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Supporting Information

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Anion-Binding to Simple Resorcinarene-Based Cavitands: The Importance of C–H•••Anion Interactions

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1. Experimental Details for the Mass Spectrometric Experiments

High resolution ESI mass spectra and MS/MS spectra were recorded on a Bruker APEX IV Fourier-transform ion-cyclotron-resonance (FT-ICR) mass spectrometer with an Apollo electrospray ion source equipped with an off-axis 70° spray needle. Typically, acetone or a mixture of acetone and methanol (e.g. 40:7 or 40:1) served as the spray solvent. The solutions were 200 to 780 μM with respect to the concentration of the hosts. In case of anionic guests (sulfate, indigo carmine) which are insoluble in pure acetone, high concentration solutions (160 mM for sulfate, 16 mM for indigo carmine) were prepared in pure methanol and then added in very small amounts to the acetone solutions of hosts. Analyte solutions were introduced into the ion source with a syringe pump (Cole-Parmers Instruments, Series 74900) at flow rates of ca. 3 - 7 μL/min. Ion transfer into the first of three differential pumping stages in the ion source occurred through a glass capillary with 0.5 mm inner diameter and nickel coatings at both ends. Ionization parameters were adjusted as follows: capillary voltage: 4.5 kV; endplate voltage: 4.0 kV; capexit voltage: -30 to -400 V; skimmer voltages: -10 to -20 V; temperature of drying gas: 150-200 °C. The flows of the drying (ca. 15 psi) and nebulizer gases (ca. 30 psi) were kept in a medium range. Depending on the achievable abundances of ions produced in the ion source, the ions were accumulated in the instrument's hexapole for 0.7 – 10.0 s. The ions are then introduced into the FT-ICR cell, which was operated at pressures below 10^{-10} mbar, and finally detected by a standard excitation and detection sequence. For each measurement 4 to 120 scans were averaged to improve the signal-to-noise ratio.

For MS/MS experiments, the whole isotope patterns of the ion of interest were isolated by applying correlated sweeps, followed by high resolution isolation shots to remove the higher isotopes (in case of $[\mathbf{14}@\mathbf{5_1 6_1}]^{2-}$: higher isotopes were not removed by isolation shots; in case of $[\mathbf{14}@\mathbf{5_1 7_1}]^{2-}$: all isotopes were removed except for *m/z* 1234.3 and *m/z* 1234.8). After isolation, argon was introduced into the ICR cell as the collision gas through a pulsed valve at a pressure of ca. 10^{-8} mbar. The ions were accelerated by a standard excitation protocol and detected after a 2 s pumping delay. A sequence of several different spectra was recorded at different excitation pulse attenuations in order to get at least a rough and qualitative idea of the effects of different collision energies on the fragmentation patterns. Typical parameter settings for the CID experiments with heterodimer complexes are:

<u>Parameters of the Apollo ESI source</u>:

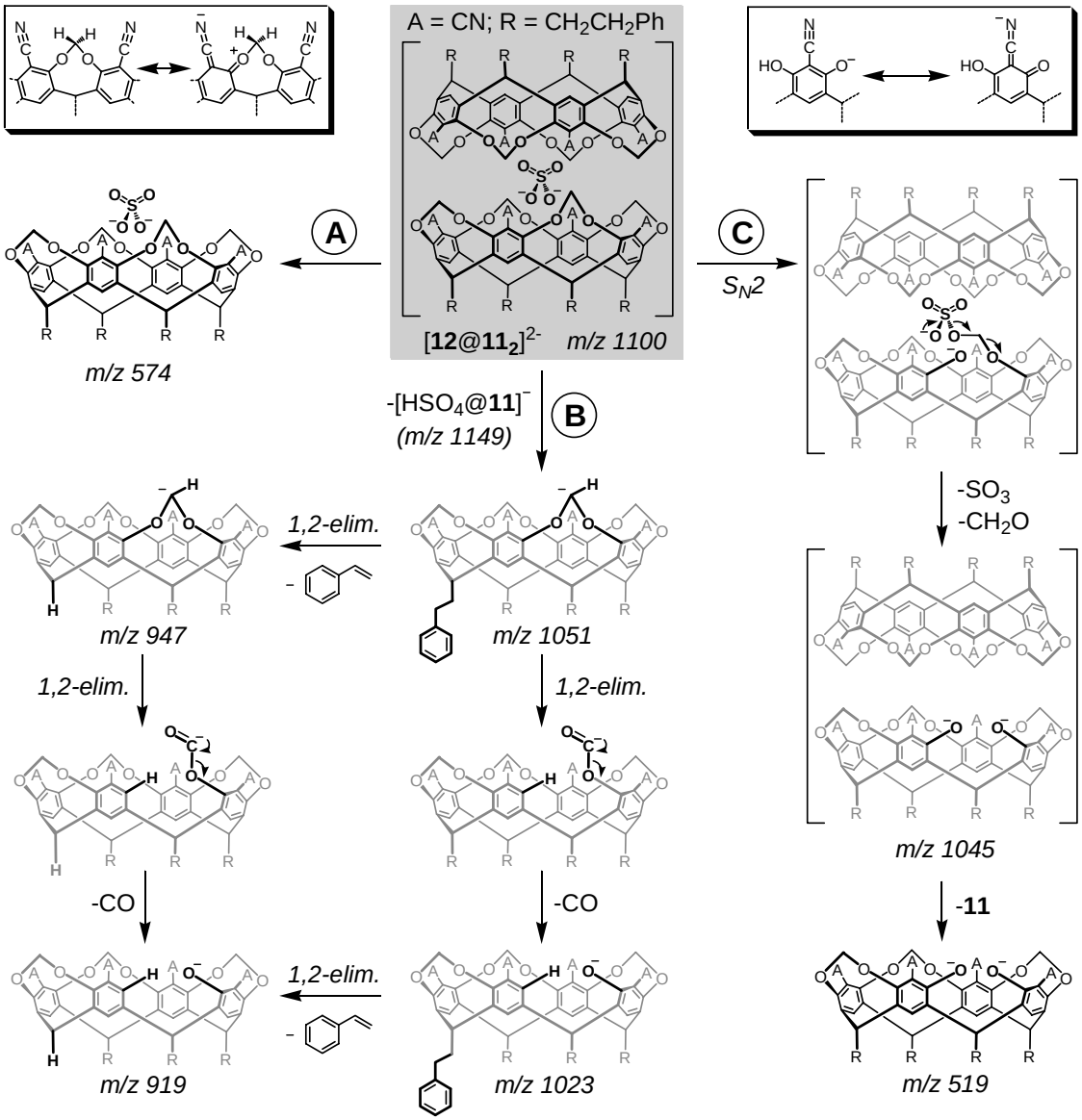
nebulizing gas: 30 psi, drying gas: 15 psi, drying gas temperature: 200°C, vacuum lens voltages: capillary 4.5 kV, end plate 4 kV, capexit -340 V, 1st skimmer -20 V, 2nd skimmer -10 V, offset -1.5 V, RF amplitude 500 V, trap -15 V, extract 15 V

Ion transfer and cell parameters of APEX IV FTICR mass spectrometer

beam steering parameter XDFL: -20 V, beam steering parameter YDFL: 0 V, voltage gradient at the cell entrance (DEV2): -3.02 V, attenuation level of excitation (excite / PL3): 3.6 dB

MSMS parameters of APEX IV FTICR mass spectrometer

attenuation level of correlated sweep (CorrSweep / PL4): 17.3 dB, attenuation level of correlated shots (CorrShot / PL7): 45.3 dB, attenuation level of ion activation (activation / PL9): 60.8 dB, collision gas: Argon 4.6, pulsed valve opening duration: 0.02 sec, pumping delay: 2 sec



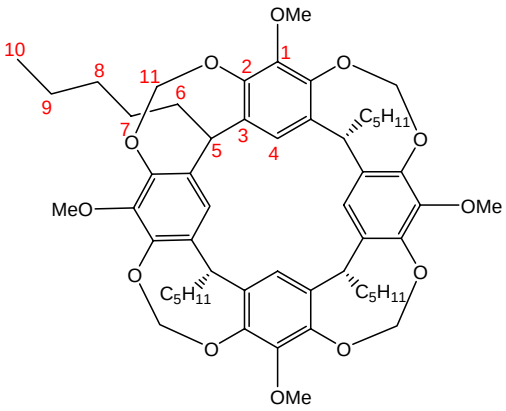
Scheme S1. Fragmentation pathways (**A**, **B**, **C**) of $[\mathbf{12}@\mathbf{11}_2]^{2-}$ as observed in the CID mass spectra. The insets show the effect of electron-withdrawing substituents such as nitrile on the acetal C-H polarization and the phenolate leaving group properties

Scheme S1 shows the gas-phase fragmentations of $[\mathbf{12}@\mathbf{11}_2]^{2-}$ as observed in the corresponding CID mass spectra (Figure 2b, main text). In these MS/MS experiments, ions corresponding to the second peak from the isotope pattern were mass-selected, which contain one ^{13}C atom. Charge-separating fragmentations preferentially lead to fragments approximately half the size of the parent ion (e.g. monomer loss from a dimer). Consequently, the ^{13}C atom can be incorporated either in the neutral or in the ionic fragment so that two product signals are observed with a peak spacing of 1 amu. Fragmentation into a product dianion and small neutral fragment (e.g. loss of SO_3 and CH_2=O) leaves almost all carbons within the ionic product, which then only appears as one, non-split signal. This approach permits to directly determine whether a fragment is singly or doubly charged and thus facilitates interpretation of the MS/MS experiments.

2. Synthesis of cavitands

General. Chemicals and dry DMF were purchased from Sigma-Aldrich, Fluka, Merck and used as received. The solvents (except DMF) were dried using standard techniques. Thin-layer chromatography (TLC) was carried out on TLC plates pre-coated with silica gel 60 F_{254} from Merck. Melting points were determined on hot stage (Mikroskop-Heiztisch) SM-Lux from Leitz. Mass spectra were recorded using Bruker APEX IV Fourier-transform ion-cyclotron-resonance (FT-ICR) mass spectrometer with an Apollo electrospray ion source equipped with an off-axis 70° spray needle. ^{1}H NMR and ^{13}C NMR spectra were recorded using 300, 400, and 500 MHz Bruker instruments.

a) 7,11,17,23-Tetramethoxy-1,21,23,25-tetrapentyl-2,20:3,19-di-metheno-1*H*,21*H*,23*H*,25*H*-bis[1,3]dioxocino[5,4-i:5´,4´-i´]benzo[1,2-d:5,4d´]bis[1,3]-benzodioxocine (**3**):

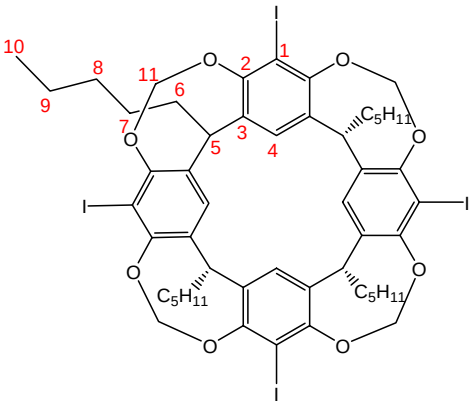


500 mg (0.61 mmol) unfunctionalized cavitand **2** was dissolved in 10 mL dry THF under argon. The solvent was then removed in vacuo. This procedure was repeated once more. **2** was again dissolved in 5 mL dry THF and cooled down to -78 °C. At this temperature, 4.08 mL (6.12 mmol, 10 eq.) *s*-BuLi was slowly added through a syringe and stirred for 30 min at -78 °C. 0.69 ml (6.12 mmol, 10 eq.) trimethylborate was then added, the reaction mixture was allowed to warm up to RT and stirred for 1 h. Upon addition of a 1:1-mixture of 4 ml 3 N sodium hydroxide solution and 4 ml hydrogen peroxide solution (35%), the mixture was stirred for 18 h at RT. Sodium sulfite solution (10%) was added, the organic layer was separated and the aqueous layer was extracted using ethyl acetate. The combined organic layers were washed with sodium bicarbonate solution, water and brine, dried over magnesium sulfate and concentrated in vacuo. 520 mg (3.66 mmol, 6 eq.) iodomethane and 674 mg (4.88 mmol, 8 eq.) potassium carbonate was added to the crude. Upon addition of 15 mL acetone, the mixture was refluxed and concentrated in vacuo after the reaction was complete. The residue was taken up in ethyl acetate, washed with water (several times) and brine (1x), dried over sodium sulfate and concentrated in vacuo. After purification by column chromatography

on silica gel (eluent: *n*-hexane/ethyl acetate = 5:1), the product was obtained as a colourless solid in 52% yield (298 mg); m. p. > 300°C; R_f = 0.26 (*n*-hexane/ethyl acetate = 5:1); ^{1}H NMR (500.1 MHz, $CDCl_3$, 25°C): δ = 0.91 (t, ^3J (H-9,H-10) = 7.1 Hz, 12H; H-10); 1.32-1.43 (m, 24H; H-7 to H-9), 2.13-2.19 (m, 8H; H-6), 3.76 (s, 12H; -OC$\underline{H}_3$), 4.36 (d, ^2J (H-11^{inside},H-11^{outside}) = -7.1 Hz, 4H; H-11^{inside}), 4.70 (t, ^3J (H-5,H-6) = 8.1 Hz, 4H; H-5), 5.84 (d, ^2J (H-11^{inside},H-11^{outside}) = -7.1 Hz, 4H; H-11^{outside}), 6.78 (s, 4H; H-4); ^{13}C NMR (125.8 MHz, $CDCl_3$, 25°C): δ = 14.2 (C-10), 22.7 (C-9), 27.6 (C-8), 29.9 (C-6), 32.1 (C-7), 37.0 (C-5), 61.1 (-O$\underline{C}H_3$), 99.7 (C-11), 114.1 (C-4), 139.0 (C-3), 145.3 (C-1), 148.2 (C-2); ESI-FTICR-MS (negative mode, sprayed from acetone, 1 eq. Bu_4NCl added): *m/z* = 971 ([M+Cl]$^-$, 100%).

References: For the borylation and hydroxylation we adapted a protocol reported by J. L. Irwin, M. S. Sherburn, *J. Org. Chem.* **2000**, *65*, 5846-5848. Methylation was performed according to a standard protecting procedure, see T. G. Greene, P. G. M. Wuts, *Protective Groups in Organic Synthesis*, 3 ed., Wiley & Sons, **1999**.

b) 7,11,17,23-Tetraiodo-1,21,23,25-tetrapentyl-2,20:3,19-di-metheno-1*H*,21*H*,23*H*,25*H*-bis[1,3]dioxocino[5,4-i:5´,4´-i´]benzo[1,2-d:5,4d´]bis[1,3]-benzodioxocine (**6**):

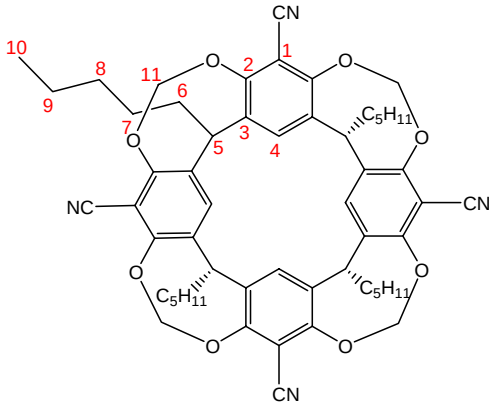


400 mg (0.35 mmol) tetrabromocavitand **5** were dissolved in 5 mL dry THF under argon. The solvent was then removed in vacuo. This procedure was repeated once more. **5** was again dissolved in in 5 mL dry THF and cooled down to -78 °C. 1.41 mL (2.12 mmol, 6 eq.) *n*-BuLi (1.5 M in *n*-hexane) was added, and the mixture was stirred for 0.5 h at this temperature. 717 mg (2.83 mmol, 8 eq.) iodine were dissolved in 5 mL dry THF and slowly dropped into the reaction mixture at -78 °C. The cooling bath was removed, and the mixture was stirred for 1 h at RT. 20 mL dichloromethane was then added. The organic layer was washed with saturated aqueous sodium thiosulfate solution, water (2x), brine (1x), dried over sodium sulfate and concentrated in vacuo. After purification by column chromatography on silica gel (eluent: *n*-

hexane/ethyl acetate = 5:1), the product was obtained as a colourless solid in 42% yield (194 mg); m. p. > 300°C; R_f = 0.93 (*n*-hexane/ethyl acetate = 5:1); ^{1}H NMR (300.1 MHz, $CDCl_3$, 25°C): δ = 0.90 (t, ^3J (H-9,H-10) = 7.1 Hz, 12H; H-10); 1.27-1.46 (m, 24H; H-7 to H-9), 2.15-2.22 (m, 8H; H-6), 4.31 (d, ^2J (H-11^{inside},H-11^{outside}) = -7.1 Hz, 4H; H-11^{inside}), 4.84 (t, ^3J (H-5,H-6) = 8.1 Hz, 4H; H-5), 5.96 (d, ^2J (H-11^{inside},H-11^{outside}) = -7.1 Hz, 4H; H-11^{outside}), 7.05 (s, 4H; H-4); ^{13}C NMR (75.5 MHz, $CDCl_3$, 25°C): δ = 14.1 (C-10), 22.7 (C-9), 27.5 (C-8), 30.1 (C-6), 31.9 (C-7), 38.0 (C-5), 93.1 (C-1), 98.8 (C-11), 120.7 (C-4), 138.8 (C-3), 154.9 (C-2); ESI-FTICR-MS (negative mode, sprayed from acetone, 1 eq. Bu_4NCl added): *m/z* = 1355 ([M+Cl]$^-$, 100%).

Reference: We adapted a procedure used for the synthesis of mono-functionalized cavitands that we reported earlier; O. Hass, A. Schierholt, M. Jordan, A. Lützen, *Synthesis* **2006**, 519-527.

c) 7,11,17,23-Tetracyano-1,21,23,25-tetrapentyl-2,20:3,19-di-metheno-1*H*,21*H*,23*H*,25*H*-bis[1,3]dioxocino[5,4-i:5´,4´-i´]benzo[1,2-d:5,4d´]bis[1,3]-benzodioxocine (**7**):



150 mg (0.11 mmol) tetraiodocavitand **6**, 96 mg (0.82 mmol, 7.2 eq.) zinc(II) cyanide, 2.4 mg (0.036 mmol, 32 mol%) zinc and 12 mg (0.023 mmol, 20 mol%) [Pd(P^{t}Bu$_3$)$_2$] were put in a Schlenk flask which was then evacuated and flushed with argon. After dissolving the solid in 5 mL dry DMF, the reaction mixture was stirred at 100°C over night. After cooling down, DMF was removed in vacuo, 5 mL dichloromethane and 5 mL water were added. The mixture was stirred briefly, and the organic layer was separated. The aqueous layer was washed with dichloromethane, the combined organic layers were dried over sodium sulfate and concentrated. After purification by column chromatography on silica gel (eluent: *n*-hexane/ethyl acetate = 5:1), the product was obtained as a colourless solid in 71% yield (72 mg); m. p. > 300°C; R_f = 0.57 (*n*-hexane/ethyl acetate = 5:1); ^{1}H NMR (400.1 MHz, $CDCl_3$,

25°C): δ = 0.90 (t, ^{3}J (H-9,H-10) = 7.1 Hz, 12H; H-10); 1.31-1.41 (m, 24H; H-7 to H-9), 2.19-2.24 (m, 8H; H-6), 4.58 (d, ^{2}J (H-11^{inside},H-11^{outside}) = -7.4 Hz, 4H; H-11^{inside}), 4.80 (t, ^{3}J (H-5,H-6) = 8.1 Hz, 4H; H-5), 6.08 (d, ^{2}J (H-11^{inside},H-11^{outside}) = -7.4 Hz, 4H; H-11^{outside}), 7.28 (s, 4H; H-4); ^{13}C NMR (100.6 MHz, $CDCl_3$, 25°C): δ = 13.0 (C-10), 21.6 (C-9), 26.2 (C-8), 28.1 (C-6), 30.7 (C-7), 35.3 (C-5), 97.8 (C-11), 103.4 (C-1), 111.0 (-CN), 123.7 (C-4), 138.1 (C-3), 155.7 (C-2); ESI-FTICR-MS (negative mode, sprayed from acetone, 1 eq. Bu_4NCl added): *m/z* = 951 ($[M+Cl]^-$, 100%).

Reference: We adapted a procedure for the cyanation of aryl halides described by J. Ramnauth, N. Bhardwaj, P. Renton, S. Rakhit, S. P. Maddaford, *Synlett* **2003**, 2237-2239.

3. Complete Reference for [19] (M. J. Frisch et al., Revision B.02 ed., Gaussian, Inc., Pittsburgh PA, **2003**.)

M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, J. Montgomery, J. A., T. Vreven, K. N. Kudin, J. C. Burant, J. M. Millam, S. S. Iyengar, J. Tomasi, V. Barone, B. Mennucci, M. Cossi, G. Scalmani, N. Rega, G. A. Petersson, H. Nakatsuji, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, M. Klene, X. Li, J. E. Knox, H. P. Hratchian, J. B. Cross, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, P. Y. Ayala, K. Morokuma, G. A. Voth, P. Salvador, J. J. Dannenberg, V. G. Zakrzewski, S. Dapprich, A. D. Daniels, M. C. Strain, O. Farkas, D. K. Malick, A. D. Rabuck, K. Raghavachari, J. B. Foresman, J. V. Ortiz, Q. Cui, A. G. Baboul, S. Clifford, J. Cioslowski, B. B. Stefanov, G. Liu, A. Liashenko, P. Piskorz, I. Komaromi, R. L. Martin, D. J. Fox, T. Keith, M. A. Al-Laham, C. Y. Peng, A. Nanayakkara, M. Challacombe, P. M. W. Gill, B. Johnson, W. Chen, M. W. Wong, C. Gonzalez, J. A. Pople, Revision B.02 ed., Gaussian, Inc., Pittsburgh PA, **2003**.