3.5 ppm in the spectrum of **2b** are caused by an included guest (compare ref. 8.).

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