Electronic Supplementary Material (ESI) for Organic and Biomolecular Chemistry

Bridge-substituted Calix[4]arenes- Syntheses, Conformations and Application

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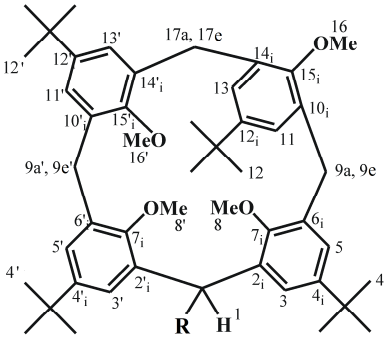
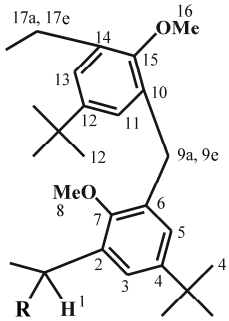
Supplementary material (ESI)

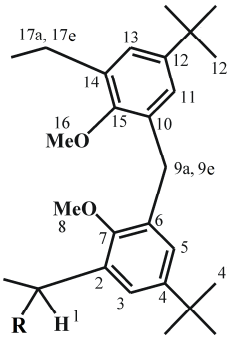
NMR measurements (exemplarily for compound **2**)



paco2 (○)

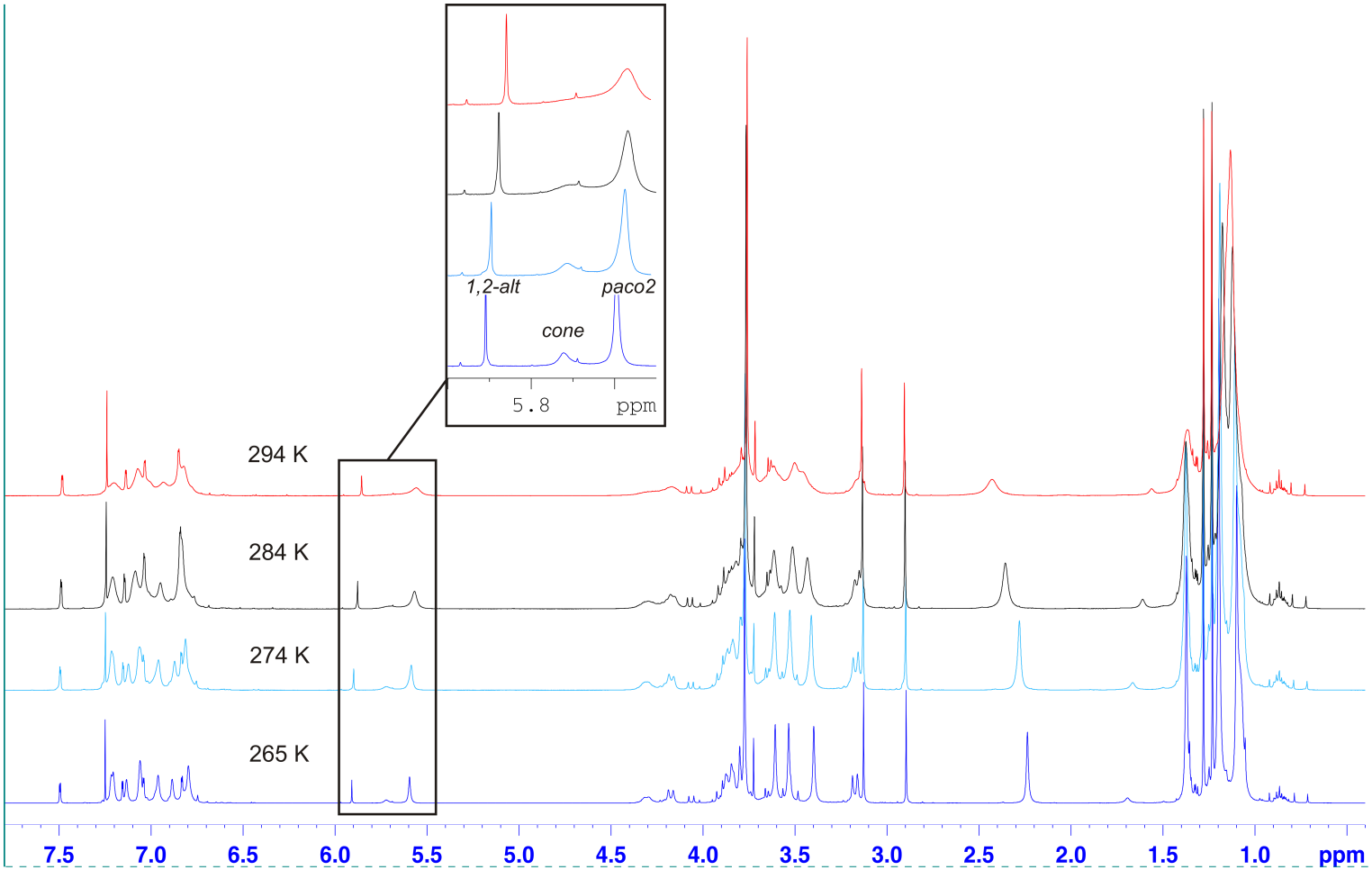


1,2-alternate (■)



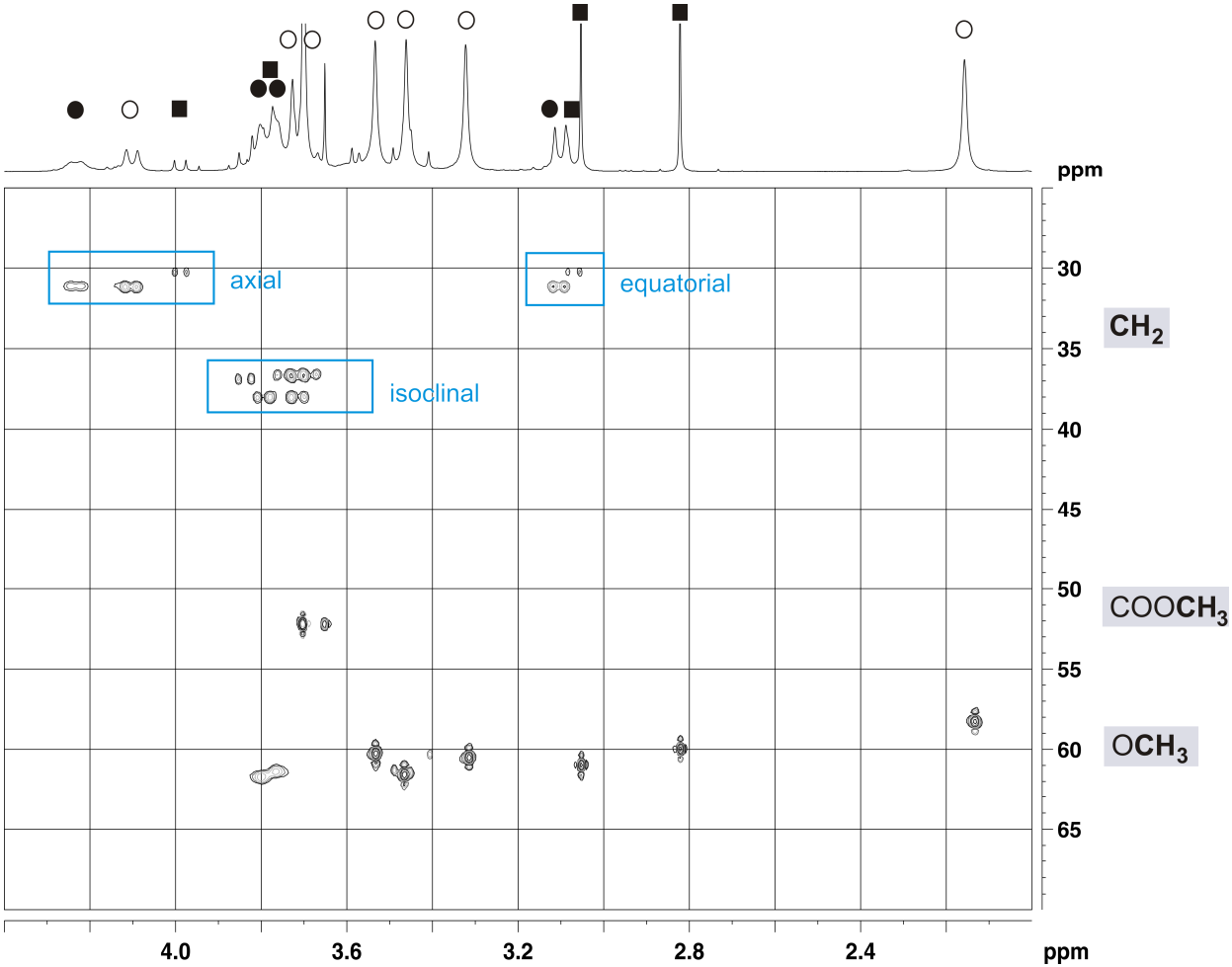
cone (●)

S1 Numbering of atoms in molecule **2** for NMR examination.

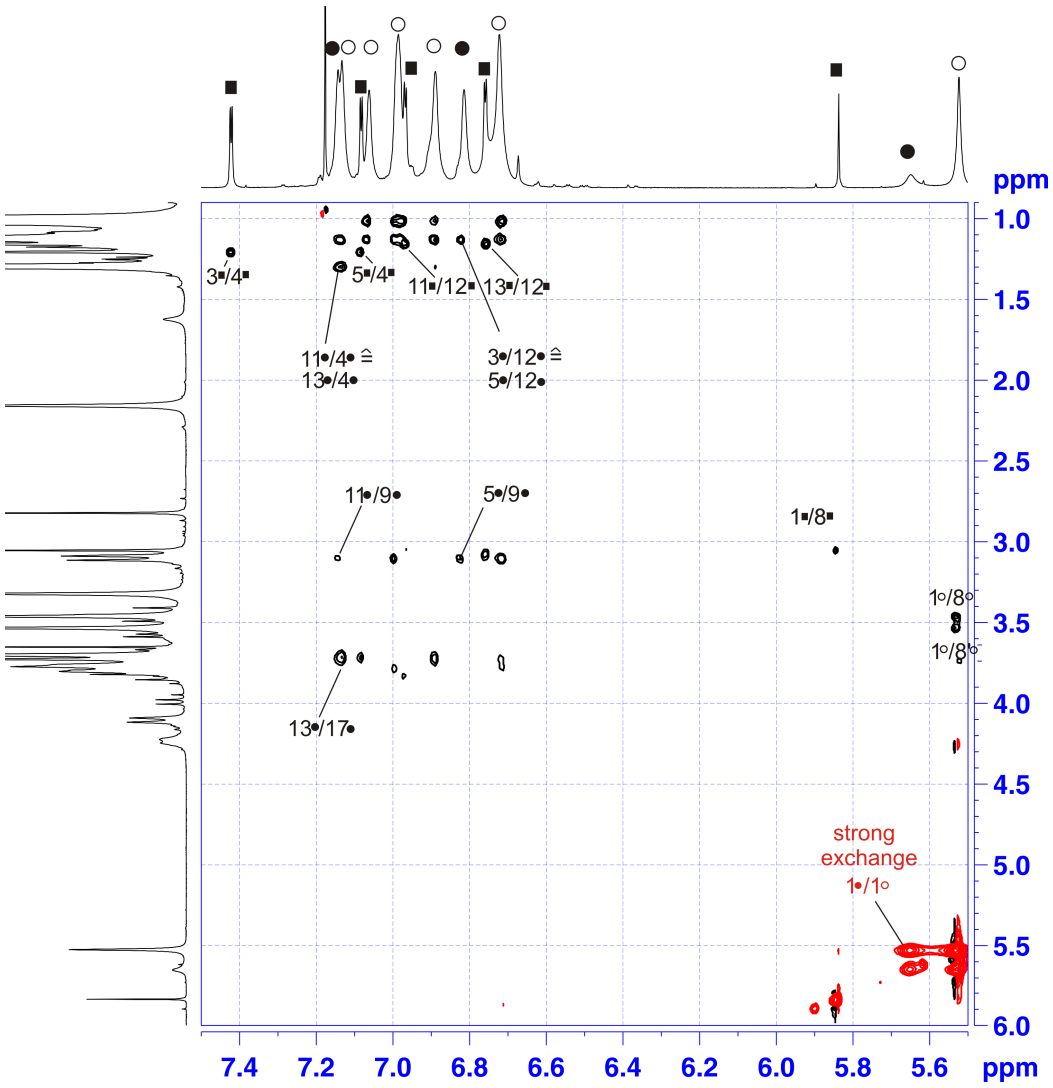


S2 Temperature-dependent ^{1}H-NMR spectrum of compound **2** in $CDCl_3$, indicating the high conformational flexibility at room temperature (294 K). The region of the methine protons of the different conformers is additionally magnified.

Comment [TG1]: Muß das nicht weg???



S3 HSQC spectrum of **2** in $CDCl_3$ at 265 K. The different orientation and position of the methylene protons in the three interfering conformers is highlighted. (Assignment: ● *cone*, ○ *paco2*, ■ *1,2-alternate*)



S4 NOESY spectrum of **2** in $CDCl_3$ at 265 K with important correlations of spatially close protons (black cross-peaks) in the different conformers. Negative cross-peaks (red) indicate the exchange of the *cone* and *paco2* conformation. (Assignment: ● *cone*, ○ *paco2*, ■ *1,2-alternate*)

Crystallographic data for compounds **2** and **4**

S5 Crystallographic and structure refinement data of the compounds studied

Compound	**2**	**4**
Empirical formula	$C_{50}H_{66}O_6$	$C_{52}H_{70}O_6$
Formula weight (g/mol)	763.03	791.08
Crystal sytstem	triclinic	monoclinic
Space group	P-*1*	P$2_1/n$
a (Å)	12.6769(2)	11.5457(2)
b (Å)	12.8446(2)	24.1928(5)
c (Å)	14.6153(3)	17.0958(3)
α (°)	91.3430(10)	90.00
β (°)	94.0610(10)	96.0980(10)
γ (°)	106.2170(10)	90.00
V (Å^3)	2277.05(7)	4748.23(15)
Z	2	4
F (000)	828	1720
Dc (mgm^{-3})	1.113	1.107
μ (mm^{-1})	0.071	0.070
Data collection		
Temperature (K)	93(2)	133(2)
No. of collected reflections	55737	43813
Within the θ limit (°)	1.4-30.4	1.68-27.1
Index ranges ±*h*, ±*k*, ±*l*	-18/18, -18/18, -20/20	-11/14, -31/30, -21/21
No. of unique reflections	13742	10457
No. of refined parameters	522	540
No. of *F* values used *[I*> 2σ *(I)]*	11351	6925
Final *R* indices		
R(= $\Sigma\mid \Delta F\mid/\Sigma\mid F_0\mid$)	0.0395	0.0581
wR on F^2	0.1304	0.1674
S (=Goodness of fit on F^2)	1.081	0.941
Final $\Delta\rho$max/$\Delta\rho$min (eÅ^{-3})	0.000	0.000

S6 Selected conformational parameters of the acid **1** and the calixarene esters **2** and **4** and their calculated packing index (KPI)

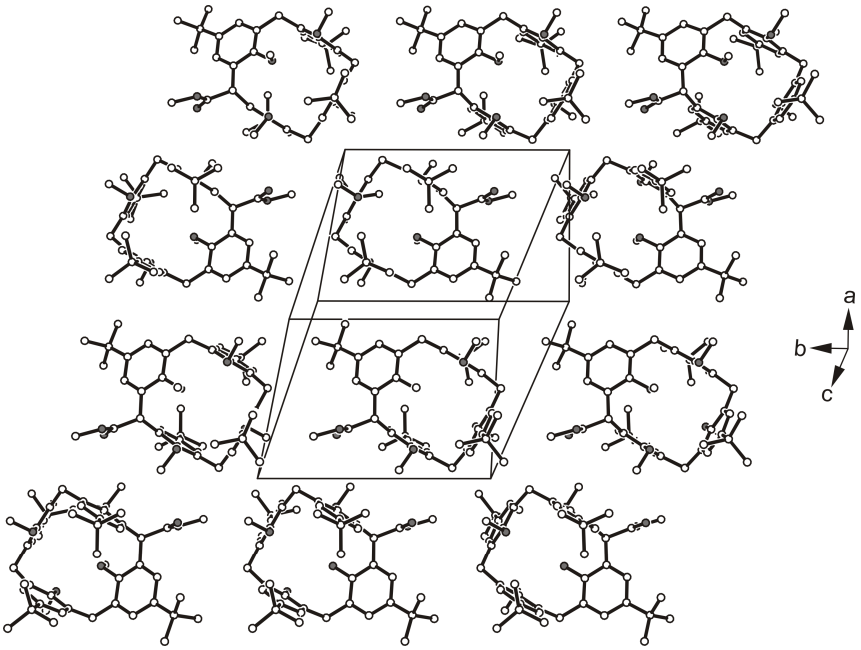
Compound	**1**	**2**	**4**
Interplanar angles (°)[a]			
mpla[b]/A	28.8(1)	85.2(1)	39.1(1)
mpla/B	86.0(1)	35.1(1)	88.8(1)
mpla/C	51.6(1)	86.4(1)	36.7(1)
mpla/D	74.2(1)	88.6(1)	88.5(1)
A/C	80.1(1)	1.4(1)	75.7(1)
B/D	19.8(1)	54.1(1)	0.6(1)
mpla/mplb[c]		81.4(1)	70.4(1)
KPI	63.7	64.1	64.1

[a] Aromatic rings: ring A: C(1)…C(6); ring B: C(8)…C(13); ring C: C(15)…C(20); ring D: C(22) …C(27);
[b] Best plane through atoms C(7), C(14), C(21) and C(28).
[c] Best plane through atoms O(5), C(49), O(6) and C(50)

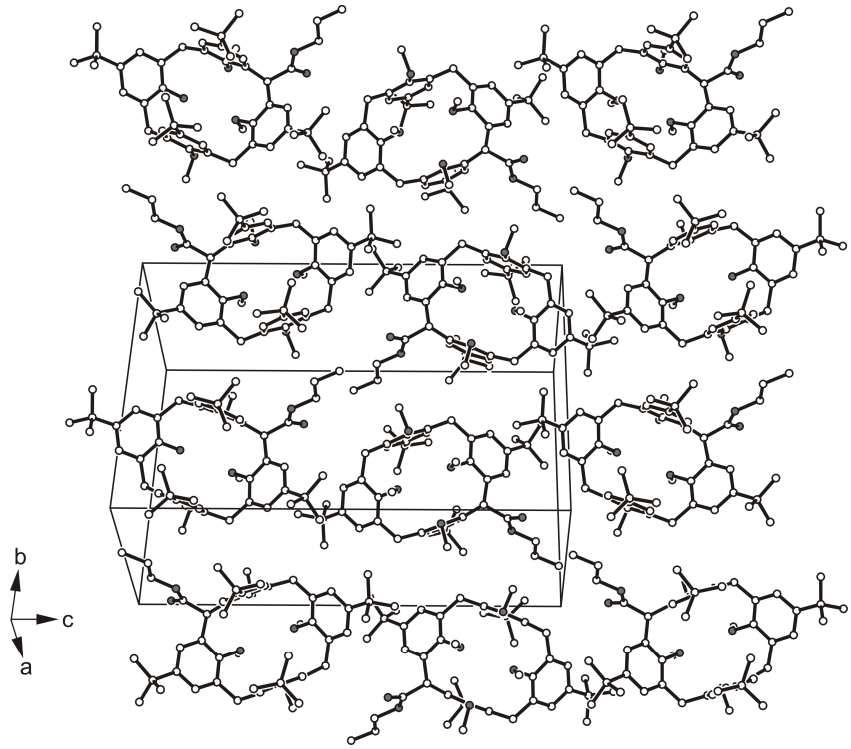
S7 Distances (Å) and angles (°) of hydrogen bond type interations of calixarenes **2** and **4.**

calixarene	Symmetry	Distances (Å)			Angle(°)
		D···H	D···A	H···A	D-H···A
2					
C(43)-H(43C)···O(5)	1-x,-y,-z	0.98	3.4996(1)	2.53	169
C(46)-H(46B)···centroid(B)[a]	1-x,1-y,-z		3.7574(4)	2.96	139
4					
C(51)-(H51)···centroid(D)[a]	-0.5+x, 0.5-y, -0.5+z		3.7003(5)	2.75	161

[a] Centroid means the centre of gravity of the respective aromatic ring, such as ring A: C1…C6; ring B: C8…C13; ring C: C15…C20; ring D: C22…C27.

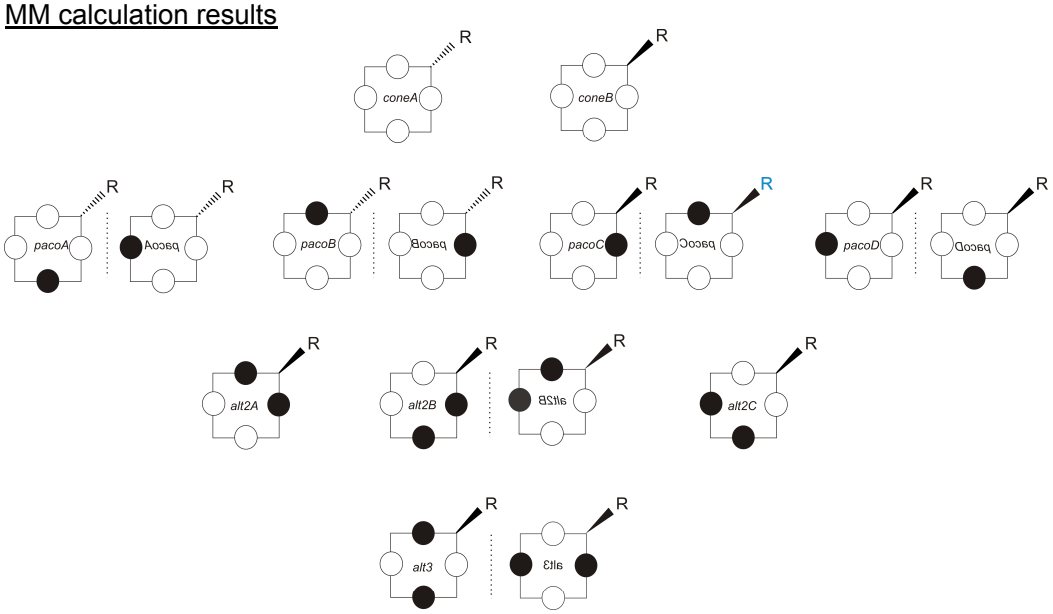


S8 Packing motif of **2** reflecting the cartoon of the *(0,1,-1)* plane**.** H-Atoms are omitted for clarity.



S9 Packing motif of **4** reflecting the cartoon of the (*1,0,-1)* plane**.** H-Atoms are omitted for clarity.

MM calculation results



S10 Possible conformers of calixarenes **1**-**7**. The filled and unfilled circles represent an ‘up’ or ‘down’ orientation of the methoxy groups, respectively. Mirror images are separated by a broken line and indicated by inverted letters.

S11 Gas phase energies (in kcal mol) for the possible conformers of compounds **1**-**7** relative to their respective lowest energy conformer (highlighted yellow)

	1	**2**	**3**	**4**	**5**	**7**
cone A	5.79	6.07	6.07	6.44	5.31	4.97
cone B	0.02	0.02	0.01	0.00	0.03	0.00
paco A	5.40	5.80	5.78	6.15	5.47	6.22
paco B	1.87	1.86	1.82	2.13	1.64	1.60
paco C	1.63	1.63	1.61	1.92	1.71	1.46
paco D	0.00	0.00	0.00	0.19	0.00	0.11
alt2A	10.43	11.60	11.55	11.83	10.60	13.13
alt2B	5.66	3.91	6.42	6.48	6.52	8.26
alt2C	3.87	3.91	3.92	3.83	3.82	3.72
alt3	1.44	1.45	1.43	1.51	1.83	1.45

S12 Cartesian coordinates of the lowest energy conformer structures of compounds **2** and **4**, as received from the MM calculations

Compound	atom-type	x_{CAL}	y_{CAL}	z_{CAL}
2				
C1	C.ar	0.5581	1.2381	8.8755
C2	C.ar	-0.3222	2.2269	8.8755
C3	C.ar	-1.1592	1.9232	7.3205
C4	C.ar	-1.1000	0.6900	6.6464
C5	C.ar	-0.1661	-0.2501	7.1107
C6	C.ar	0.6829	0.0114	8.2047
C7	C.3	1.7357	-1.0161	8.5770
C8	C.ar	3.8002	-0.1659	7.3265
C9	C.ar	2.8274	-1.1585	7.5317
C10	C.ar	2.8150	-2.2800	6.6825
C11	C.ar	3.7116	-2.4123	5.6111
C12	C.ar	4.6242	-1.3604	5.3980
C13	C.ar	4.6834	-0.2281	6.2323
C14	C.3	5.5779	0.9677	5.8791
C15	C.ar	4.5787	3.3294	5.8105
C16	C.ar	4.7610	2.0747	5.2074
C17	C.ar	4.0899	1.8139	3.9975
C18	C.ar	3.1908	2.7282	3.4186
C19	C.ar	2.9854	3.9416	4.0941
C20	C.ar	3.6525	4.2514	5.2942
C21	C.3	3.3135	5.5452	6.0119
C22	C.ar	1.4027	4.7504	7.5203
C23	C.ar	2.6652	5.3448	7.3685
C24	C.ar	3.3775	5.7115	8.5236
C25	C.ar	2.8937	5.4563	9.8206
C26	C.ar	1.6594	4.7964	9.9268
C27	C.ar	0.9128	4.4179	8.7947
C28	C.3	-0.3647	3.6238	8.9959
C29	C.3	-2.0232	0.4216	5.4456
C30	C.3	-1.9245	1.5728	4.4182

C31	C.3	-3.4783	0.3179	5.9471
C32	C.3	-1.6949	-0.8846	4.6870
C33	C.3	0.7384	1.0824	11.1636
C34	C.3	3.3000	-3.1321	3.2366
C35	C.3	3.6876	-3.6145	4.6512
C36	C.3	5.0831	-4.2749	4.6003
C37	C.3	2.6810	-4.7167	5.0529
C38	C.3	4.6740	0.7477	9.2551
C39	C.3	2.4668	2.3696	2.1096
C40	C.3	3.4979	2.3298	0.9628
C41	C.3	1.7894	0.9842	2.2269
C42	C.3	1.3631	3.3760	1.7128
C43	C.3	6.5145	4.2175	6.6780
C44	C.3	3.7314	5.8560	11.0468
C45	C.3	3.9994	7.3766	11.0230
C46	C.3	5.0785	5.1014	11.0195
C47	C.3	3.0552	5.5355	12.3993
C48	C.3	-0.1913	5.4616	6.0175
C49	C.2	6.8364	0.6088	5.0959
C50	C.3	8.8156	-0.6800	5.1989
H3	H	-1.8579	2.6854	6.9816
H5	H	-0.0648	-1.2117	6.6148
H7A	H	1.2307	-1.9793	8.7321
H7B	H	2.1952	-0.7962	9.5451
H10	H	2.0576	-3.0388	6.8609
H12	H	5.2841	-1.4095	4.5345
H14	H	5.9818	1.3581	6.8205
H17	H	4.2610	0.8577	3.5082
H19	H	2.2797	4.6715	3.7067
H21A	H	2.6516	6.1671	5.3972
H21B	H	4.2321	6.1378	6.1068
H24	H	4.3517	6.1809	8.4006
H26	H	1.2597	4.5370	10.9034
H28A	H	-0.6062	4.5420	10.0628
H28B	H	-1.1983	4.1973	8.5727
H30A	H	-2.3031	2.5209	4.8147
H30B	H	-2.5117	1.3524	3.5189
H30C	H	-0.8870	1.7376	4.1081
H31A	H	-3.5868	-0.4883	6.6823
H31B	H	-4.1678	0.1108	5.1205
H31C	H	-3.8140	1.2449	6.4259
H32A	H	-0.6648	-0.8826	4.3113
H32B	H	-2.3565	-10.167	3.8224
H32C	H	-1.8254	-1.7677	5.3231
H33A	H	-0.2147	1.5957	11.3273
H33B	H	1.4062	1.3371	11.9919
H33C	H	0.5855	-0.0019	11.1726
H35A	H	2.3223	-2.6354	3.2431
H35B	H	3.2429	-3.9721	2.5345
H35C	H	4.0260	-2.4205	2.8281
H36A	H	5.8503	-3.5991	4.2071
H36B	H	5.0780	-5.1603	3.9537
H36C	H	5.4049	-4.5930	5.5991
H37A	H	2.8953	-5.1125	6.0525
H37B	H	2.7205	-5.5613	4.3544
H37C	H	1.6496	-4.3454	5.0456
H38A	H	5.7003	0.5299	8.9418
H38B	H	4.6860	1.6766	9.8325
H38C	H	4.3092	-0.0516	9.9075
H40A	H	4.0030	3.2966	0.8514
H40B	H	3.0172	2.0922	0.0068
H40C	H	4.2725	1.5736	1.1338

H41A	H	1.1951	0.7571	1.3340
H41B	H	1.1206	0.9436	3.0934
H41C	H	2.5154	0.1712	2.3343
H42A	H	1.7730	4.3751	1.5252
H42B	H	0.5980	3.4611	2.4936
H42C	H	0.8556	3.0638	0.7922
H43A	H	7.1757	3.5031	6.1770
H43B	H	6.9792	4.5001	7.6273
H43C	H	6.4093	5.1222	6.0699
H45A	H	4.5828	7.6824	10.1477
H45B	H	4.5636	7.6925	11.9084
H45C	H	3.0601	7.9421	11.0067
H46A	H	4.9223	4.0163	11.0104
H46B	H	5.6849	5.3436	11.9000
H46C	H	5.6780	5.3540	10.1380
H47A	H	2.0936	6.0519	12.5014
H47B	H	3.6835	5.8532	13.2402
H47C	H	2.8805	4.4599	12.5192
H48A	H	-0.9347	5.6702	6.7932
H48B	H	-0.7236	5.1418	5.1167
H48C	H	0.3623	6.3749	5.7769
H50A	H	8.5996	-1.1974	4.2592
H50B	H	9.3233	-1.3758	5.8721
H50C	H	9.4692	0.1805	5.0266
O1	O.3	1.3643	1.5111	9.9534
O2	O.3	3.8095	0.9439	8.1356
O3	O.3	5.2458	3.6310	6.9731
O4	O.3	0.6840	4.4020	6.4033
O5	O.2	7.1380	1.0483	3.9934
O6	O.3	7.6003	-0.2621	5.8260

4

C1	C.ar	6.7134	-2.8490	6.7444
C2	C.ar	8.0761	-3.1557	6.6260
C3	C.ar	8.4554	-4.4841	6.4053
C4	C.ar	7.5153	-5.5194	6.3179
C5	C.ar	6.1645	-5.1859	6.4770
C6	C.ar	5.7501	-3.8671	6.6979
C7	C.3	9.1427	-2.0993	6.8238
C8	C.ar	3.756	-2.0046	8.9128
C9	C.ar	4.0666	-3.2870	8.4417
C10	C.ar	4.2635	-4.3227	9.3623
C11	C.ar	4.1777	-4.1113	10.7427
C12	C.ar	3.8999	-2.8115	11.1812
C13	C.ar	3.6909	-1.7510	10.2912
C14	C.3	3.5171	-0.3463	10.8425
C15	C.ar	5.9129	0.4740	10.9174
C16	C.ar	4.7607	0.0691	11.6090
C17	C.ar	4.8237	-0.0790	13.0001
C18	C.ar	6.0020	0.1614	13.7174
C19	C.ar	7.1416	0.5332	12.9923
C20	C.ar	7.1182	0.6806	11.6015
C21	C.3	8.4075	0.9591	10.8585
C22	C.ar	8.8854	-0.5228	8.8248
C23	C.ar	8.9435	-0.2990	10.2083
C24	C.ar	9.4567	-1.3032	11.0384
C25	C.ar	9.9038	-2.5286	10.5306
C26	C.ar	9.8103	-2.7290	9.1482
C27	C.ar	9.2964	-1.7517	8.2891
C28	C.3	4.2880	-3.5849	6.9743

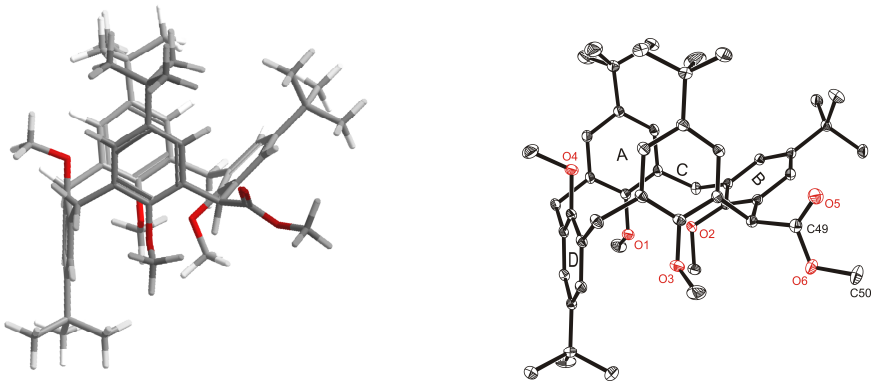
C29	C.3	7.9921	-6.9508	6.1010
C30	C.3	8.9163	-7.3746	7.2656
C31	C.3	8.7715	-7.0490	4.7703
C32	C.3	6.8390	-7.9785	6.0346
C33	C.3	6.0582	-0.7995	5.8026
C34	C.3	4.4352	-5.2144	11.7630
C35	C.3	5.4492	-4.7456	12.8342
C36	C.3	5.0127	-6.5030	11.1324
C37	C.3	3.1050	-5.5817	12.4552
C38	C.3	2.2118	-0.7834	7.6372
C39	C.3	6.0974	-0.0164	15.2283
C40	C.3	4.7675	-0.4608	15.8796
C41	C.3	7.1517	-1.0969	15.5622
C42	C.3	6.5091	1.3191	15.8872
C43	C.3	5.5500	1.8949	9.0818
C44	C.3	10.4329	-3.6479	11.4198
C45	C.3	10.3025	-3.3410	12.9297
C46	C.3	9.6535	-4.9581	11.1564
C47	C.3	11.9291	-3.8800	11.1156
C48	C.3	9.3608	1.3422	7.4840
C49	C.2	2.2169	-0.1293	11.6189
C50	C.3	0.3916	-1.1090	12.8324
C51	C.3	0.2263	-2.3456	13.7162
C52	C.3	1.3191	-2.4640	14.7873
H3	H	9.5283	-4.7178	6.3204
H5	H	5.3969	-5.9737	6.4526
H7A	H	3.6611	-4.4578	6.6842
H7B	H	3.9390	-2.7493	6.3323
H10	H	4.5152	-5.3201	8.9724
H12	H	3.8621	-2.6078	12.2615
H14	H	3.4330	0.3481	9.9765
H17	H	3.9229	-0.4173	13.5318
H19	H	8.0940	0.6913	13.5224
H21A	H	9.1755	1.3617	11.5567
H21B	H	8.2472	1.7634	10.1109
H24	H	9.4864	-1.1130	12.1215
H26	H	10.1316	-3.6896	8.7165
H28A	H	8.999	-1.2011	6.2172
H28B	H	10.1209	-2.4594	6.4330
H30A	H	9.8335	-6.7497	7.3313
H30B	H	9.2564	-8.4284	7.1576
H30C	H	8.3968	-7.2974	8.2471
H31A	H	8.1442	-6.7349	3.9063
H31B	H	9.1095	-8.0896	4.5679
H31C	H	9.6825	-6.4116	4.7627
H32A	H	6.2510	-8.0105	6.9789
H32B	H	7.2216	-9.0099	5.8674
H32C	H	6.1349	-7.7640	5.1999
H33A	H	6.9572	-0.7285	5.1563
H33B	H	5.7578	0.2277	6.0946
H33C	H	5.2312	-1.2504	5.2163
H35A	H	6.3971	-4.3910	12.3719
H35B	H	5.7161	-5.5680	13.5344
H35C	H	5.0604	-3.9163	13.4636
H36A	H	4.3075	-6.9731	10.4118
H36B	H	5.2276	-7.2743	11.9051
H36C	H	5.9705	-6.3117	10.5982
H37A	H	2.6587	-4.7146	12.9894
H37B	H	3.2414	-6.3901	13.2074
H37C	H	2.3475	-5.9388	11.7223
H38a	H	1.7999	-1.6904	7.1468
H38B	H	2.1608	0.0586	6.9159

H38C	H	1.5832	-0.5299	8.5165
H40A	H	4.4238	-1.4473	15.4966
H40B	H	4.8702	-0.5704	16.9822
H40C	H	3.9507	0.2760	15.7108
H41A	H	7.2196	-1.2797	16.6576
H41B	H	8.1728	-0.8166	15.2233
H41C	H	6.9036	-2.0705	15.0830
H42A	H	5.7799	2.1282	15.6586
H42B	H	7.5069	1.6713	15.5459
H42C	H	6.5637	1.2312	16.9950
H43A	H	4.5526	2.2155	9.4472
H43B	H	5.5270	1.8831	7.9726
H43C	H	6.3046	2.6407	9.4060
H45A	H	10.8939	-2.4478	13.2303
H45B	H	10.6746	-4.1858	13.5511
H45C	H	9.2448	-3.1680	13.2304
H46A	H	8.5601	-4.8202	11.3090
H46B	H	9.9779	-5.7734	11.8404
H46C	H	9.7937	-5.3419	10.1228
H47A	H	12.1018	-4.1828	10.0594
H47B	H	12.3592	-4.6825	11.7552
H47C	H	12.5296	-2.9603	11.2950
H48A	H	9.8726	1.8864	8.3052
H48B	H	8.8599	2.0859	6.8300
H48C	H	10.1199	0.8009	6.8814
H50A	H	-0.4676	-1.0203	12.1322
H50B	H	0.4100	-0.1959	13.4658
H51A	H	0.2258	-3.2620	13.0813
H51B	H	-0.7693	-2.3070	14.2169
H52A	H	1.3295	-1.5779	15.4605
H52B	H	2.3317	-2.5504	14.3354
H52C	H	1.1661	-3.3630	15.4254
O1	O.3	6.3287	-1.5609	6.9716
O2	O.3	3.5631	-0.9887	8.0227
O3	O.3	5.8774	0.5966	9.5594
O4	O.3	8.3895	0.4439	8.0006
O5	O.2	1.7545	0.9776	11.7879
O6	O.3	1.5947	-1.2365	12.0814

S13 Fit of the calculated energies (MMFF94) of the lowest energy conformer of compounds **2** and **4** compared to the current energy of the molecules in the obtained crystal structures (kJ mol^{-1})

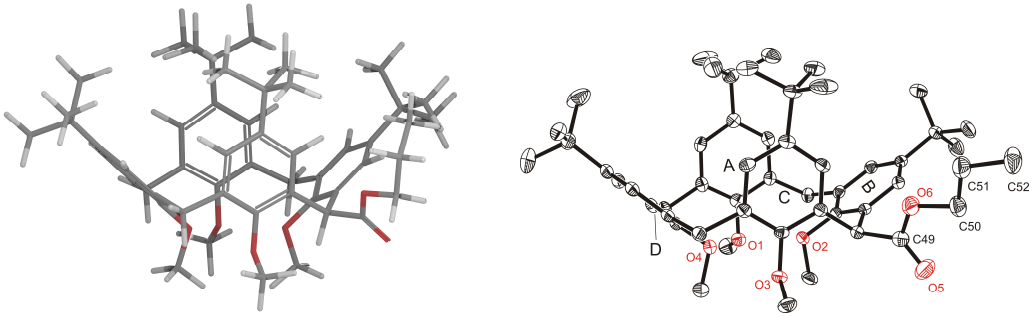
	MMFF94	X-ray	Fit
2	981.4565	981.4557	0.9999
4	1030.5874	1015.3318	0.9852

calixarene **2**



(a) (b)

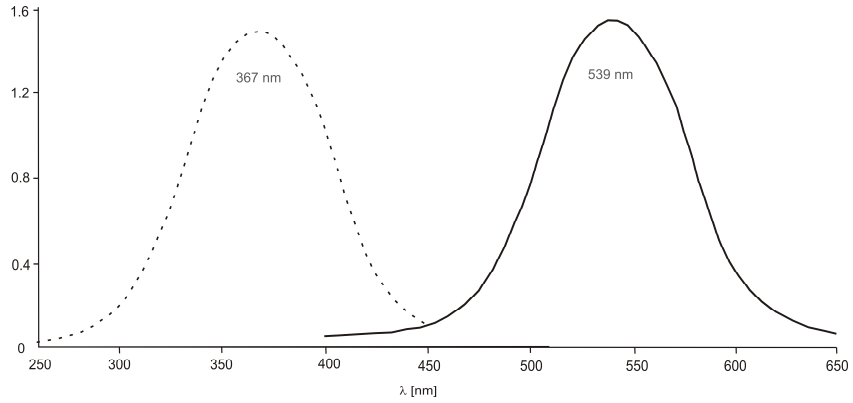
calixarene **4**



(a) (b)

S14 Comparison of calculated (a) and X-ray structures (b) of calixarenes **2** and **4**.

Excitation and Emission spectra for compound **7**



S15 Corrected excitation (left) and emission spectra (right) of calixarene **7** (35 μmol L^{-1}) in acetonitrile solution.

Experimental details

S16

General

Melting points were determined on a microscope heating stage PHMK Rapido (VEB Dresden Analytik) and are uncorrected. IR spectra were measured on a Nicolet FT-IR 510 as KBr pellets (Table S17). Analytical TLC was carried out on precoated silica gel plates (Merck, 60 F_{254}), and for column chromatography silica gel (Merck, particle size 0.040-0.063 mm, 230-240 mesh) was used. Corrected excitation and emission spectra were obtained on a Perkin-Elmer LS 50 B fluorescence spectrometer. NMR spectra were recorded on a Bruker Avance DRX 500 spectrometer at 500.1 MHz (^{1}H NMR) and 125.7 MHz (^{13}C NMR), respectively, in $CDCl_3$ solution. Chemical shifts δ are reported in ppm relative to the internal reference TMS. Mass spectra were measured on an Applied Biosystems (Applera) Mariner ESI-TOF or in case of APCI technique on a Varian 320 MS. Elemental analyses were perfomed on a Heraeus CHN-Rapid Analyzer. Reagents and chemicals for the synthesis were used as purchased from chemical suppliers. The solvents used were purified or dried according to common literature procedures.[1]

The laterally monocarboxylated calix[4]arene **1** was prepared from commercially available 5,11,17,23-tetra-tert-butyl-25,26,27,28-tetrahydroxy-calix[4]aren[2] according to the published procedure.[3]

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[1] B. A. Furniss, A. J. Hannaford, P.W. G. Smith and A. R. Tatchell, *Vogel's Textbook of Practical Organic Chemistry*, Prentice Hall, Upper Saddle River, 5th ed., 1989.
[2] C. D. Gutsche, M. Iqbal and D. Steward, *J. Org. Chem.*, 1986, **51**, 742-745.
[3] P. A. Scully, T. M. Hamilton and J. L. Bennett, *Org. Lett.*, 2001, **3**, 2741.

compound	IR(KBr, cm^{-1})
2	2958, 2930, 2863, 2822, 1739, 1603, 1581, 1480, 1461, 1429, 1391, 1359, 1334, 1302, 1280, 1252, 1211, 1173, 1150, 1122, 1021, 976, 951, 872, 812, 799, 723, 669
3	2958, 2929, 2864, 2822, 1733, 1603, 1580, 1481, 1461, 1430, 1391, 1358, 1331, 1300, 1281, 1242, 1208, 1173, 1151, 1120, 1022, 975, 950, 872, 812, 799, 723, 656
4	2958, 2927, 2866, 2822, 1720, 1603, 1581, 1483, 1464, 1432, 1391, 1359, 1299, 1280, 1245, 1233, 1207, 1173, 1150, 1119, 1062, 1024, 973, 948, 872, 812, 799, 720, 641
5	3459, 2958, 2901, 2870, 2819, 1600, 1581, 1483, 1461, 1429, 1394, 1359, 1287, 1245, 1207, 1173, 1122, 1081, 1021, 948, 869, 812, 799, 644
6	2958, 2901, 2870, 2828, 1606, 1581, 1483, 1461, 1435, 1391, 1359, 1299, 1245, 1207, 1182, 1122, 1008, 941, 869, 808, 799, 644
7	2952, 2867, 2821, 1577, 1480, 1462, 1361, 1244, 1202, 1173, 1118, 1019, 952, 880, 789, 731, 628, 574
8	3045, 2961, 2901, 2870, 2822, 1805, 1625, 1483, 1464, 1362, 1306, 1204, 1121, 1083, 1019, 872