Cavitand Zn(II)−Porphyrin Capsules with High Affinities for Pyridines and *N*-Methylimidazole

Oskar Middel, Willem Verboom,* and David N. Reinhoudt*

Laboratory of Supramolecular Chemistry and Technology, MESA+ Research Institute, University of Twente, P.O. Box 217, NL-7500 AE Enschede, The Netherlands

smct@ct.utwente.nl

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Covalent cavitand Zn(II)−porphyrins **17**−**20** were prepared via multistep syntheses. These host molecules show moderate to excellent binding affinities to *N*-methylimidazole and pyridine guests. The complexing behavior strongly depends on the spacer's length, number, and rigidity, in addition to the guest size. Cavitand capping and strapping of porphyrins strongly influence the complex formation and result in a 10−700-fold enhancement of the binding strength compared to tetraphenyl Zn(II)−porphyrin.

Introduction

Porphyrins are of biological importance and therefore widely used in supramolecular chemistry in order to mimic porphyrin-containing active sites of proteins and enzymes.[1] Fenced, strapped, and a few capped porphyrins show that a hydrophobic pocket on top of the metal-containing porphyrin platform enhances the coordination of electron-donating ligands to the metal center.[2] The capability of the hydrophobic pocket of the capped, strapped, and fenced Zn(II)-porphyrins to stabilize the axial binding of ligands is commonly studied by comparison with tetraphenylporphyrin(Zn) (TPP(Zn)).[3]

A number of porphyrin-containing receptors has been published in the literature during the past two decades. Different host molecules such as cyclodextrins,[4] crown ethers,[5] and calix[4]arenes[6] have been used to bridge or cap a porphyrin. In addition to the Zn(II)−porphyrin trimer reported by Sanders et al.,[7] there are a few Zn(II)−porphyrin-containing receptors that bind axial guests in organic solvents with an association constant of $>10^6$ M^{-1}. The capped porphyrins reported by Nolte et al.[8] and Uemori et al.[9] show binding of axial guests with an association constant up to 10^7 M^{-1} in $CDCl_3$. As part of our work to build receptors via a combination of simple building blocks,[10] we have reported a calix[4]arene doubly strapped porphyrin.[6] The receptor binds *N*-heterocycles approximately $10-10^3$ times stronger than unsubstituted porphyrins, reflecting the shielding effect of the calix[4]arene moieties; for picoline and *N*-methylimidazole *K* values $>10^6$ M^{-1} in $CDCl_3$ were found. In the literature a few other calix[4]arene−porphyrin assemblies are known. A calix[4]arene was used to cap an Fe(III)−porphyrin resulting in an excellent oxygen carrier in membranes[11] and a calix[4]arene was coupled to a porphyrin using the porphyrin as a fluorescent probe for monitoring the binding of organic guests in the calix[4]arene.[12]

A cavitand has a completely rigidified and defined cavity, and a strong enhancement of the binding properties of the Zn(II)−porphyrin is therefore expected when the cavitand functions as a porphyrin cap. This paper describes the first cavitand-capped and -strapped porphyrins together with a systematic study on the shielding effect of the cavitand related to the number, flexibility, and length of the spacers. This is expressed in a very strong enhancement of the binding of *N*-methylimidazole and pyridine guests compared to the binding to TPP(Zn).

Results and Discussion

Synthesis. The capped and strapped porphyrins were synthesized starting from cavitand tetraamine **1**[13] and diamine **2**,[14] respectively (Scheme 1). Reaction of the amines with either chloroacetyl chloride or 6-bromohexanoic acid chloride gave the corresponding di- (**3**, **4**) and tetraamides (**5**, **6**) in excellent yields (>93%), whereupon the corresponding aldehydes **7**−**10** were prepared via a Williamson ether synthesis by reacting amides **3**−**6** with salicylaldehyde. The dialdehydes **7** and **8** were converted to the corresponding bis(di-2-pyrrolylmethyl) precursors **11** and **12** by adding 10 mol % of trifluoroacetic acid to a solution of **7** and **8** in pyrrole, respectively.

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(11) Kobayashi, N.; Mizuno, K.; Osa, T. *Inorg. Chim. Acta* **1994**, *224*, 1.
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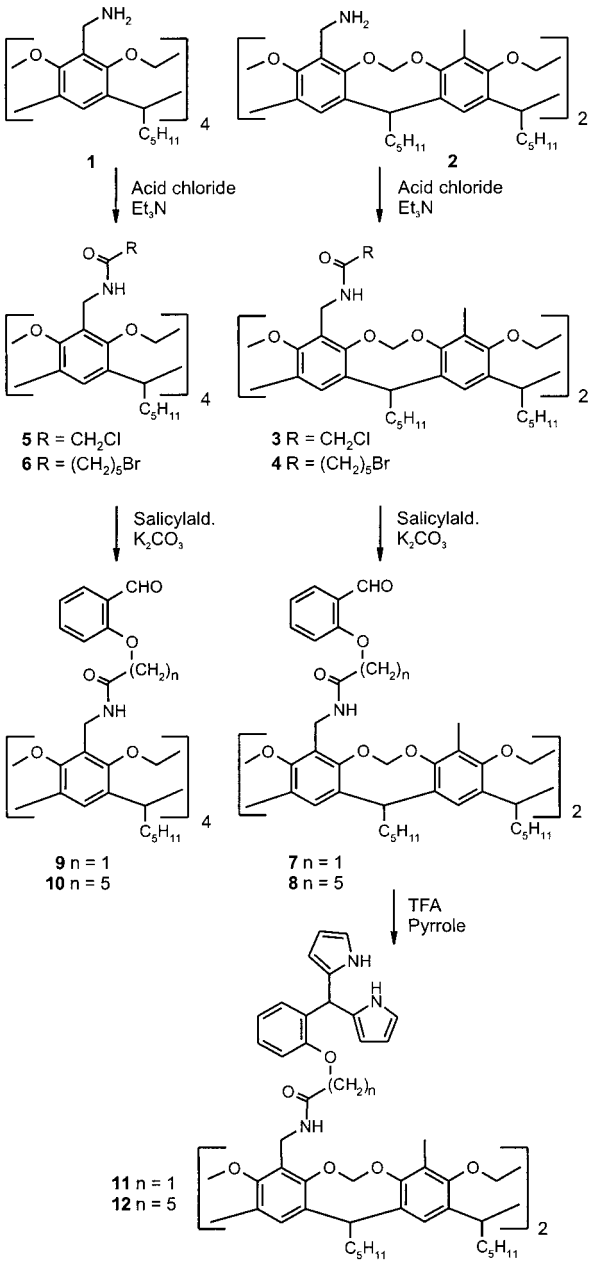
Scheme 1



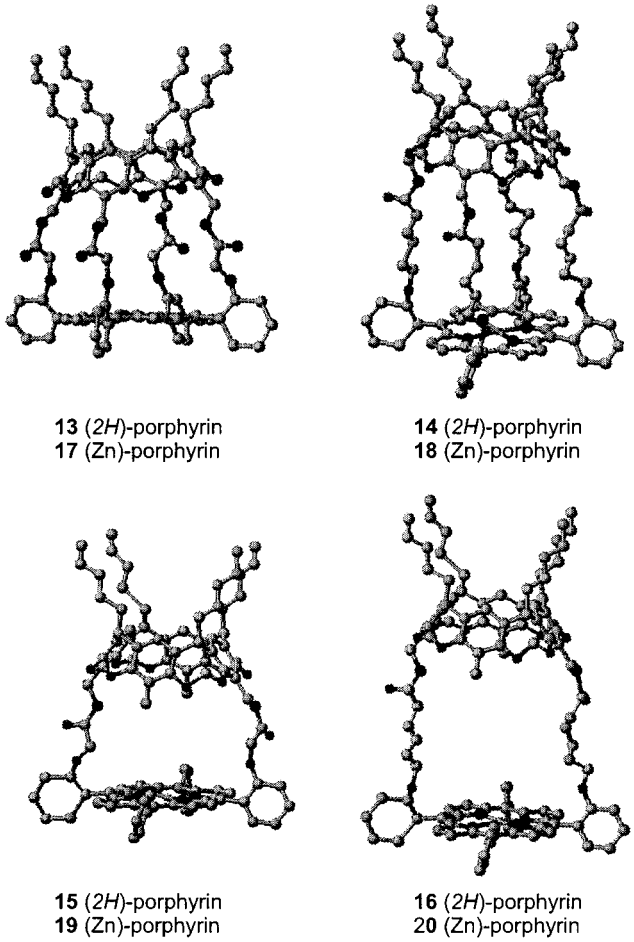
The conversion of tetraaldehydes **9** and **10** and dipyrromethanes **11** and **12** to capped porphyrins **13** and **14** and strapped porphyrins **15** and **16** was accomplished in yields comparable to those of other systems reported and proved to be strongly dependent on the synthetic methods applied. The conversion of **9** to capped porphyrin **13** could only be accomplished by using the Adler conditions;[15] other methods showed no porphyrin formation. Only when applying the Lindsey equilibrium conditions,[16] using BF_3 as the catalyst, could capped porphyrin **14** be obtained. The best results for strapped porphyrins **15** and **16** were obtained via the Lindsey method[16] via TFA and BF_3 catalysis, respectively (Chart 1).[17]

(15) Adler, A. D.; Longo, F. R.; Finarelli, J. D.; Goldmacher, J.; Assour, J.; Korsakoff, L. *J. Org. Chem.* **1967**, *32*, 476.

(16) Lindsey, J. S.; Schreiman, I. C.; Hsu, H. C.; Kearney, P. C.; Marguerettaz, A. M. *J. Org. Chem.* **1987**, *52*, 827.

(17) We have chosen ball-and-stick model representations for the cavitand Zn(II)−porphyrins instead of, e.g., Isis-draw pictures for clarity.

Chart 1



The capped (*2H*)-porphyrins **13**−**16** were easily identified by the signals of the porphyrin-core hydrogen atoms resonating around δ −2.8 in the ^{1}H NMR spectra and by the molecular ion peak in the positive FAB mass spectra. They could not be obtained analytically pure after column chromatography due to their slight instability. Treatment of the capped (*2H*)-porphyrins **13**−**16** with a large excess of $Zn(OAc)_2$ afforded the stable cavitand Zn(II)−porphyrins **17**−**20** which could easily be purified by flash column chromatography.[18] The overall yields for **17**−**20** of the last two reaction steps, the porphyrin syntheses and the subsequent insertion of the Zn(II) center, were 0.9%, 6%, 3%, and 5%, respectively.

NMR Analysis. Structural proof for the cavitand Zn(II)−porphyrins **17**−**20** was obtained by several NMR techniques. The ^{1}H NMR spectrum of capped Zn(II)−porphyrin **18** (Figure 1) clearly shows its C-4 symmetry. The assignment of the signals originating from the flexible pentylamido-*N*-methylene spacers was accomplished by combining the COSY and TOCSY NMR spectra. The middle three methylene groups have shifted (about 1.0 ppm) to an upfield position due to the porphyrin's ring current; two of the methylene groups are resonating at around δ 0.7, the other (closest to the porphyrin) at δ 0.9. The OCH_2 methylene group is just outside the ring current since it is residing as a triplet at δ 3.74.

The introduction of short amide-containing spacers rigidifies the cavitand−porphyrin system for **17** and **19**.

(18) The purity of capped Zn(II)−porphyrin **18** follows from the ^{1}H NMR spectrum (Figure 1).

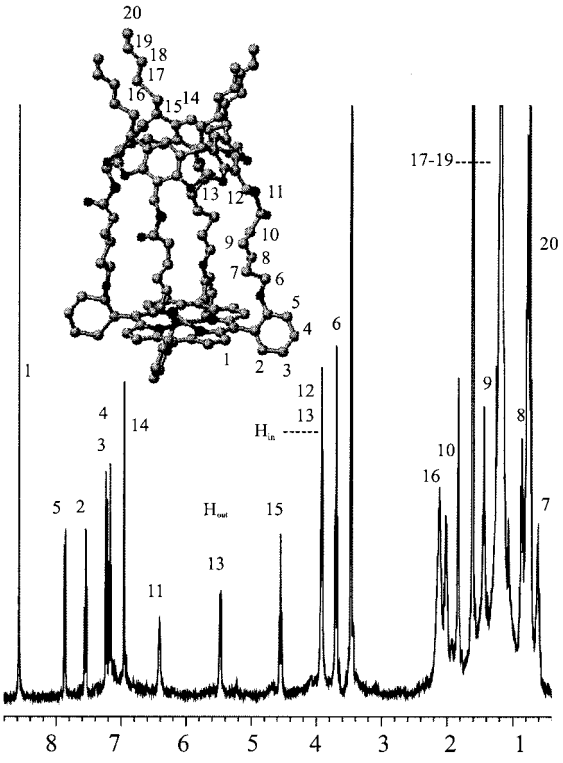


Figure 1. ^{1}H NMR spectrum of **18** in $CDCl_3$.

The distance between the cavitand cap and the porphyrin will be fixed and is contrasting the structural flexibility in **18**. Slow rotation of the short linker groups results in an ^{1}H NMR spectrum consisting of broadened multiple signals for, e.g., the spacers and methylenedioxy bridges,[19] and the expected C_4 symmetry of **17** and the C_2 symmetry of **19** is lost. COSY and NOESY spectra only show the expected contacts for the cavitand and porphyrin part of the molecule and in particular between the H_{in} and H_{out} multiplet regions for the hydrogen atoms of the methylenedioxy bridges and between the different multiplet regions residing from the hydrogen atoms of the spacer.

Strapped porphyrin **20** exhibits a complex ^{1}H NMR spectrum in CD_2Cl_2. The aryl substituents of the porphyrin reside as two multiplet regions between δ 7.4 and 7.8. Furthermore, many of the signals are doubled or broadened. A clear contact in the ROESY NMR spectrum was found between the resonances of the $OCH_{in}O$ and the resonance of one hydrogen atom of one of the benzene substituents of the porphyrin. In addition, contacts between the phenyl group and three of the five methylene spacer groups could be observed. Flexibility of the spacers might enable the receptor to accommodate its cavity size to that of the guest. However, in strapped porphyrin **20** self-inclusion takes place by the association of one of the phenyl substituents of the porphyrin into the cavity of the cavitand when dissolved in CD_2Cl_2.

This self-inclusion process is solvent dependent as can be clearly seen in Figure 2. In the competitive solvent THF-d_8,[20,21] the cavity is occupied by a solvent molecule resulting in a ^{1}H NMR spectrum with a C_2-symmetry

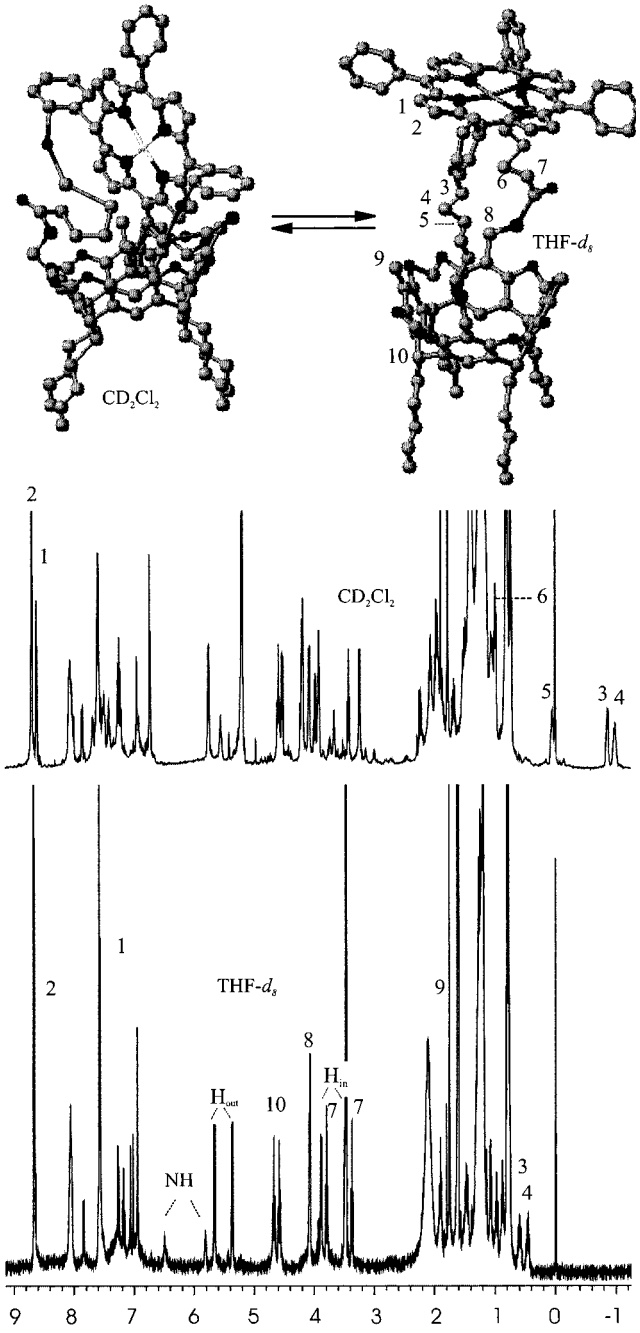


Figure 2. Self-inclusion of **20** illustrated by its ^{1}H NMR spectra in CD_2Cl_2 (top) and in THF-d_8 (bottom).

expressed by the doubled set of signals for the amide, methine, and methylenedioxy bridges (Figure 2). The plane of symmetry can only be positioned where it is bisecting two distal methylenedioxy bridges. This is the case when, on average, the oxygen atom of the bound THF-d_8 is pointing out of the cavity toward one of the amides. Although the amides have an equal distance to the plane of symmetry, they are therefore inequivalent, which is also reflected in the Ar−H signals of the cavitand; one of the two expected signals is doubled giving three signals integrating in a 1:1:2 fashion.

(19) Different rotamers are formed. The carbonyl groups in the linkers can be positioned inward versus outward and combinations thereof.

(20) Solvent inclusion has been described by Cram: Cram, D. J. *Science* **1988**, *240*, 760.

(21) From other aminomethyl-substituted cavitands prepared in our laboratories, it is already known that, in $CDCl_3$, THF is bound inside the cavity with an association constant of ~500 M^{-1}. Unpublished results.

Because of the ring current of the porphyrin, in CD_2Cl_2 the CH_2 signals of the spacers are expected to resonate at an upfield position;[22] due to the self-inclusion process, they have even shifted to negative δ values (Figure 2). In THF-d_8 these resonances have shifted far downfield at positions where they are expected. The combination of TOCSY and COSY spectra was used to assign the signals of the methylene groups of the spacers of **20** in CD_2Cl_2. The OCH_2 group (δ −0.91) has only one contact in the COSY spectrum with its neighboring methylene group (δ −0.96), which has two contacts. The other methylene substituents were assigned by TOCSY NMR spectroscopy and are located at δ 0.14, 1.03, and 3.79.[23] Knowing the positions, the COSY spectrum reveals the position of the methylene groups in the spacer. The methylene group next to the amide is residing at δ 3.79, and it has a contact with its neighboring methylene group located at δ 1.03. Consequently, the middle methylene group is located at δ 0.14.

Illustrative also are the changes in the splitting patterns for the two different hydrogen atoms of the pyrrole moieties of the porphyrin part of the receptor when going from CD_2Cl_2 to THF-d_8. Because of the folding of the molecule in CD_2Cl_2, these two signals, and many others, split up into multiple signals (Figure 2). In the THF-d_8 complex[21] they become two signals which reside as a broad singlet at δ 8.06 and as a multiplet at around δ 8.67. The phenyl substituents now exhibit one narrow multiplet.[24]

UV−Binding Experiments. The complexation behavior of the cavitand Zn(II)−porphyrin receptors **17**−**20** toward *N*-methylimidazole and a series of pyridine guests in $CHCl_3$ was studied by UVtitrations. As an illustration, Figure 3 shows the Soret band for cavitand-capped Zn(II)−porphyrin **17** and of the complex in $CHCl_3$ upon picoline addition. Both the decrease of the Soret absorbance band of the free host at $\lambda = 424$ nm and the increase of the Soret absorbance band of the complex at $\lambda = 434$ nm are plotted as a function of the guest concentration. Both curves gave, after correction for dilution, a perfect fit to a 1:1 model ($K_{ass} = 2.3 \times 10^5$ M^{-1}). The UV titration spectra, when corrected for dilution, show the typical isosbestic point between the maximum absorbance of the free host and that of the complex.

The results of the binding studies are summarized in Table 1.[25] For a few cases, the binding affinities of the cavitand Zn(II)−porphyrins are in the same range (about 10^6 M^{-1}) as those of the the best known receptors for organic guests in organic solvents to date,[6−9] demonstrating the strong potential of a cavitand as a hydrophobic pocket. Some important trends can be seen from the results. The strongest axial binding of *N*-methylimidazole and pyridine guests was found for cavitand-capped Zn(II)−porphyrin **17**, with the shortest distance between the cavitand and the porphyrin increasing the shielding effect. Furthermore, it has four spacers rigidifying the structure to a receptor having a defined cavity. A large difference between the smallest and the larger guests is observed. The larger guests (nicotin, nicotinamides, and *p*-phenylpyridine) bind at the outside of the receptor with

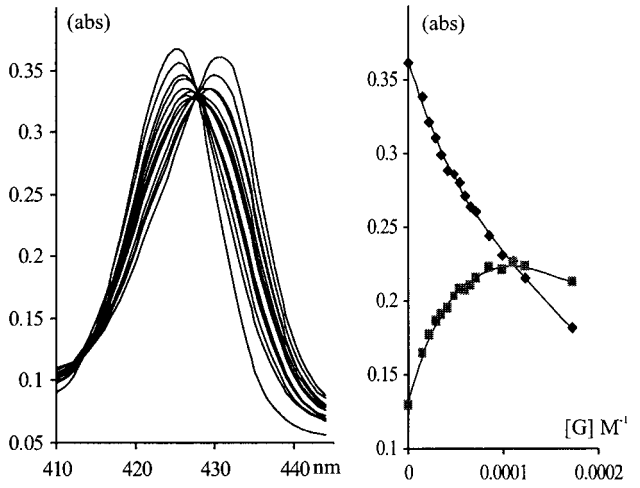
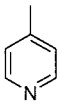
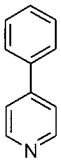
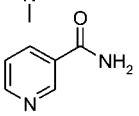
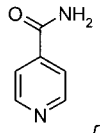
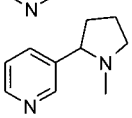


Figure 3. UV titration spectra showing the decrease of the Soret band of **17** and the increase of the Soret band of the complex upon picoline addition. The uncorrected data fit to a calculated curve for a 1:1 complexation with a stability constant of 2.3×10^5 M^{-1}.

Table 1. Binding Constants ($\times 10^3$ M^{-1}) of the Complexation of *N*-Methylimidazole and Pyridine Guests by Cavitand Zn(II)−Porphyrins 17−20 Determined by UV Titration Experiments in $CHCl_3$. The Experiments Were Carried Out in Duplicate with an Error Margin between 3 and 10%

Guest	17	18	19	20	TPP(Zn)
	147	15	18	6.8	0.9
	233	46	80	20	1.6
	0.4	10	52	13	1.4
	1077	140	290	79	1.5
	0.7	0.3	62	19	0.3
	0.4	13	15	1.6	0.3
	0.2	16	20	41	1.4

(22) Momenteau, M.; Mispelter, J.; Loock, B.; Bisagni, E. *J. Chem. Soc., Perkin Trans. 2* **1983**, 189.

(23) Many contacts are observed for the alkyl region in the COSY NMR spectrum. TOCSY NMR shows the expected four contacts for all spacer methylene groups in a straight line.

(24) When the sample was measured at 223 K, the hydrogens of the porphyrin−pyrrole units appear as two doublets between δ 8.1 and 8.2 and as two doublets between δ 8.6 and 8.7. In addition, the doublet originating from the methylene group between the amide and the cavitand is doubled at 223 K, which clearly indicates the difference in spatial freedom between both amide moieties in time and the symmetry elements being lost.

(25) Pyridine, picoline, and *N*-methylimidazole are common guests for studying the binding properties of porphyrin receptors, and some additional guests were selected to demonstrate a clear guest to cavity-size selection. The binding of *N*-methylimidazole is commonly accepted as a model for oxygen binding capacities. See, e.g., ref 11.

a binding strength equal to or even lower[26] than that to TPP(Zn). The binding of the smaller guests, *N*-methylimidazole, pyridine, and picoline, is strongly influenced by the capping effect of the cavitand, and they bind strongest following the trend of highest electron density on the donating nitrogen atom.

The longer and flexible spacers in **18** lead to a larger but less defined cavity, and most guests bind inside the receptor (except nicotin, not fitting in the cavity). The longer spacer reduces the capping effect of the cavitand, and the smaller guests bind typically weaker, although in the same order as **17**. For the pyridines the cavitand capping effect is a factor[27] of 6−32 (compared to TPP-(Zn)), and the highest (94) value is that for *N*-methylimidazole.

The cavitand-strapped porphyrin **19** lacks two spacers with respect to capped porphyrin **17**. Consequently, the shielding effect on the porphyrin will be reduced and, more importantly, the flexibility of the system and the cavitand−porphyrin distance are slightly increased. This increase of distance allows *p*-phenylpyridine to be bound inside the receptor. The two new windows enable the sterically more demanding guests to bind inside. Strapped porphyrin **19** binds nicotinamide[28] by a factor 200 times stronger (!) than that of TPP(Zn) and is the best of receptors **17**−**20** for binding nicotinamide, *p*-phenylpyridine, and isonicotinamide.

The elongation of the spacers in cavitand-strapped porphyrin **20** results in a diminished cavitand capping effect compared to **19**. In **20** the flexibility of the spacers allows the molecule to fold its spacers toward the interior of the receptor, thereby minimizing its cavity size (vide supra). This folding process promotes the self-inclusion of a porphyrin phenyl moiety into the cavitand cavity. The axial binding of guests in $CHCl_3$, in this case, has to compete with this process which is an additional energy barrier to overcome. In general, the overall binding affinities are less than those for **17**−**19**, except for nicotin, which probably has a cooperative hydrogen-bond interaction with one of the spacer amides[29] enhancing the binding to receptor **20**, thereby becoming the best receptor for nicotin.

The binding of *N*-methylimidazole by cavitand Zn(II)−porphyrin **18** has been studied by ^{1}H NMR spectroscopy in $CDCl_3$ to corroborate the result with the data obtained with UV spectroscopy (vide supra). Characteristic for the binding of *N*-methylimidazole[30] ($K_{ass} = 1.4 \times 10^5$ M^{-1}) are the very large shifts for the signals of the guest owing to the strong influence of the ring current of the porphyrin and its partial location in the cavity of the cavitand; the methyl group shifts from δ 3.6 to −0.9. Only small shifts are observed for signals originating from the hydrogen atoms at the porphyrin and the OCH_2 moiety of the spacer.

Conclusions

Our results clearly demonstrate that a cavitand is an excellent cap for a porphyrin. The complexation depends on the rigidity of the receptor, the number of spacers, and the distance between the porphyrin and the cavitand. Long flexible spacers result in a broader range of potential guests. In the case of **18** and **20**, a moderate enhancement (10−90-fold) of the porphyrin binding properties is observed due to self-inclusion. Short, rigid spacers on the cavitand have a large impact on the binding properties. Strapped porphyrin **19** shows large binding enhancements for *N*-methylimidazole, picoline, and nicotinamide (50−200-fold). The two additional rigid spacers in capped porphyrin **17** increase the capping effect to 700-fold in the case of *N*-methylimidazole. Cavitand Zn(II)−porphyrin receptors **17** and **19** belong to the best receptors for *N*-heterocycles reported to date.

Experimental Section

General. Melting points are uncorrected. Mass positive (FAB) spectra were obtained using *m*-nitrobenzyl alcohol as a matrix. Column chromatography was performed using silica gel 60 from Merck. All reactions were carried out under an argon atmosphere, and solvents, if necessary, were purified by standard procedures prior to use. The presence of solvents in the analytical samples was confirmed by ^{1}H NMR spectroscopy.

NMR. All ^{1}H (300 MHz) and ^{13}C NMR (63 MHz) spectra were recorded in $CDCl_3$ at ambient temperature (30 °C) unless stated otherwise. The chemical shifts are expressed relative to $CHCl_3$ for ^{1}H NMR (at δ 7.14) and ^{13}C NMR (at δ 78.4). NOESY,[31] ROESY,[32] TOCSY (MLEV 17),[33] and COSY[34] spectra were performed using standard Varian pulse programs. The TOCSY (MLEV 17) experiments were performed with mixing times of 30 ms. The mixing times of the NOESY experiments ranged from 10 to 90 ms. The mixing time of the ROESY experiments consisted of a spin−lock pulse of 2 kHz field strength with a duration of 30 ms, typically. All 2-D experiments were collected using 2-D hypercomplex data[35] and Fourier transformed in the phase-sensitive mode after weighting with shifted square sine bells or shifted Gaussian functions. NMR data were processed by the standard VnmrS software packages on the Unity 400 WB host computers (SUN IPX and Sparc stations). Concentrations of the samples used were typically in the 5 mM range. 6,18-Bis(aminomethyl)-12,-24-(dimethyl)pentylcavitand[14] **1**, 6,12,18,24-tetrakis(aminomethyl)pentylcavitand[13] **2**, and 6,12,18,24-tetrakis(chloroacetamido-*N*-methylene)pentylcavitand[13] **5** were synthesized according to literature procedures reported by our group.

UV Titration Experiments and Binding Constant Determination. The concentrations of cavitand Zn(II)−porphyrins used for the determination of the binding constants by UV titrations were between 2 and 5 μM, and *N*-methylimidazole and pyridine guests were added until more than 90% of complex formation was observed. Binding constants were determined by plotting the Soret absorbance band decrease of the free hosts against the guest concentration, and also by that of the Soret absorbance band increase of the complexes against the guest concentrations. The experimental data were fitted with the least-squares method to a theoretical curve calculated with a 1:1 binding model. The experiments were carried out in duplicate with an error margin between 3 and 10%.

General Workup Procedures. **Procedure A.** The reaction was quenched with HCl (2 N, 100 mL), followed by

(26) One side of the porphyrin is blocked.

(27) The capping effect is expressed by comparison of the receptors binding affinity to that of (Zn)TPP.

(28) On the basis of CPK molecular models, a cooperative hydrogen bond is possible between one of the amides of the spacers and the nicotinamide guest.

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(30) From the literature it is known that 2-methylimidazole typically binds stronger than *N*-methylimidazole. See, e.g., ref 7.

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(32) Bothner-By, A. A.; Stephens, R. L.; Lee, L.; Warren, C. D.; Jeanloz, R. W. *J. Am. Chem. Soc.* **1984**, *106*, 811.

(33) Bax, A.; Davis, D. *J. Magn. Reson.* **1985**, *65*, 355.

(34) Bax, A.; Freeman, R. *J. Magn. Reson.* **1981**, *44*, 542.

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washing the organic layer with water (100 mL) and 6 N NaOH (50 mL), drying the organic layer over $MgSO_4$, and evaporation of the solvent. **Procedure B.** The solvent was removed in vacuo, and the residue was redissolved in CH_2Cl_2/H_2O (200 mL/100 mL). The organic layer was dried over Na_2SO_4 and concentrated to 10 mL (approximately), and the residue was separated by column chromatography (SiO_2, EtOAc). Elution was performed with a gradient of MeOH (0, 5, 7, 10%) in EtOAc. **Procedure C.** The excess of pyrrole was removed in vacuo, and the residue was taken up in CH_2Cl_2/0.1 N NaOH (200 mL/50 mL). The organic layer was dried over Na_2SO_4 and concentrated to 10 mL (approximately), and the residue was separated by column chromatography (SiO_2, CH_2Cl_2).

6,18-Bis(chloroacetamido-*N*-methylene)-12,24-dimethylpentylcavitand (3). A solution of chloroacetyl chloride (1.05 g, 9.30 mmol) in CH_2Cl_2 (20 mL) was added dropwise to a solution of 6,18-bis(aminomethyl)-12,24-(dimethyl)pentylcavitand **1** (1.68 g, 1.86 mmol) in a mixture of CH_2Cl_2 (150 mL) and Et_3N (15 mL) at −18 °C, whereupon stirring was continued overnight at rt. Workup procedure **A** yielded **3** (1.92 g, 98%) as a white solid, mp 100−102 °C: ^{1}H NMR δ 0.92 (t, J = 7.2 Hz, 12H), 1.30−1.50 (m, 24H), 1.95 (s, 6H), 2.10−2.30 (m, 8H), 4.02 (s, 4H), 4.34 (d, J = 6.9 Hz, 4H), 4.40 (d, J = 6.0 Hz, 4H), 4.76 (t, J = 7.4 Hz, 4H), 5.94 (d, J = 6.9 Hz, 4H), 6.96 (s, 2H), 7.02 (t, J = 6.4 Hz, 2H), 7.11 (s, 2H); ^{13}C NMR δ 10.5, 14.1, 22.7, 27.6, 30.9, 32.1, 35.5, 37.0, 42.7, 62.3, 99.5, 117.1, 120.6, 122.8, 124.1, 137.5, 138.6, 153.5, 153.5, 165.8; FAB m/z 1055.5 $[M + H]^+$, calcd 1055.5. Anal. Calcd for $C_{60}H_{76}Cl_2N_2O_{10}\cdot 0.3CH_2Cl_2$: C, 66.96; H, 7.14; N, 2.59. Found: C, 66.85; H, 7.02; N, 2.73.

6,18-Bis(5-bromopentylamido-*N*-methylene)-12,24-dimethylpentylcavitand (4). A solution of 6-bromohexanoyl chloride (1.99 g, 9.30 mmol) in CH_2Cl_2 (50 mL) was added dropwise to a solution of 6,18-bis(aminomethyl)-12,24-(dimethyl)pentylcavitand **1** (1.68 g, 1.86 mmol) in a mixture of CH_2Cl_2 (150 mL) and Et_3N (15 mL) at −10 °C, whereupon stirring was continued for 2 h at rt. Workup procedure A was followed by flash column chromatography (SiO_2, CH_2Cl_2/EtOAc 7:3, R_f = 0.8), yielding **4** (2.12 g, 91%) as a white solid, mp 143−145 °C: ^{1}H NMR δ 0.95 (t, J = 7.1 Hz, 12H), 1.25−1.45 (m, 16H), 1.45−1.55 (m, 4H), 1.55−2.00 (m, 12H), 1.96 (s, 6H), 2.12−2.22 (m, 4H), 2.29 (t, J = 6.8 Hz, 4H), 3.47 (t, J = 7.0 Hz, 4H), 4.35 (d, J = 4.5 Hz, 4H), 4.37 (d, J = 7.2 Hz, 4H), 4.74 (t, J = 7.7 Hz, 4H), 5.91 (d, J = 7.2 Hz, 4H), 6.23 (t, J = 5.2 Hz, 2H), 6.96 (s, 2H), 7.11 (s, 2H); ^{13}C NMR δ 10.5, 14.2, 22.7, 23.5, 24.2, 26.1, 27.4, 27.6, 30.2, 32.3, 36.3, 44.7, 60.3, 99.3, 117.2, 120.1, 123.5, 123.9, 137.5, 138.5, 153.4, 153.6, 172.7; FAB MS m/z 1255.5 $[M + H]^+$, calcd 1255.5. Anal. Calcd for $C_{68}H_{92}Br_2N_2O_{10}\cdot 0.3Et_3N$: C, 64.96; H, 7.38; N, 2.23. Found: C, 64.68; H, 7.49; N, 2.55.

6,12,18,24-Tetrakis(5-bromopentylamido-*N*-methylene)-pentylcavitand (6). A solution of 6-bromohexanoyl chloride (5.60 g, 26.17 mmol) in CH_2Cl_2 (50 mL) was added dropwise to a solution of 6,12,18,24-tetrakis(aminomethyl)pentylcavitand **2** (2.77 g, 2.97 mmol) in a mixture of CH_2Cl_2 (100 mL) and Et_3N (10 mL) at 0 °C, whereupon stirring was continued overnight at rt. Workup procedure **A** was followed by flash column chromatography (SiO_2, EtOAc/MeOH 4:1, R_f = 0.3). Addition of hexane to a CH_2Cl_2 solution yielded **4** (4.26 g, 88%) as a colorless oil: ^{1}H NMR δ 0.95 (t, J = 6.7 Hz, 12H), 1.20−1.51 (m, 32H), 1.51−1.69 (m, 8H), 1.69−1.90 (m, 8H), 2.05−2.30 (m, 16H), 3.52 (t, J = 6.2 Hz, 8H), 4.31 (d, J = 4.5 Hz, 4H), 4.38 (d, J = 6.5 Hz, 4H), 4.72 (t, J = 8.6 Hz, 4H), 5.92 (d, J = 7.2 Hz, 4H), 5.93 (t, J = 5.2 Hz, 4H), 7.04 (s, 4H); ^{13}C NMR δ 13.6, 22.1, 24.2, 25.9, 27.1, 31.5, 31.7, 33.6, 35.7, 36.4, 44.3, 52.7, 99.1, 119.3, 123.2, 137.6, 153.1, 172.0; FAB MS m/z 1637.5 $[M + H]^+$, calcd for $C_{80}H_{112}Br_4N_4O_{12}$ 1637.5.

6,18-Bis[(2-formylphenoxy)acetamido-*N*-methylene]-12,24-dimethylpentylcavitand (7). A solution of salicylaldehyde (1.39 g, 11.4 mmol) in CH_3CN (10 mL) was added to a suspension of **3** (3.0 g, 2.84 mmol), K_2CO_3 (1.69 g, 12.2 mmol), and NaI (100 mg, catalyst) in CH_3CN (100 mL), whereupon the reaction mixture was refluxed overnight. Workup procedure B and column chromatography (SiO_2, EtOAc, R_f = 0.3) yielded **7** (2.91 g, 84%) as a white solid, mp 215−217 °C: ^{1}H NMR δ 0.91 (t, J = 6.9 Hz, 12H), 1.28−1.45 (m, 24H), 1.91 (s, 6H), 2.13−2.27 (m, 8H), 4.37 (d, J = 6.9 Hz, 4H), 4.50 (d, J = 7.3 Hz, 4H), 4.53 (s, 4H), 4.78 (t, J = 8.1 Hz, 4H), 5.98 (d, J = 7.3 Hz, 4H), 6.90 (d, J = 8.4 Hz, 2H), 6.98 (s, 2H), 7.12 (s, 2H), 7.18 (t, J = 7.5 Hz, 4H), 7.57 (t, J = 7.2 Hz, 2H), 7.78 (d, J = 7.5 Hz, 2H), 7.83 (t, J = 5.7 Hz, 2H), 10.18 (s, 2H); ^{13}C NMR δ 9.9, 13.6, 20.3, 27.1, 29.6, 31.5, 33.3, 36.4, 59.8, 67.7, 99.0, 112.6, 116.5, 119.8, 121.6, 122.8, 123.4, 124.5, 133.4, 135.5, 136.9, 137.9, 152.9, 153.2, 157.2, 166.8, 170.5, 189.6; FAB MS m/z 1249.5 $[M + H + Na]^+$, calcd 1249.6. Anal. Calcd for $C_{74}H_{86}N_2O_{14}\cdot 0.3CH_2Cl_2$: C, 71.22; H, 6.97; N, 2.24. Found: C, 71.05; H, 6.89; N, 2.31.

6,18-Bis[5-(2-formylphenoxy)pentylamido-*N*-methylene]-12,24-dimethylpentylcavitand (8). A solution of salicylaldehyde (1.17 g, 10.4 mmol) in CH_3CN (5 mL) was added to a suspension of **4** (3.0 g, 2.84 mmol) and K_2CO_3 (1.69 g, 12.2 mmol) in CH_3CN (50 mL), whereupon the reaction mixture was refluxed overnight. Workup procedure B and column chromatography (SiO_2, CH_2Cl_2/EtOAc 1:1.1, R_f = 0.1) yielded **8** (2.91 g, 77%) as a white solid, mp 145−147 °C: ^{1}H NMR δ 0.88 (t, J = 6.7 Hz, 12H), 1.25−1.44 (m, 32H), 1.44−1.57 (m, 2H), 1.57−1.80 (m, 2H), 1.80−1.91 (m, 2H), 1.92 (s, 6H), 2.10−2.25 (m, 8H), 4.01−4.10 (m, 8H), 4.20−4.32 (m, 8H), 4.74 (t, J = 8.1 Hz, 4H), 5.92 (d, J = 6.9 Hz, 4H), 6.15 (t, J = 8.1 Hz, 4H), 6.90−7.10 (m, 8H), 7.11 (s, 2H), 7.46−7.53 (m, 2H), 7.78−7.81 (m, 2H), 10.48 (s, 2H); ^{13}C NMR δ 9.8, 13.5, 19.7, 22.1, 24.1, 24.6, 25.2, 25.9, 27.1, 27.8, 27.9, 28.0, 28.3, 29.5, 31.5, 31.7, 32.6, 33.7, 35.2, 35.9, 36.5, 44.2, 59.8, 67.6, 76.8, 98.7, 112.0, 116.7, 119.7, 120.0, 123.1, 123.5, 124.3, 127.7, 135.5, 137.0, 137.3, 138.0, 152.9, 153.0, 160.9, 162.0, 172.1, 189.2; FAB MS m/z 1339.8 $[M + H]^+$, calcd 1339.7. Anal. Calcd for $C_{82}H_{102}N_2O_{14}\cdot 0.8CH_2Cl_2$: C, 70.65; H, 7.42; N, 1.99. Found: C, 70.35; H, 7.61; N, 2.29.

6,12,18,24-Tetrakis[(2-formylphenoxy)acetamido-*N*-methylene]pentylcavitand (9). A solution of salicylaldehyde (2,40 g, 21.4 mmol) in CH_3CN (5 mL) was added to a suspension of 6,12,18,24-tetrakis(chloroacetamidomethyl)-pentylcavitand **5** (5.0 g, 3.96 mmol), NaI (0.1 g, catalytic), and K_2CO_3 (5.0 g, mmol) in CH_3CN (300 mL), whereupon the reaction mixture was refluxed overnight. Workup procedure B and elution with a gradient of EtOH (0, 10, 33%) in EtOAc yielded **6** (3.87 g, 61%) (33% EtOH, R_f = 0.3) as a red-brown oil: ^{1}H NMR δ 0.91 (t, J = 6.6 Hz, 12H), 1.05−1.70 (m, 24H), 2.00−2.40 (m, 8H), 4.35 (d, J = 6.1 Hz, 4H), 4.36 (d, J = 7.4 Hz, 4H), 4.51 (s, 4H), 4.78 (t, J = 7.3 Hz, 4H), 6.01 (d, J = 7.4 Hz, 4H), 6.90 (d, J = 8.0 Hz, 4H), 7.01 (s, 4H), 7.14 (t, J = 4.8 Hz, 4H), 7.44−7.55 (m, 8H), 7.77 (d, J = 6.4 Hz, 4H), 10.08 (s, 4H); ^{13}C NMR δ 14.0, 22.5, 27.4, 30.0, 31.9, 33.6, 36.8, 42.4, 67.5, 99.7, 113.0, 119.8, 121.9, 123.2, 124.9, 133.0, 135.9, 138.1, 153.5, 157.8, 167.1, 189.9; FAB MS m/z 1602.7 $[M + H + Na]^+$, calcd for $C_{92}H_{100}N_4NaO_{20}$ 1602.8.

6,12,18,24-Tetrakis[5-(2-formylphenoxy)pentylamido-*N*-methylene]pentylcavitand (10). A solution of salicylaldehyde (744 mg, 6.1 mmol) in CH_3CN (5 mL) was added to a suspension of **4** (1.0 g, 0.61 mmol) and K_2CO_3 (1.69 g, 12.2 mmol) in CH_3CN (50 mL), whereupon the reaction mixture was refluxed overnight. Workup procedure B and elution with a gradient of MeOH (0, 5, 7, 10%) in EtOAc yielded **6** (960 mg, 87%) (10% MeOH, R_f = 0.2) as a yellow-brown oil: ^{1}H NMR δ 0.93 (t, J = 6.9 Hz, 12H), 1.20−1.50 (m, 32H), 1.50−1.71 (m, 8H), 1.71−1.91 (m, 8H), 2.00−2.25 (m, 16H), 4.09 (t, J = 4.8 Hz, 8H), 4.27 (d, J = 6.4 Hz, 4H), 4.38 (d, J = 7.5 Hz, 4H), 4.75 (t, J = 8.1 Hz, 4H), 5.95 (d, J = 7.5 Hz, 4H), 5.94 (t, J = 5.1 Hz, 4H), 6.94−7.08 (m, 8H), 7.09 (s, 4H), 7.50−7.75 (m, 4H), 7.82 (d, J = 7.2 Hz, 4H), 10.50 (s, 4H); ^{13}C NMR δ 13.6, 22.1, 24.6, 25.9, 27.1, 31.5, 31.7, 33.6, 35.8, 36.4, 44.3, 67.7, 99.1, 112.0, 119.3, 120.0, 123.2, 124.3, 127.8, 135.5, 137.6, 153.1, 160.9, 172.0, 189.5; FAB MS m/z 1806.2 $[M + H]^+$, calcd 1805.9. Anal. Calcd for $C_{108}H_{132}N_4O_{20}\cdot 1.7CH_2Cl_2$: C, 67.55; H, 7.00; N, 2.87. Found: C, 67.33; H, 7.11; N, 3.25.

6,18-Bis[(2-pyrrolylmethylphenoxy)acetamido-*N*-methylene]-12,24-dimethylpentylcavitand (11). To a degassed solution of dialdehyde **7** (150 mg, 0.12 mmol) in pyrrole (40 mL) was added TFA (0.4 mL, catalytic). Stirring for 30

min at rt, followed by workup procedure C and column chromatography (SiO_2, CH_2Cl_2/EtOAc 1:1, R_f = 0.2) yielded **11** (161 mg, 90%) as a gray-blue heat- and light-sensitive solid, decomposing upon standing (!): ^{1}H NMR δ 0.94 (t, J = 7.2 Hz, 12H), 1.25−1.50 (m, 24H), 1.82 (s, 6H), 2.10−2.35 (m, 8H), 4.09 (d, J = 7.3 Hz, 4H), 4.20 (d, J = 5.1 Hz, 4H), 4.26 (s, 4H), 4.74 (t, J = 8.4 Hz, 4H), 5.55 (brs, 2H), 5.63 (d, J = 7.5 Hz, 2H), 5.95−6.05 (m, 6H), 6.65 (d, J = 8.1 Hz, 2H), 7.14 (s, 2H), 7.21 (s, 2H), 7.21−7.25 (m, 4H), 8.34 (brs, 2H); ^{13}C NMR (CD_2Cl_2) δ 9.0, 13.3, 13.4, 22.1, 27.1, 29.7, 31.5, 32.9, 36.6, 38.2, 59.7, 66.3, 98.4, 106.0, 107.5, 111.1, 116.4, 117.5, 119.8, 121.5, 122.3, 123.3, 127.8, 128.9, 130.4, 130.6, 137.4, 137.6, 152.9, 153.1, 153.6, 166.8; FAB MS m/z 1458.7 $[M + H]^+$, calcd 1458.8. Anal. Calcd for $C_{90}H_{102}N_6O_{12}$: C, 74.05; H, 7.04; N, 5.76. Found: C, 74.32; H, 6.92; N, 5.67.

6,18-Bis[5-(2-pyrrolylmethylphenoxy)pentylamido-*N*-methylene]-12,24-dimethylpentylcavitand (12). To a degassed solution of dialdehyde **8** (1.0 g, 0.75 mmol) in pyrrole (65 mL) was added TFA (0.1 mL, catalytic). Stirring for 30 min at rt followed by workup procedure C and column chromatography (SiO_2, CH_2Cl_2/EtOAc 5:2, R_f = 0.3) yielded **12** (620 mg, 53%) as an off-white heat- and light-sensitive solid, decomposing upon standing (!): ^{1}H NMR δ 0.91 (t, J = 7.2 Hz, 12H), 1.25−1.50 (m, 32H), 1.52−1.75 (m, 4H), 1.78 (s, 6H), 2.10−2.35 (m, 12H), 3.93 (t, J = 6.3 Hz, 4H), 4.15−4.30 (m, 8H), 4.74 (t, J = 8.1 Hz, 4H), 5.80 (s, 2H), 5.84 (d, J = 7.1 Hz, 4H), 5.85 (brs, 2H), 6.06−6.10 (m, 2H), 6.61−6.64 (m, 2H), 6.83−6.90 (m, 4H), 6.95 (s, 2H), 7.06−7.10 (m, 2H), 7.09 (s, 2H), 7.14−7.22 (m, 2H), 8.46 (brs, 2H); ^{13}C NMR δ 14.1, 14.2, 22.7, 25.1, 25.6, 27.6, 28.8, 30.1, 32.1, 32.2, 34.2, 36.3, 36.8, 37.0, 37.8, 67.8, 99.1, 106.5, 108.0, 112.0, 116.6, 117.2, 120.2, 120.8, 123.5, 124.1, 127.9, 129.5, 131.3, 132.9, 137.6, 138.6, 153.4, 153.5, 156.0, 172.9; FAB MS m/z 1571.8 $[M + H]^+$, calcd 1571.9. Anal. Calcd for $C_{98}H_{118}N_6O_{12}$: C, 74.88; H, 7.57; N, 5.35. Found: C, 74.43; H, 7.42; N, 5.57.

General Procedure for the Insertion of Zn(II). The reaction mixture of the cavitand (*2H*)-porphyrin synthesis was evaporated to dryness and redissolved in CH_2Cl_2 (100 mL) and aqueous $NaHCO_3$ (50 mL). The organic layer was dried over Na_2SO_4, and the residue was separated by column chromatography (SiO_2, CH_2Cl_2/Et_3N, 99:1). The strongly colored porphyrin bands of the cavitand (*2H*)-porphyrins **13**−**16**, containing non-porphyrin impurities, were isolated by elution with a gradient of MeOH (1 up to 10%) in CH_2Cl_2/Et_3N (99:1) and evaporated to dryness. The residues were redissolved in $CHCl_3$/MeOH (1:1) and refluxed overnight with a large excess (approximately 50 equiv) of $Zn(OAc)_2$. The reaction mixture was evaporated to dryness and redissolved in CH_2Cl_2 (50 mL) and H_2O (20 mL). The organic layer was dried over Na_2SO_4 and evaporated to dryness. This residue was redissolved in the eluent needed for column chromatography.

Cavitand-Capped Zn(II)−Porphyrin 17. A mixture of tetraaldehyde **9** (655 mg, 0.41 mmol) and pyrrole (111 mg, 1.66 mmol) in propionic acid (200 mL) was refluxed overnight. For the workup of **13**, 2% MeOH was used in the eluent. The fraction with R_f = 0.4−0.7 was again separated by column chromatography (SiO_2, Et_2O/$CHCl_3$ 2:5). Zn(II) was inserted via the general procedure. Final purification by preparative TLC (SiO_2, Et_2O/$CHCl_3$ 2:5, R_f = 0.15) gave **17** (7.0 mg, 0.9%) as a pinkish-purple solid, mp 209−211 °C (dec). Compound **13** consisting of at least two rotamers/isomers: ^{1}H NMR δ −2.72 (s, 1H), −2.80 (s, 1H). Compound **17**: ^{1}H NMR (400 MHz) δ 0.78 (t, J = 7.0 Hz, 6H), 0.93 (t, J = 7.0 Hz, 6H), 1.05−1.50 (m, 16H), 1.60−1.85 (m, 8H), 3.29 (s, 2H), 3.33 (s, 4H), 3.34 (s, 2H), 3.50−3.80 (m, 8H), 4.18 (d, J = 7.2 Hz, 4H), 4.62−4.78 (m, 4H), 4.91 (brs, 1H), 5.16 (d, J = 7.2 Hz, 4H), 5.90−5.98 (brs, 1H), 6.43 (t, J = 4.8 Hz, 1H), 6.51 (brs, 1H), 7.02 (s, 1H), 7.14−7.30 (m, 7H), 7.40−7.76 (m, 8H), 8.08 (d, J = 8.0 Hz, 4H), 8.60−8.68 (m, 8H); ^{13}C NMR δ 12.8, 16.9, 26.1, 28.9, 31.5, 33.2, 30.1, 32.1, 32.2, 33.8, 35.5, 40.5, 47.9, 67.8, 99.1, 104.6, 104.9, 118.0, 121.4, 122.4, 123.6, 120.8, 124.0, 124.6, 128.1, 129.6, 130.6, 134.4, 134.7, 134.9, 138.3, 141.8, 142.0, 153.8, 153.9, 157.4, 163.0; FAB MS m/z 1836.0 $[M + H]^+$, calcd 1836.5. Anal. Calcd for $C_{108}H_{104}N_8O_{16}Zn$: C, 70.67; H, 5.71; N, 6.10. Found: C, 70.30; H, 6.02; N, 5.99.

Cavitand-Capped Zn(II)−Porphyrin 18. A solution of tetraaldehyde **10** (800 mg, 0.443 mmol) in freshly distilled CH_2Cl_2 (500 mL) was degassed at −40 °C and, subsequently, saturated with argon. The solution was allowed to warm to rt, whereupon a solution of freshly distilled pyrrole (119 mg, 1.80 mmol) in CH_2Cl_2 (2 mL) was added via a septum followed by the addition of a solution of freshly distilled BF_3·OEt_2 (252 mg, 1.80 mmol) in CH_2Cl_2 (2 mL). After the solution was stirred for 45 min, *p*-chloroanil (500 mg, excess) was added, and the reaction mixture was refluxed for 1 h. For the workup procedure, 7% MeOH in CH_2Cl_2 was used for column chromatography to obtain (*2H*)-porphyrin **14**. Upon the introduction of Zn(II) via the general procedure, the reaction mixture was separated by column chromatography (SiO_2, CH_2Cl_2/EtOAc 1:1, R_f = 0.2), yielding **18** (53 mg, 6%) as a purple solid, mp 208−210 °C (dec). Compound **14**: ^{1}H NMR δ −2.88 (s, 2H). Compound **18**: ^{1}H NMR (400 MHz, THF-d_8) δ 0.60−0.63 (m, 8H), 0.63−0.92 (m, 40H), 1.09−1.60 (m, 24H), 1.72−2.15 (m, 16H), 3.74 (t, J = 6.4 Hz, 8H), 3.90−3.95 (m, 12H), 4.53 (t, J = 8.4 Hz, 4H), 5.51 (d, J = 7.2 Hz, 4H), 6.71 (t, J = 6.0 Hz, 4H), 6.97 (s, 4H), 7.17−7.27 (m, 8H), 7.56−7.70 (m, 4H), 7.81−7.88 (m, 4H), 8.59 (s, 8H); ^{13}C NMR δ 16.8, 26.0, 28.8, 31.1, 32.8, 33.1, 33.9, 35.4, 37.2, 38.4, 40.4, 72.9, 76.2, 104.3, 116.4, 119.5, 122.6, 128.6, 132.4, 134.1, 137.0, 139.3, 141.4, 153.7, 157.6, 163.3, 174.6; FAB MS m/z 2058.3 $[M + H]^+$, calcd for $C_{124}H_{136}N_8O_{16}Zn$ 2057.9.

Cavitand-Strapped Zn(II)−Porphyrin 19. A solution of dipyrromethane **11** (0.54 g, 0.37 mmol) and benzaldehyde (79 mg, 0.74 mmol) in freshly distilled CH_2Cl_2 (200 mL) was degassed at −40 °C and, subsequently, saturated with argon. The solution was allowed to warm to rt and TFA (0.2 mL, catalytic) was added, whereupon the reaction mixture was stirred for 45 min. Subsequently, *p*-chloroanil (500 mg, excess) was added and the reaction mixture was refluxed for 1 h. For the workup procedure, 2% MeOH in CH_2Cl_2 was used for column chromatography to obtain (*2H*)-porphyrin **15**. Zn(II) was inserted via the general procedure and followed by column chromatography first using CH_2Cl_2 as the eluent to remove some impurities. Strapped porphyrin **19** (17 mg, 3%) was isolated (CH_2Cl_2/EtOAc 1:1, R_f = 0.5) as a purple solid, mp 152−154 °C (dec). Compound **15**: ^{1}H NMR δ −2.68 (brs, 2H). Compound **19**: ^{1}H NMR (400 MHz, $CDCl_3$/THF-d_8 = 1:1) δ 0.85−1.10 (m, 12H), 1.10−1.80 (m, 24H), 2.00 (s, 3H), 2.03 (s, 3H), 2.12−2.16 (m, 8H), 3.06 (d, J = 6.9 Hz, 4H), 3.55−3.95 (m, 4H), 4.00−4.20 (m, 4H), 4.72 (m), 5.14 (d, J = 6.9 Hz, 4H), 5.52−5.56 (brs, 1H), 5.93−5.97 (brs, 1H), 6.48 (s, 2H), 6.75 (s, 2H), 7.32−7.35 (m, 4H), 7.40−7.50 (m, 6H), 7.62 (d, J = 7.1 Hz, 2H), 7.65 (d, J = 7.1 Hz, 2H), 7.68−7.80 (m, 8H), 8.64−8.90 (m, 8H); ^{13}C NMR δ 12.8, 16.9, 26.1, 28.9, 31.5, 33.2, 33.8, 35.5, 40.4, 40.5, 40.5, 47.9, 67.8, 102.2, 102.5, 115.8, 120.5, 121.0, 122.2, 123.7, 124.0, 127.8, 129.9, 130.4, 132.3, 134.2, 134.4, 134.5, 137.9, 139.0, 141.1, 142.2, 147.7, 153.8, 153.8, 154.2, 157.6, 157.8, 157.9, 162.7, 163.6, 174.2; FAB MS m/z 1501.2 $[M]^-$, calcd 1501.2. Anal. Calcd for $C_{104}H_{102}N_6O_{12}Zn$·1.0THF-$d_8$:[36] C, 73.14; H, 5.80; N, 4.74. Found: C, 72.95; H, 5.64; N, 4.39.

Cavitand-Strapped Zn(II)−Porphyrin 20. A solution of dipyrromethane **12** (0.81 g, 0.61 mmol) and benzaldehyde (128 mg, 1.22 mmol) in freshly distilled CH_2Cl_2 (200 mL) was degassed at −40 °C and, subsequently, saturated with argon. The solution was allowed to warm to rt and freshly distilled BF_3·OEt_2 (0.1 mL, catalytic) was added, whereupon the reaction mixture was stirred for 3 h. Subsequently, *p*-chloroanil (500 mg, excess) was added and the reaction mixture was refluxed for 1 h. For the workup procedure, 2% MeOH in CH_2Cl_2 was used for column chromatography to obtain (*2H*)-porphyrin **16**. Zn(II) was inserted via the general procedure, and the reaction mixture was separated by column chromatography using (CH_2Cl_2/EtOAc 1:1, R_f = 0.5) as the eluent. Strapped porphyrin **20** (55 mg, 5%) was isolated as a purple solid, mp 159−161 °C (dec). Compound **16**: ^{1}H NMR δ −2.68 (brs, 2H).

(36) The sample used for ^{13}C NMR was evaporated to dryness and used for elemental analysis. The cavity is probably occupied by a molecule of THF-d_8.

Compound **20**: ^{1}H NMR (400 MHz, THF-d_8) δ 0.43−0.50 (m, 2H), 0.56−0.61 (m, 2H), 0.76−0.82 (m, 12H), 0.88 (t, J = 7.2 Hz, 2H), 0.98 (t, J = 7.2 Hz, 2H), 1.04−1.16 (m, 2H), 1.19−1.40 (m, 24H), 1.44−1.60 (m, 4H), 1.75 (s, 6H), 1.85−1.95 (m, 2H), 2.00−2.30 (m, 8H), 3.37 (t, J = 6.8 Hz, 2H), 3.47 (d, J = 7.2 Hz, 2H), 3.80 (t, J = 6.8 Hz, 2H), 3.88 (d, J = 7.2 Hz, 2H), 4.07−4.09 (m, 4H), 4.60 (t, J = 8.0 Hz, 2H), 4.68 (t, J = 8.0 Hz, 2H), 5.37 (d, J = 7.2 Hz, 2H), 5.66 (d, J = 7.2 Hz, 2H), 5.82 (brs, 1H), 6.50 (brs, 1H), 6.95 (s, 2H), 7.02 (s, 1H), 7.07 (s, 1H), 7.18 (t, J = 7.6 Hz, 2H), 7.26 (d, J = 8.0 Hz, 2H), 7.37−7.63 (m, 12H), 7.84 (d, J = 7.6 Hz, 2H), 8.06 (brs, 4H), 8.65−8.67 (m, 4H); ^{13}C NMR (63 MHz, THF-d_8) δ 12.8, 16.9, 26.1, 28.4, 30.1, 31.3, 32.1, 33.0, 33.1, 33.8, 35.5, 36.0, 36.1, 36.8, 38.5, 39.3, 40.6, 47.9, 48.4, 72.0, 102.3, 102.5, 118.8, 120.2, 120.9, 122.0, 122.5, 123.3, 123.8, 123.9, 127.7, 128.4, 128.7, 129.6, 130.5, 132.7, 134.5, 134.5, 138.0, 139.1, 139.9, 141.3, 141.8, 147.5, 156.6, 157.0, 158.5, 174.2; FAB MS m/z 1825.8 $[M + H + Na]^+$, calcd 1825.8. Anal. Calcd for $C_{112}H_{118}N_6O_{12}Zn\cdot 0.8MeOH$: C, 73.99; H, 6.67 N, 4.59. Found: C, 73.85; H, 6.37; N, 4.32.

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