DOI: 10.1002/chem.201002237

# Host–Guest-Driven Copolymerization of Tetraphosphonate Cavitands

Francesca Tancini,[a] Roger M. Yebeutchou,[a] Laura Pirondini,[a] Rita De Zorzi,[b] Silvano Geremia,[b] Oren A. Scherman,[c] and Enrico Dalcanale*[a]

**Abstract:** The outstanding complexing properties of tetraphosphonate cavitands towards *N*-methylpyridinium salts were exploited to realise a new class of linear and cyclic AABB supramolecular polymers through host–guest interactions. The effectiveness of the selected self-association processes was tested by $^1$H NMR studies, whereas microcalorimetric analyses clarified the binding thermodynamics and revealed the possibility of tuning entropic contributions by acting on the flexibility of the guest linker. Although the formation of linear polymeric chains for a rigid system was demonstrated by X-ray analysis, the presence of a concentration-dependent ring–chain equilibrium was indicated by solution viscosity measurements in the case of a very flexible ditopic BB guest co-monomer.

**Keywords:** cavitands · copolymerization · host–guest systems · self-assembly · supramolecular chemistry

## Introduction

Supramolecular polymers[1] are constitutionally dynamic materials,[2] based on modular components reversibly linked through non-covalent interactions. They occupy a special position among functional materials because they integrate the remarkable properties of polymers with the key features of self-assembly to give unique mechanical,[3] electronic,[4] biological[5] and self-healing[6] properties. Additionally, the supramolecular approach offers the possibility of controlling polymer topology and molecular-level mixing.[7] The incorporation of multiple switchable functionalities into a single monomer leads to topological control of the realized supramolecular systems,[8] which allows for interconversion between different polymeric architectures.[9]

The vast majority of supramolecular polymers reported so far are assembled through hydrogen bonding or metal–ligand coordination.[10] A less travelled route employs host–guest interactions as the driving force for polymerization.[8,11,12,13] The main reason for its limited use is that very high association constants ($\geq 10^5$) are required to obtain polymers with high molecular weight. This stringent requirement greatly reduces the number of suitable host–guest systems, out of the large number available.

As in the case of covalent polymers, the formation of supramolecular copolymers widens the spectrum of synthetic options and useful properties. Alternating copolymers offer new opportunities for structural incorporation of functional groups at very specific points along the chain. So far, the number of supramolecular copolymers made by host–guest interactions is rather small.[14] We previously reported the design and synthesis of self-complementary heteroditopic AB monomers[9] by exploiting the outstanding complexing properties[15] of tetraphosphonate cavitands towards *N*-methylpyridinium guests to form supramolecular homopolymers. The designed monomers were cavitands bearing four inward-facing P=O groups at the upper rim and a single *N*-methylpyridinium unit at the lower rim. The corresponding homopolymers featured guest-triggered reversibility, template-driven conversion from linear to star-branched forms and responsiveness to electrochemical stimuli.[16]

Herein we introduce cavitand-based supramolecular copolymers in which the host and guest functionalities are

[a] Dr. F. Tancini, Dr. R. M. Yebeutchou, Dr. L. Pirondini, Prof. Dr. E. Dalcanale
Dipartimento di Chimica Organica e Industriale and Unità INSTM UdR Parma, Università di Parma
Viale G. P. Usberti 17/a, 43124 Parma (Italy)
Fax: (+39) 0521-905472
E-mail: enrico.dalcanale@unipr.it

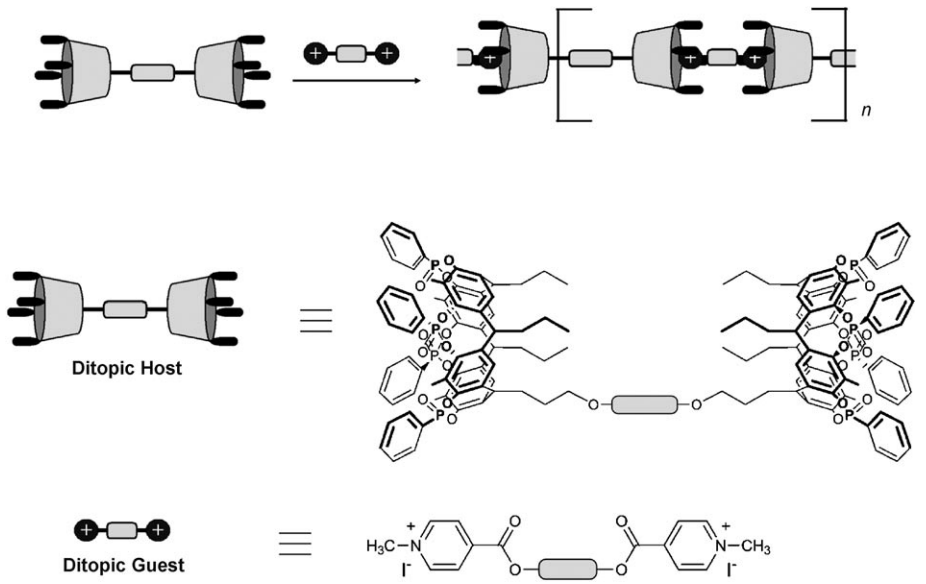
[b] Dr. R. De Zorzi, Prof. Dr. S. Geremia
Centro di Eccellenza in Biocristallografia
Dipartimento di Scienze Chimiche
Università di Trieste, Viale Giorgeri 1, 34127 Trieste (Italy)

[c] Dr. O. A. Scherman
Melville Laboratory for Polymer Synthesis
Department of Chemistry, University of Cambridge
Lensfield Road, CB2 1EW Cambridge (UK)

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/chem201002237.

present on two different species: 1) ditopic hosts (AA) with two tetraphosphonate cavitands covalently attached at their lower rim, and 2) ditopic guests (BB), in which flexible ethylene oxide chains of different length are functionalized with two *N*-methylpyridinium end groups (Scheme 1). The formation of linear and cyclic supramolecular species with an AABB copolymerization motif was investigated by using different techniques: the influence of the monomers' structures on the thermodynamic parameters of polymerization was analyzed by isothermal titration calorimetry (ITC); the linear polymer structure and relative chain length were determined by using X-ray analysis and viscosity measurements, respectively.

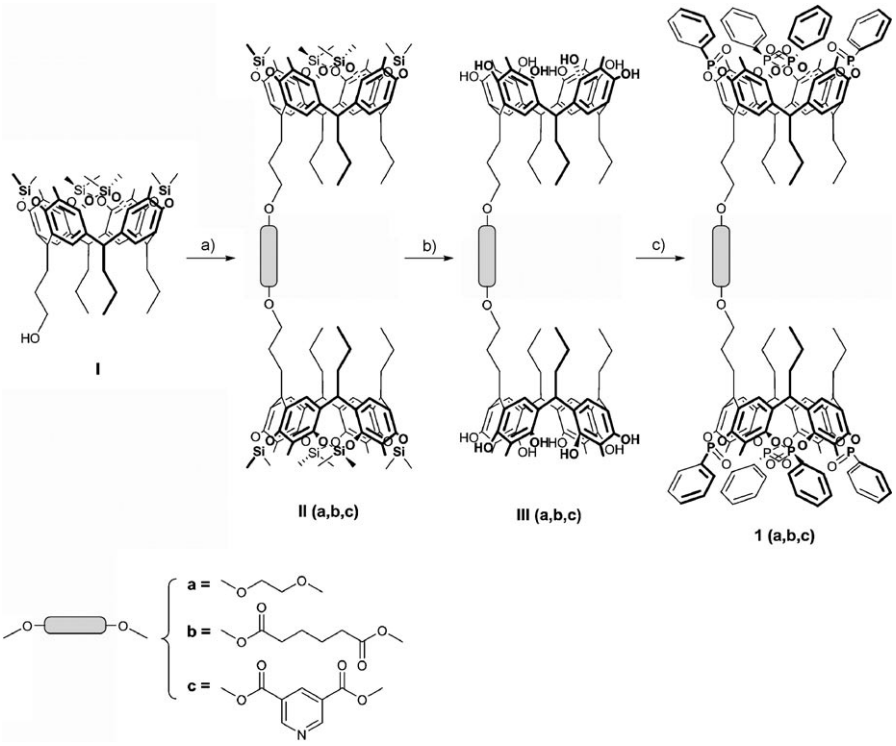



Scheme 1. AABB host–guest polymerization mode.

## Results and Discussion

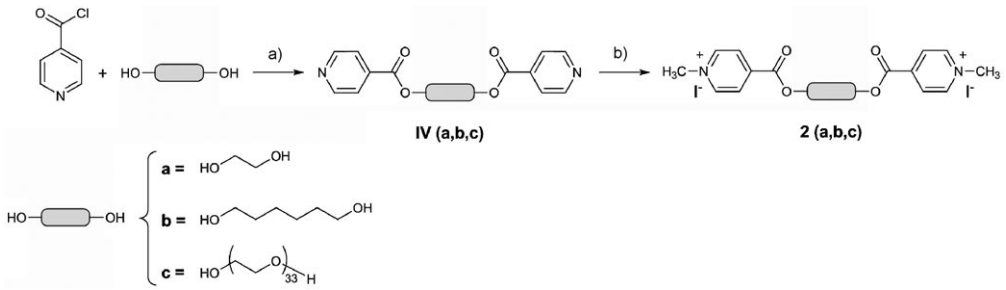
**Synthesis of the building blocks**: Three ditopic hosts (**1a–c**) and three ditopic guests (**2a–c**) with different connecting units were synthesized (Schemes 2 and 3). The aliphatic spacers were chosen to impart different lengths and flexibilities to the corresponding monomers to evaluate the influence of these factors on the polymerization process and product. In the case of the host, a more rigid heterocyclic tether was also introduced, namely, pyridinedicarboxylate (**1c**), to ease crystal structure determination. In the case of the guest, the presence of a polyethylene glycol chain made the corresponding monomer **2c** polymeric in nature.

Target hosts **1a**, **1b** and **1c** were synthesized in three steps, starting from the already reported monohydroxy-footed silylcavitand **I**[9] (Scheme 2). Different dimerization protocols were followed to bind together two units of **I**. Esterification reactions with adipic acid and 3,5-pyridinedicarboxylic acid in the presence of 1,3-dichlorohexylcarbodiimide (DCC) and 4-dimethylaminopyridine (DMAP), were employed for **IIb** and **IIc**, respectively. In the case of **IIa**, silylcavitand **I** was treated with dimethoxymethane in the presence of *p*-toluenesulfonic acid monohydrate. Treatment of the resulting intermediates **IIa–c** with a 36% aqueous solution of HF caused selective removal of the dimethylsilyl bridges to give




Scheme 2. Synthesis of target hosts. a) Dry $CH_2Cl_2$, DCC/DMAP, overnight, RT; b) DMF/$CHCl_3$, HF, overnight, 45 °C; c) dry pyridine, $PhPCl_2$, 3 h, 80 °C, then $H_2O_2$, 30 min, RT.




Scheme 3. Synthesis of target guests. a) Pyridine, 3 h, 100 °C; b) acetonitrile, $CH_3I$, overnight, reflux.

the corresponding resorcinarenes **III a–c**, ready to be functionalized with dichlorophenylphosphine. This reaction gave rise to a tetraphosphonite intermediate, which was oxidized in situ by addition of $H_2O_2$[9] to give tetraphosphonate cavitands **1a–c**. On account of the stereospecificity of this reaction, only the isomers having four inward-facing phosphonate bridges were formed in all cases. The target guests **2a**, **2b** and **2c** were prepared in two steps (Scheme 3) by treatment of isonicotinoyl chloride hydrochloride with ethylene glycol, 1,6-hexanediol and polyethylene glycol, respectively. Subsequent methylation with iodomethane afforded the desired products in quantitative yield.

**Host–guest-driven complexation**: Complexation of *N*-methylpyridinium-based guests inside the host cavity was first determined by $^1$H NMR titration. Figure 1 shows $^1$H NMR spectra monitoring the system formed by **1b** and **2c**. Diagnostic upfield shifts of the guest signals were observed, as expected for included species that experience the shielding effect of the cavity. The $CH_3$-pyridinium resonance moved more than 3 ppm upfield; *ortho* and *meta* pyridinic protons showed a smaller shift in the same direction, from $\delta = 8.60$ to 8.39 ppm and from $\delta = 8.51$ to about 7.98 ppm, respectively.

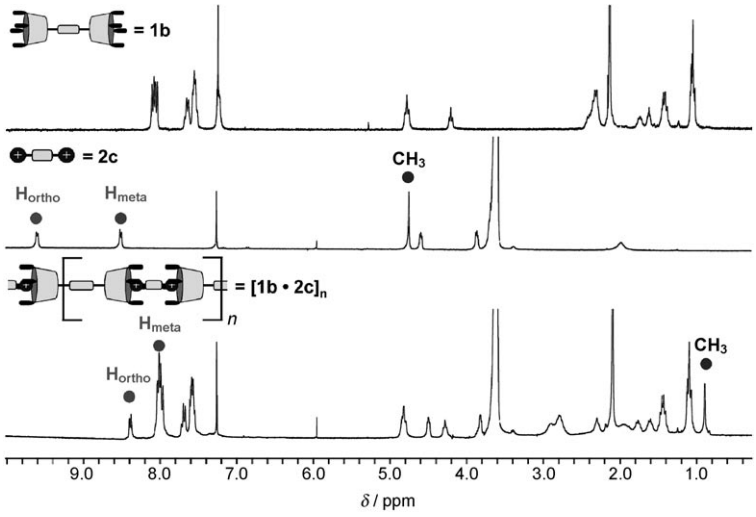



Figure 1. Section of $^1$H NMR spectra ($CDCl_3$) monitoring host–guest complexation. Top: Free host (5 mM). Middle: Free guest (5 mM). Bottom: Host–guest complex (1:1 stoichiometry).

The presence of complexed species was also confirmed by ESI-MS spectrometry. Short ditopic guest **2b***, which is structurally equivalent to **2b** and features $PF_6^-$ as the counterion instead of $I^-$, was chosen to give a suitable mass range for ESI analysis. The ESI-MS spectrum in acetone/methanol of a 1:1 mixture of **1b** and **2b*** showed two main peaks at *m/z* 1451.1 and 3047.1, due to doubly and singly charged ions of **1b·2b***, respectively (see Figure S1, Supporting Information).

**ITC measurements**: ITC studies[17] were carried out to quantify the thermodynamic parameters $\Delta H°$, $K_{ass}$, $\Delta G°$ and $\Delta S°$ associated with the inclusion process.[18] Preliminary experiments performed with both monotopic and ditopic species (see Figure S2 and Table S1, Supporting Information) revealed that no cooperativity, either positive or negative, is present when multiple binding occurs. More significant in this context is the comparison between the data collected for ditopic host **1b** with the three ditopic guests **2a**, **2b** and **2c**.

As shown in Table 1, although the $K_{ass}$ values remain very close to each other, a clear trend is seen for the entropic contribution. On moving from the short methylene linker to the longer and flexible ones, the negative $T\Delta S°$ term first becomes almost neutral and then positive. Particularly appealing for the realization of robust supramolecular architectures is the favourable thermodynamics of the **1b·2c** system. In this case, the high flexibility of the polyethylene glycol spacer imparts conformational freedom in the final complex, which reduces the entropy loss that generally occurs during self-association and leads to a process that is both enthalpy- and entropy-driven. As control experiments, the titration of **2c**

Table 1. Thermodynamic parameters and $K_{ass}$ values for ITC titration of **1b** with **2a**, **2b** and **2c** in methanol at 25 °C. [**1b**] = 0.5 mM; [guest] = 4 mM. All data fitted the 1:1 binding profile well.

| | $K_{ass}$ [$M^{-1}$] | $\Delta H°$ [kJ mol$^{-1}$] | $T\Delta S°$ [kJ mol$^{-1}$] | $\Delta G°$ [kJ mol$^{-1}$] |
|---|---|---|---|---|
| **1b·2a** | $(1.3\pm0.1)\times10^5$ | $-34.8\pm0.6$ | $-5.6\pm0.5$ | $-29.2\pm0.2$ |
| **1b·2b** | $(8.4\pm0.6)\times10^4$ | $-26.7\pm0.3$ | $1.5\pm0.4$ | $-28.2\pm0.2$ |
| **1b·2c** | $(4.9\pm0.2)\times10^5$ | $-25.4\pm0.1$ | $7.1\pm0.3$ | $-32.5\pm0.1$ |

Table 2. Thermodynamic parameters and $K_{ass}$ values for ITC titration of **2c** with **1a** and **1c** in methanol at 25 °C. [host] = 0.5 mM; [**2c**] = 4 mM. All data fitted well for a 1:1 binding profile.

| | $K_{ass}$ [$M^{-1}$] | $\Delta H°$ [kJ mol$^{-1}$] | $T\Delta S°$ [kJ mol$^{-1}$] | $\Delta G°$ [kJ mol$^{-1}$] |
|---|---|---|---|---|
| **1a·2c** | $(2.3\pm0.2)\times10^5$ | $-25.4\pm0.5$ | $5.1\pm0.3$ | $-30.6\pm0.2$ |
| **1c·2c** | $(3.9\pm0.2)\times10^5$ | $-23.9\pm0.2$ | $8.0\pm0.2$ | $-31.9\pm0.1$ |

was repeated with **1a** and **1c** to test the efficiency of these other hosts. As highlighted in Table 2, no significant differences are observed in comparison to **1b·2c**. Therefore, within the domain of the ditopic hosts the different flexibility of the spacers does not affect the thermodynamic signature of the host–guest interaction.

The most relevant result obtained from ITC measurements is the solvent effect. When the titration between **1b** and **2c** was repeated in dichloromethane, a gain of two orders of magnitude for the $K_{ass}$ value was recorded on moving from MeOH to $CH_2Cl_2$ (at 25 °C, [**1b**] = 0.4 mM and [**2c**] = 2.5 mM, $K_{ass} = (1.8\pm0.5)\times10^7\,M^{-1}$, $\Delta H° = -35.3\pm0.2$ kJ mol$^{-1}$, $T\Delta S° = 6.0\pm0.5$ kJ mol$^{-1}$, $\Delta G° = -41.2\pm0.6$ kJ mol$^{-1}$). The ITC data indicate that the gain is totally enthalpic in origin. This result can be rationalized by taking into account two factors: 1) the limited solvation exerted by dichloromethane on the methylpyridinium moieties, which leads to a preference for its inclusion in the cavity; 2) the host affinity for MeOH, which competes with the guest for cavity complexation.[19] The combination of the two factors accounts for the large decrease in complexation observed in MeOH. Because of the higher association constant assured by chlorinated solvents, they were chosen as eligible media for creation of polymeric chains.

**Viscosity and static light scattering measurements**: To evaluate the average degree of polymerization in the self-assembly of **1b** and **2c**, viscosity measurements were carried out in chloroform at 25 °C. While a linear relationship between concentration and specific viscosity was initially observed (1.8–31.5 g L$^{-1}$, 0.4–7 mM), a sharp rise in viscosity was recorded upon increasing the concentration (Figure 2a). Three distinct regions can be distinguished in the corresponding log–log plot (Figure 2b), indicative of a gradual transition from cyclic to linear species.[20]

At low concentrations, the slope of the linear fit is about 1.4, as expected for cyclic oligomers with constant size.[20] Further evidence for the formation of cyclic structures in this concentration regime came from static light scattering (SLS) measurements providing the average molecular weight ($M_w$) in the concentration range of 1.5–4.0 mM

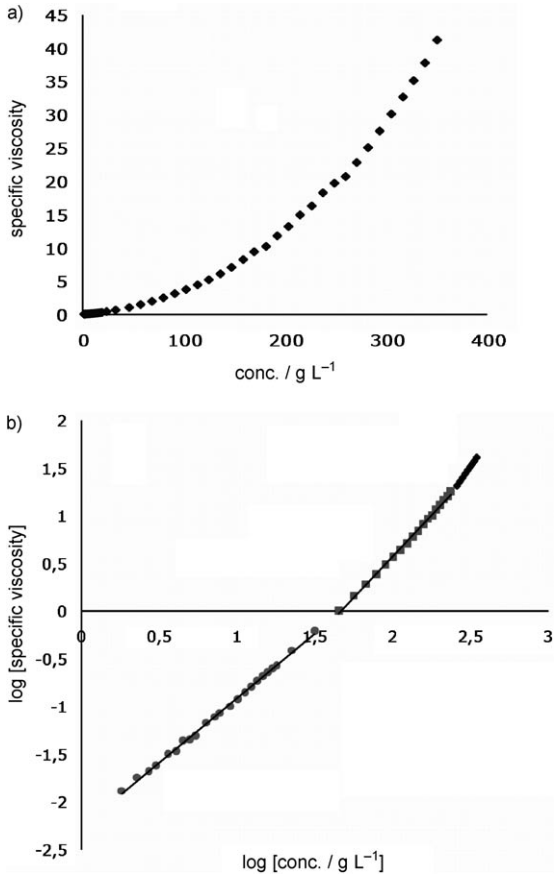



Figure 2. a) Specific viscosity vs. concentration and b) log–log plot of specific viscosity vs. concentration for a solution of a mixture of **1b** and **2c** (1:1) in chloroform. ●: 31.5–1.8 g L$^{-1}$ (7.0–0.4 mM), $y = 1.3509x - 2.2602$, $R^2 = 0.9982$; ■: 237.1–45.0 g L$^{-1}$ (52.5–10.0 mM), $y = 1.7378x - 2.8984$, $R^2 = 0.9975$; ◆: 350.3–248.3 g L$^{-1}$ (77.5–57.5 mM), $y = 2.2841x - 4.1968$, $R^2 = 0.9998$.

(Table 3). Below this threshold concentration, the low number of connected monomer units $N$ obtained is in agreement with the presence of $(H+G)_1$ or $(H+G)_2$ cyclic oligomers.

In the intermediate concentration regime (slope of 1.7) the fraction of open oligomers increases at the expense of the cyclic adducts. The formation of linear supramolecular polymers was observed at higher concentrations, where a further rise in viscosity was observed (slope of 2.28). The recorded final slope of the curve is comparable to that of ureidopyrimidone-based self-assembling systems reported by Meijer, Schenning et al. (slope of 2.48).[21] This result is justi-

Table 3. SLS measurements of $M_w$ for a 1:1 mixture of **1b** and **2c** in chloroform ($dn/dc = 0.102$ mL g$^{-1}$).

| $c$ [g L$^{-1}$] | $M_w$ | $N$ |
|---|---|---|
| 7 (1.5 mM) | 4500 | (H+G) |
| 7.8 (1.7 mM) | 4500 | (H+G) |
| 8.8 (1.9 mM) | 4700 | (H+G) |
| 16.6 (3.6 mM) | 8700 | $(H+G)_2$ |
| 18.5 (4.0 mM) | 9500 | $(H+G)_2$ |
| 20.7 (4.6 mM) | out of scale | – |

fied by the troublesome achievement of the exact 1:1 ratio between host and guest due to the polydispersity of the PEG-based monomer. Taking into account the detrimental effect that even tiny deviations from the 1:1 ratio have on the degree of polymerization,[1a] the obtained results are consistent with the formation of reasonably long polymeric chains.

The specific viscosity of a solution of unfunctionalized PEG ($M_w = 1500$ Da; 40 mM) in chloroform was measured to be 0.4, and thus the higher value observed for the **1b·2c** system cannot be simply related to the presence of the PEG spacer in the BB monomers. Moreover, control experiments performed by measuring the viscosity of 1:2 mixtures of **1b** and monotopic *N*-methyl(propylisonicotinate) iodide (compound **4**, Supporting Information) at different concentrations in $CHCl_3$ revealed that the viscosity increased from 0.1 to 0.6 at 0.5 mM and 40 mM, respectively (see Figure S11, Supporting Information). Thus, short oligomeric species (trimers in this specific case) cannot account for the high viscosities recorded for **1b·2c** in the high-concentration regime.

Additional viscosity measurements were performed in 1,1′,2,2′-tetrachloroethane as a function of temperature. An equimolar solution of **1b** and **2c** (40 mM) was heated from 25 to 80 °C, and first showed a decrease in specific viscosity, followed by an increase above a critical temperature of 50 °C (Figure 3).

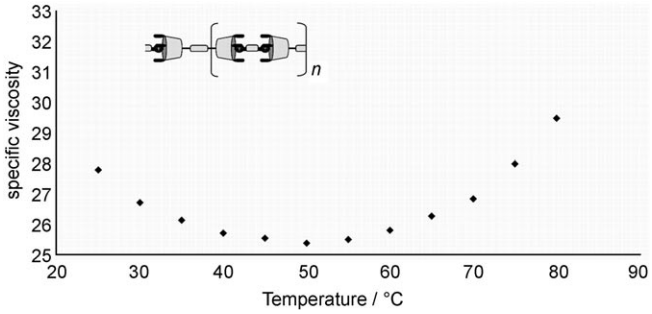



Figure 3. Specific viscosity of a solution of a mixture of **1b** and **2c** (1:1) in tetrachloroethane as a function of temperature.

This behaviour is in line with the thermodynamic signature of host–guest polymerization. As discussed in the ITC section, complexation and polymerization of **1b·2c** is both enthalpy- and entropy-driven. However, enthalpy is more effective at 25 °C, so that in the low-temperature regime heating negatively affects polymerization by inducing reversible formation of smaller oligomeric and cyclic species, and accounts for the observed viscosity decrease. Nevertheless, because entropy also plays a favourable role in the complexation, a critical temperature should exist above which the entropic contribution becomes dominant. At this temperature, sufficient energy is provided to the system to break small rings, and consequently elongation of the PEG chains is allowed. This occurs by exposing "reactive end groups" on the different oligomers, causing their assembly into long polymeric species that are responsible for the recorded viscosity increase. On cooling the solution and measuring its viscosity again at 25 °C, a higher value than the starting one is recorded (34.8 versus 26.7). This hysteresis is indicative of the higher stability of the polymeric species with respect to the corresponding cyclic adducts in a medium-high concentration regime.

As a control experiment, the same temperature-dependent measurements were performed on a solution of unfunctionalized PEG (40 mM) in 1,1′,2,2′-tetrachloroethane. A similar trend was observed, even though the viscosity enhancement above 50 °C was definitely less marked. It can be attributed to elongation of the PEG chains (see Figure S12, Supporting Information). This hypothesis is further supported by the fact that when the solution was cooled at room temperature, its initial viscosity was restored.

**X-ray analysis**: An equimolar mixture of rigid homoditopic host **1c** and methyl viologen hexafluorophosphate was crystallized from acetonitrile/water (9:1). A section of the crystal packing (Figure 4) highlights the eight P=O groups facing inward toward the cavity and making ion–dipole interactions with the positively charged nitrogen atom of the methyl viologen guest. The average $N^+\cdots O{=}P$ distance is $3.04 \pm 0.03$ Å, and the average distance between the protons of the $CH_3$-pyridinium moiety and the plane of the aromatic rings is $3.60 \pm 0.02$ Å. One $PF_6^-$ counterion is located at the bottom of the cavity and interacts with the alkyl chains at the lower rim of the cavitand. Moreover, one of the P–F bonds points toward the centre of the cavity, stabilising the ion pair with the complexed methylpyridinium moiety.[22]

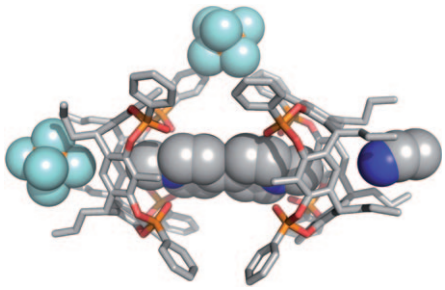


Figure 4. Section of the linear polymer **1c**·methyl viologen featuring ion–dipole and CH–π interactions, and fitting of one $PF_6^-$ counterion between the alkyl chains of the cavitands.

The crystal structure was obtained by the molecular replacement method with the atomic coordinates of a monotopic tetraphosphonate cavitand as search model.[23] The solution showed two crystallographically independent monotopic molecules in the $P2_1/n$ space group, in agreement with a single molecule of **1c** in the asymmetric unit. During refinement, two $PF_6^-$ ions (one distributed over three sites at partial occupancy) and 2.5 molecules of acetonitrile (placed in four sites: one site at full occupancy and three sites at

half occupancy each) were detected in the asymmetric unit. The analysis of electron density maps obtained after the initial refinement cycles revealed regions with residual electron density. The electron density observed in the region between the two resorcinarene cavities was successfully assigned to a methyl viologen molecule. Moreover, another region of residual electron density was located close to an alkyl chain on the lower rim of a resorcinarene moiety (Figure S13, Supporting Information), assignable to residual 3,5-dicarboxypyridine, the linker between the two host moieties. In the following refinement cycles, this fragment was introduced into the model, but attempts to find its correct position to interpret the electron density were hampered by the high degree of disorder of this group. Seven possible positions for the 3,5-dicarboxypyridine residue were modelled for the site of the linker. However, refined structures showed high values for the thermal parameters of the atoms of the 3,5-dicarboxypyridine and high values of the *R* factor in all cases. Nonetheless, the seven positions that were not excluded by topology considerations support a polymeric supramolecular structure (Figure 5). In fact, in all these models, the resorcinarene cavities linked by the dicarboxypyridine face in opposite directions, as in the polymeric configuration, rather than towards the same direction, as would be expected for formation of tetrameric rings.

## Conclusion

Host–guest-driven self-assembly of complementary homoditopic molecules has been exploited to realize supramolecular copolymers both in solution and in the solid state. An accurate thermodynamic description of the binding events leading to polymerization was obtained by ITC. The highly desirable positive entropic contribution to binding requires the introduction of a flexible spacer in the guest co-monomer. However, the conformational mobility of the spacer allows for the formation of cyclic species, absent in the parent homopolymer.[9] Viscosity measurements demonstrated the strong influence that both monomer concentration and temperature exert on the conversion of cyclic oligomeric species to linear polymeric chains.[24] The crystal structure of the copolymer between methyl viologen and **1a**/**1c** validates the proposed interaction mode among the monomeric units and shows the preference of the system for linear polymerization in the solid state.

The formation of supramolecular alternating copolymer **1b**·**2c** is particularly significant, due to the polymeric nature of monomer **2c**. The dilution of the two interacting units at the end of a long alkyl chain does not hamper polymer assembly, on account of the positive entropic contribution to binding. This bodes well for the use of this host–guest system in topological and miscibility control of covalent polymers. Moreover, the pyridine ligand embedded in ditopic host linker **1c** can be used as a ligand for metal-directed switching from linear to cross-linked supramolecular networks.

## Experimental Section

**General**: All reagents and chemicals were purchased from commercial sources and used without further purification. Pyridine was dried before use by distillation from KOH according to the standard procedures.

$^1$H NMR spectra were obtained by using a Bruker AC-300 (300 MHz) or a Bruker AVANCE 300 (300 MHz) spectrometer. All chemical shifts, $\delta$, are reported in ppm relative to the proton resonances resulting from incomplete deuteration of the NMR solvents. $^{31}$P NMR spectra were obtained by using a Bruker AMX-400 (162 MHz) spectrometer.

ESI-MS experiments were performed by using a Waters ZMD spectrometer equipped with an electrospray interface. Exact masses were determined by using a LTQ ORBITRAP XL Thermo spectrometer equipped with an electrospray interface. GC-MS analysis was performed by using a (Hewlett Packard) HP 6890/5973 GC/MSD system.

Static light scattering (SLS) measurements were performed by using a multi-angle laser light scattering (MALS) Dawn DSP-F photometer from Wyatt (Santa Barbara, CA, USA) in off-line (batch) mode in freshly distilled chloroform at RT. All polymer solutions were accurately filtered through 0.2 μm PTFE filters. The MALS photometer used a vertically

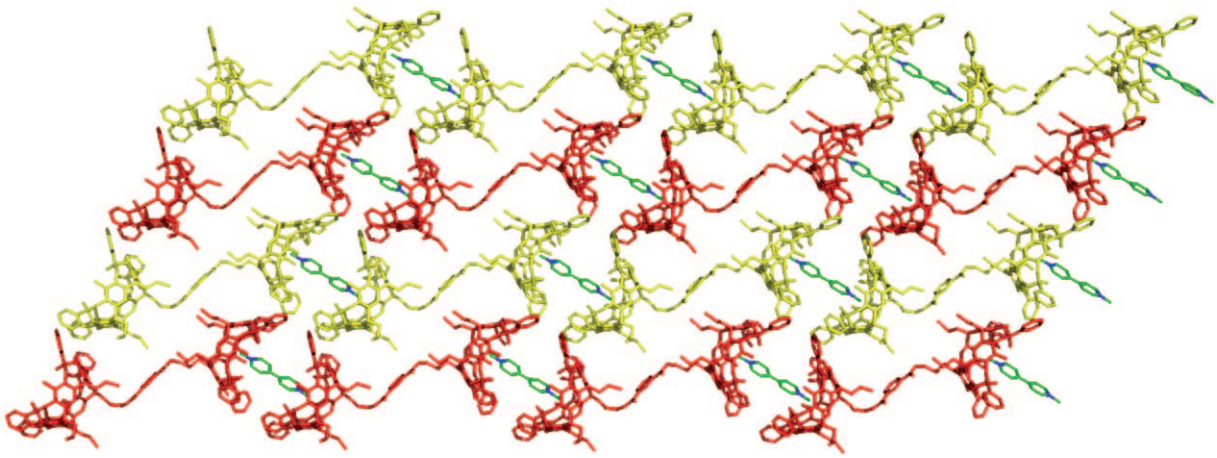


Figure 5. Structure of the alternate copolymer formed by self-assembly between methyl viologen and **1c**. Experimental details are given in the Supporting Information.

polarized He–Ne laser ($\lambda = 632.8$ nm) and simultaneously measured the intensity of the scattered light at 18 angular locations ranging from 19.2 to 149.2°. The MALS calibration constant was calculated by using toluene as a standard and assuming a Rayleigh factor of $1.406\times10^{-5}$ cm$^{-1}$. The different photodiodes were normalized by measuring the scattering intensity of a polystyrene standard of narrow molecular weight distribution ($M_p = 10.3$ kg mol$^{-1}$, $M_w/M_n = 1.03$, $R_g = 2.6$ nm) in chloroform, assumed to act as isotropic scatterer.

The incremental refractive index *dn*/*dc* for an equimolar mixture of **1b** and **2c** in chloroform ($n = 1.446$) at 25 °C was measured to be 0.102 mL g$^{-1}$ by using a KMX-16 differential refractometer from LDC Milton Roy (Riviera Beach, FL, USA).

ITC studies were performed by using an isothermal titration microcalorimeter MicroCal VP-ITC, thermostated at 25 °C. Experimental titration curves were analyzed by using the MicroCal Origin 5.0 program. $\Delta H$, $\Delta S$ and $K_{ass}$ values were calculated as the average of a set of independent experiments; $\Delta G$ value is given by $\Delta G = \Delta H - T\Delta S$. Standard deviations for $\Delta H$, $\Delta S$ and $K$ were calculated according to Equation (1):

$$\sqrt{\frac{\Sigma_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \quad (1)$$

in which $n$ is the number of three independent experiments, $x_i$ is the value recorded in the $i$-experiment, and $\bar{x}$ is the average value for $x$. Standard deviation for $\Delta G$ was calculated according to Equation (2):

$$\delta(\Delta G) = \sqrt{[(\partial G/\partial K_{ass})\delta(K_{ass})]^2} = \sqrt{[-RT\delta(K_{ass})/K_{ass}]^2} = RT\delta(K_{ass})/K_{ass} \quad (2)$$

Enthalpies of dilution of the hosts and the guests were determined in separate experiments, and found to be negligible. All the measurements were carried out by titrating a host solution (in the cell) with a guest solution (in the syringe).

Viscosity measurements were performed by using an Ubbelohde dilution viscometer. Solutions of polymers were prepared in chloroform (HPLC grade) or 1,1′,2,2′-tetrachloroethane (98%, GC grade). The temperature was controlled by using a thermostated water bath (for the experiments at 25 °C) or an oil bath (for measurements at variable temperature). Solvents and solutions were filtered through 0.2 μm Teflon membrane filters directly into the viscometer.

The molecular structure of $C_{156}H_{153}N_3O_{28}P_8{\cdot}2\,PF_6^-{\cdot}2.5\,CH_3CN$ was determined by single-crystal X-ray diffraction. Experimental details are summarized in Table S1 (see Supporting Information). Intensity data were collected with $Cu_{K\alpha}$ radiation ($\lambda = 1.54$ Å) and a CCD area detector at −173 °C. The structure was solved by direct methods with DENZO-SMN, SCALEPACK and AMoRe SHELXL programs.

**Methylenebis(silylcavitand) IIa**: Dimethoxymethane (0.86 mL, $9.72\times10^{-3}$ mol) and *p*-toluenesulfonic acid monohydrate (0.02 g, $1.26\times10^{-4}$ mol) were added to a solution of silylcavitand **I** (2.06 g, $2.16\times10^{-3}$ mol) in dry $CH_2Cl_2$ (25 mL). The reaction mixture was heated to reflux overnight under nitrogen by using a modified Soxhlet extractor filled with molecular sieves (3 Å). The mixture was allowed to cool and washed with 0.3 M NaOH to neutralize the acid catalyst. Concentration of the organic phase to dryness afforded the crude product, which was purified by silica column chromatography ($CH_2Cl_2$/MeOH 99:1) to give pure **IIa** (0.66 g, 32%). $^1$H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 7.19$ (s, 4H; ArH), 7.18 (s, 4H; ArH), 4.71 (s, 2H; $OCH_2O$), 4.61 (t, $^3J$(H,H) = 8.0 Hz, 8H; ArCH), 3.62 (brt, 4H; $CH_2CH_2O$), 2.27 (m, 4H; $CH_2CH_2CH_2O$), 2.17 (m, 12H; $CH_2CH_2CH_3$), 1.91 (s, 24H; $ArCH_3$), 1.58 (m, 4H; $CH_2CH_2CH_2O$), 1.30 (m, 12H; $CH_2CH_2CH_3$); 0.98 (t, $^3J$(H,H) = 6.6 Hz, 18H; $CH_2CH_2CH_3$), 0.71 (s, 24H; $SiCH_{3,out}$), −0.69 ppm (s, 24H; $SiCH_{3,in}$); ESI-MS: *m*/*z* calcd for $C_{105}H_{144}O_{18}Si_8Na^+$: 1941.8; found: 1941.5 $[M+Na]^+$.

**Adipic acid bis(silylcavitand) ester IIb**: Silylcavitand **I** (0.34 g, $3.57\times10^{-4}$ mol), DCC (0.07 g, $3.57\times10^{-4}$ mol) and DMAP (0.02 g, $1.18\times10^{-4}$ mol) were added to a solution of adipic acid (0.03 g, $1.79\times10^{-4}$ mol) in dry $CH_2Cl_2$/DMF (95:5, 15 mL). The resulting suspension was stirred overnight at RT. The mixture was filtered, and the crude product, recovered by solvent evaporation, was purified by silica column chromatography ($CH_2Cl_2$) affording pure **IIb** (0.15 g, 42%). $^1$H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 7.16$ (s, 4H; ArH), 7.14 (s, 4H; ArH), 4.59 (t, $^3J$(H,H) = 7.9 Hz, 8H; ArCH), 4.12 (t, $^3J$(H,H) = 6.6 Hz, 4H; $CH_2OC(O)CH_2$), 2.30 (m, 4H; $CH_2OC(O)CH_2$), 2.16 (m, 16H; $ArCHCH_2$), 1.89 (s, 24H; $ArCH_3$), 1.64 (m, 4H+4H; $OC(O)CH_2CH_2CH_2CH_2C(O)O + CH_2CH_2CH_2O$), 1.28 (m, 12H; $CH_2CH_2CH_3$), 0.96 (m, 18H; $CH_2CH_2CH_3$), 0.50 (s, 24H; $SiCH_{3,out}$), −0.70 ppm (s, 24H; $SiCH_{3,in}$); ESI-MS: *m*/*z* calcd for $C_{110}H_{150}O_{20}Si_8Cl^-$: 2052.5; found: 2052.3 $[M+Cl]^-$.

**3,5-Pyridinedicarboxylic acid bis(silylcavitand) ester IIc**: DCC (0.05 g, $2.61\times10^{-4}$ mol) and DMAP (0.01 g, $8.73\times10^{-5}$ mol) were added to a solution of 3,5-pyridinedicarboxylic acid (0.02 g, $1.20\times10^{-4}$ mol) in dry $CH_2Cl_2$/DMF (8:1, 9 mL). The resulting suspension was stirred at RT until complete dissolution. Silylcavitand **I** (0.25 g, $2.61\times10^{-4}$ mol) was added. The reaction mixture was stirred at RT for 24 h and finally quenched by solvent removal. The crude was suspended in water (10 mL) and filtered. Purification by silica column chromatography ($CH_2Cl_2$/EtOH 99:1) yielded desired product **IIc** (0.11 g, 41%). $^1$H NMR (300 MHz, $CDCl_3$, 25 °C): $\delta = 9.32$ (d, $^5J$(H,H) = 2.0 Hz, 2H; $H_{p\text{-}py}$), 8.81 (d, $^5J$(H,H) = 2.0 Hz, 1H; $H_{o\text{-}py}$), 7.16 (s, 4H; ArH), 7.14 (s, 4H; ArH), 4.62 (t, $^3J$(H,H) = 8.1 Hz, 8H; ArCH), 4.45 (t, $^3J$(H,H) = 6.7 Hz, 4H; $CH_2OC(O)$), 2.32 (m, 4H; $CH_2CH_2CH_2OC(O)$), 2.17 (m, 12H; $ArCHCH_2$), 1.87 (s, 24H; $ArCH_3$), 1.82 (m, 4H; $CH_2CH_2CH_2OC(O)$), 1.27 (m, 12H; $ArCHCH_2CH_2$), 0.94 (m, 18H; $CH_2CH_2CH_3$), 0.51 (s, 24H; $SiCH_{3,out}$), −0.68 ppm (s, 24H; $SiCH_{3,in}$); ESI-MS: *m*/*z* calcd for $C_{111}H_{145}NO_{20}Si_8Na^+$: 2061.0; found: 2060.8 $[M+Na]^+$.

**Methylenebis(resorcinarene) IIIa**: An aqueous solution of HF (36%; 1.3 mL) was added to **IIa** (0.66 g, $3.44\times10^{-4}$ mol) in $CHCl_3$/DMF (1/1, 30 mL). The mixture was heated at 45 °C overnight. The solvent was removed in vacuo and the product suspended in water. Vacuum filtration afforded pure **IIIa** (0.46 g, 91%). $^1$H NMR (300 MHz, [D$_6$]acetone, 25 °C): $\delta = 7.95$ (s, 16H; ArOH), 7.44 (s, 4H; ArH), 7.43 (s, 4H; ArH), 4.64 (s, 2H; $OCH_2O$), 4.41 (t, $^3J$(H,H) = 7.5 Hz, 8H; ArCH), 3.57 (t, $^3J$(H,H) = 6.6 Hz, 4H; $CH_2CH_2O$), 2.35 (m, 4H; $CH_2CH_2CH_2O$), 2.28 (m, 12H; $CH_2CH_2CH_3$), 2.05 (s, 24H; $ArCH_3$), 1.56 (m, 4H; $CH_2CH_2CH_2O$), 1.31 (m, 12H; $CH_2CH_2CH_3$), 0.95 ppm (m, 18H; $CH_2CH_2CH_3$); ESI-MS: *m*/*z* calcd for $C_{89}H_{111}O_{18}^-$: 1967.8; found: 1467.9 $[M-H]^-$.

**Adipic acid bis(resorcinarene) ester IIIb**: An aqueous solution of HF (36%; 0.4 mL) was added to **IIb** (0.42 g, $2.33\times10^{-4}$ mol) in $CHCl_3$/DMF (1:1, 16 mL). The mixture was heated at 45 °C overnight. The solvent was removed in vacuo and the product was suspended in water. Vacuum filtration afforded pure **IIIb** (0.37 g, quantitative yield). $^1$H NMR (300 MHz, (300 MHz, [D$_6$]DMSO, 25 °C): $\delta = 8.63$ (s, 16H; ArOH), 7.25 (s, 8H; ArH), 4.19 (t, $^3J$(H,H) = 7.3 Hz, 8H; ArCH), 4.01 (t, $^3J$(H,H) = 6.2 Hz, 4H; $CH_2OC(O)CH_2$), 2.21 (m, 4H+16H; $CH_2OC(O)CH_2$ + $ArCHCH_2$), 1.90 (s, 24H; $ArCH_3$), 1.47 (m, 4H+4H; $OC(O)CH_2CH_2CH_2CH_2(O)CO + CH_2CH_2CH_2O$), 1.17 (m, 12H; $CH_2CH_2CH_3$), 0.88 ppm (m, 18H; $CH_2CH_2CH_3$); ESI-MS: *m*/*z* calcd for $C_{94}H_{117}O_{20}^-$: 1566.8; found: 1467.0 $[M-H]^-$.

**3,5-Pyridinedicarboxylic acid bis(resorcinarene) ester IIIc**: An aqueous solution of HF (36%; 0.8 mL) was added to **IIc** (1.0 g, $4.90\times10^{-4}$ mol) dissolved in $CHCl_3$/DMF (1/1, 30 mL). The mixture was heated at 45 °C overnight. The solvent was removed in vacuo and the product was suspended in water. Vacuum filtration afforded pure **IIIc** (0.75 g, 96%). $^1$H NMR (300 MHz, [D$_6$]DMSO, 25 °C): $\delta = 9.25$ (d, $^5J$(H,H) = 2.0 Hz, 2H; $H_{p\text{-}py}$), 8.63 (s, 16H; ArO*H*), 7.93 (d, $^5J$(H,H) = 2.0 Hz, 1H; $H_{o\text{-}py}$), 7.25 (s, 8H; ArH), 4.37 (t, $^3J$(H,H) = 8.1 Hz, 8H; ArCH), 4.19 (t, $^3J$(H,H) = 6.7 Hz, 4H; $CH_2OC(O)$), 2.35 (m, 4H; $CH_2CH_2CH_2OC(O)$), 2.18 (m, 12H; $ArCHCH_2$), 1.91 (s, 24H; $ArCH_3$), 1.80 (m, 4H; $CH_2CH_2CH_2OC(O)$), 1.20 (m, 12H; $ArCHCH_2CH_2$), 0.87 ppm (m, 18H; $CH_2CH_2CH_3$); ESI-MS: *m*/*z* calcd for $C_{95}H_{112}NO_{20}^-$: 1587.8; found: 1587.8 $[M-H]^-$.

**Methylenebis(tetraphosphonate cavitand) 1a**: Dichlorophenylphosphine (0.36 mL, $2.64\times10^{-4}$ mol) was added slowly at RT to a solution of **IIIa** (0.46 g, $3.10\times10^{-4}$ mol) in freshly distilled pyridine (20 mL) under argon. After stirring for 3 h at 70 °C, the solution was allowed to cool to RT and a mixture of aqueous 35% $H_2O_2$ and $CHCl_3$ (1:1, 12 mL) was added. The

resulting mixture was stirred for 30 min at RT, and then the solvent was removed in vacuo. Addition of water resulted in precipitation of a white powder, which was collected by filtration to give pure **1a** (0.74 g, 97%). $^1$H NMR (300 MHz, [D$_6$]acetone, 25°C): $\delta$ = 8.12 (m, 16H; P(O)ArH$_o$), 7.74 (m, 8H; P(O)ArH$_p$), 7.64 (m, 8H+8H; ArH+P(O)ArH$_m$), 4.88 (t, $^3J$(H,H) = 7.6 Hz, 8H; ArCH), 4.71 (s, 2H; OCH$_2$O), 3.64 (br t, 4H; CH$_2$CH$_2$O), 2.47 (m, 16H; ArCHCH$_2$), 2.10 (s, 24H; ArCH$_3$), 1.65 (m, 4H; CH$_2$CH$_2$CH$_2$O), 1.42 (m, 12H; CH$_2$CH$_2$CH$_3$), 1.00 ppm (m, 18H; CH$_2$CH$_2$CH$_3$); $^{31}$P NMR (162 MHz, CDCl$_3$, 25°C): $\delta$ = 5.64 ppm (s, P(O)); HR-ESI-MS: *m/z* calcd for $C_{137}H_{140}NO_{26}P_8^+$ 2462.75647; found: 2462.76380 $[M+NH_4]^+$.

**Adipic acid bis(tetraphosphonate cavitand) ester 1b**: Dichlorophenylphosphine (0.25 mL, $1.83\times10^{-3}$ mol) was added slowly to a solution of **IIIb** (0.35 g, $2.23\times10^{-4}$ mol) in freshly distilled pyridine (10 mL) at RT under argon. After 3 h of stirring at 70°C, the solution was allowed to cool to RT and a mixture of aqueous 35% $H_2O_2$ and $CHCl_3$ (1:1, 10 mL) was added. The resulting mixture was stirred for 30 min at RT, then the solvent was removed in vacuo. Addition of water resulted in the precipitation of a white powder, which was collected by filtration to give pure **1b** (0.55 g, 97%). $^1$H NMR (300 MHz, CDCl$_3$, 25°C): $\delta$ = 8.08 (m, 16H; P(O)ArH$_o$), 7.68–7.52 (m, 8H+16H; P(O)ArH$_p$+P(O)ArH$_m$), 7.25 (s, 8H; ArH), 4.78 (t, $^3J$(H,H) = 7.8 Hz, 8H; ArCH), 4.21 (t, $^3J$(H,H) = 6.0 Hz, 4H; CH$_2$OC(O)), 2.46–2.27 (m, 4H+16H; CH$_2$OC(O)CH$_2$+ArCHCH$_2$), 2.13 (s, 24H; ArCH$_3$), 1.74 (m, 4H; CH$_2$CH$_2$CH$_2$O), 1.62 (m, 4H; OC(O)CH$_2$CH$_2$CH$_2$CH$_2$(O)CO), 1.42 (m, 12H; CH$_2$CH$_2$CH$_3$), 1.06 ppm (m, 18H; CH$_2$CH$_2$CH$_3$); $^{31}$P NMR (162 MHz, CDCl$_3$/D$_2$O, 25°C): $\delta$ = 6.59 ppm (s, P(O)); HR-ESI-MS: *m/z* calcd for $C_{142}H_{143}O_{28}P_8^+$: 2543.76669; found: 2543.77453 $[M+H]^+$.

**3,5-Pyridinedicarboxylic acid bis(tetraphosphonate cavitand) ester 1c**: Dichlorophenylphosphine (0.14 mL, $1.03\times10^{-3}$ mol) was added slowly to a solution of **IIIc** (0.20 g, $1.26\times10^{-4}$ mol) in freshly distilled pyridine (10 mL) at RT under argon. After stirring for 3 h at 70°C, the solution was allowed to cool to RT and a mixture of aqueous 35% $H_2O_2$ and $CHCl_3$ (1:1, 8 mL) was added. The resulting mixture was stirred for 30 min at RT, then the solvent was removed in vacuo. Addition of water resulted in the precipitation of a white powder, which was collected by filtration to give pure **1c** (0.31 g, $1.21\times10^{-4}$ mol, 90%). $^1$H NMR (300 MHz, CDCl$_3$, 25°C): $\delta$ = 9.25 (d, $^5J$(H,H) = 2.0 Hz, 2H; H$_{p\text{-py}}$), 8.80 (d, $^5J$(H,H) = 2.0 Hz, 1H; H$_{o\text{-py}}$), 8.05 (m, 16H; P(O)ArH$_o$), 7.63–7.53 (m, 8H+16H; P(O)ArH$_p$+P(O)ArH$_m$), 7.24 (s, 8H; ArH), 4.80 (t, $^3J$(H,H) = 7.4 Hz, 8H; ArCH), 4.53 (t, $^5J$(H,H) = 6.3 Hz, 4H; CH$_2$OC(O)), 2.50 (m, 4H; CH$_2$CH$_2$CH$_2$OC(O)), 2.33 (m, 12H; ArCHCH$_2$), 2.20 (s, 24H; ArCH$_3$), 1.92 (m, 4H; CH$_2$CH$_2$CH$_2$OC(O)), 1.20 (m, 12H; ArCHCH$_2$CH$_2$), 1.00 ppm (m, 18H; CH$_2$CH$_2$CH$_3$); $^{31}$P NMR (162 MHz, CDCl$_3$, 25°C): $\delta$ = 4.02 ppm (s, P(O)); HR-ESI-MS: *m/z* calcd for $C_{143}H_{138}NO_{28}P_8^+$ 2564.73065; found: 2564.73965 $[M+H]^+$.

**Ethylene glycol diisonicotinate (IVa)**: Ethylene glycol (1.16 mL, $2.81\times10^{-3}$ mol) was added to a solution of isonicotinoyl chloride hydrochloride (1.50 g, $8.42\times10^{-3}$ mol) in pyridine (15 mL). The reaction mixture was stirred at 100°C for 3 h and the solvent was removed under vacuum. A solution of potassium carbonate in water (20 mL) was added and the mixture extracted with $CH_2Cl_2$. Concentration to dryness of the organic phase afforded pure **IVa** (0.82 g, 71%). $^1$H NMR (300 MHz, CDCl$_3$, 25°C): $\delta$ = 8.79 (d, $^3J$(H,H) = 6.1 Hz, 4H; H$_o$), 7.85 (d, $^3J$(H,H) = 6.1 Hz, 4H; H$_m$), 4.71 ppm (s, 4H; CH$_2$); GC-MS: *m/z* calcd for $C_{14}H_{12}N_2O_4$: 272.2; found: 272 $[M]^+$.

**1,6-Hexanediol diisonicotinate (IVb)**: 1,6-Hexanediol (1.22 g, $1.87\times10^{-3}$ mol) was added to a solution of isonicotinoyl chloride hydrochloride (1.00 g, $5.62\times10^{-3}$ mol) in pyridine (10 mL). The reaction mixture was stirred at 100°C for 3 h and then the solvent was removed under vacuum. The crude product was washed with an aqueous solution of $K_2CO_3$. Vacuum filtration afforded pure **IVb** (0.65 g, 70%). $^1$H NMR (300 MHz, CDCl$_3$, 25°C): $\delta$ = 8.75 (d, $^3J$(H,H) = 6.0 Hz, 4H; H$_o$), 7.82 (d, $^3J$(H,H) = 6.0 Hz, 4H; H$_m$), 4.35 (t, $^3J$(H,H) = 6.6 Hz, 4H; CH$_2$O), 1.80 (m, 4H; CH$_2$CH$_2$O), 1.51 ppm (m, 4H; CH$_2$CH$_2$CH$_2$O); GC-MS: *m/z* calcd for $C_{18}H_{20}N_2O_4$: 328.4; found: 328 $[M]^+$.

**α,ω-PEG diisonicotinate IVc**: PEG ($M_w$ = 1500 Da, 1.26 g, $8.43\times10^{-3}$ mol) was added to a solution of isonicotinoyl chloride hydrochloride (0.60 g, $3.35\times10^{-3}$ mol) in pyridine (25 mL). The reaction mixture was stirred at 100°C for 3 h and then the solvent was removed under vacuum. The crude product was washed with water and extracted with $CH_2Cl_2$. Concentration to dryness of the organic phase afforded pure **IVc** (2.06 g, 69%). $^1$H NMR (300 MHz, CDCl$_3$, 25°C): $\delta$ = 8.72 (d, $^3J$(H,H) = 6.0 Hz, 4H; H$_o$), 7.80 (d, $^3J$(H,H) = 6.0 Hz, 4H; H$_m$), 4.45 (t, $^3J$(H,H) = 4.8 Hz, 4H; CH$_2$OCC(O)), 3.78 (m, 4H; CH$_2$CH$_2$OC(O)), 3.58 ppm (m, 116H; O(CH$_2$CH$_2$O)$_{29}$).

**Ditopic guest with ethylene glycol spacer 2a**: $CH_3I$ (0.8 mL, $1.28\times10^{-2}$ mol) was added to a solution of **IVa** (0.82 g, $2.99\times10^{-3}$ mol) dissolved in $CHCl_3$/acetonitrile (2:1, 21 mL). The reaction mixture was stirred at reflux overnight. The solvent was removed in vacuo and the crude product was recrystallized from diethyl ether to give pure **2a** (1.40 g, 84%). $^1$H NMR (300 MHz, [D$_6$]DMSO, 25°C): $\delta$ = 9.18 (d, $^3J$(H,H) = 6.1 Hz, 4H; H$_o$), 8.51 (d, $^3J$(H,H) = 6.1 Hz, 4H; H$_m$), 4.78 (s, 4H; CH$_2$), 4.43 ppm (s, 6H; NCH$_3$); HR-ESI-MS: *m/z* calcd for $C_{16}H_{18}N_2O_4^{2+}$: 151.06278; found: 151.06267 $[M-2I]^{2+}$.

**Ditopic guest with 1,6-hexanediol spacer 2b**: $CH_3I$ (0.33 mL, $5.34\times10^{-3}$ mol) was added to a solution of **IVb** (0.40 g, $1.22\times10^{-3}$ mol) in acetonitrile (10 mL). The reaction mixture was stirred at reflux overnight. The solvent was removed in vacuo and the crude product was recrystallized from CH$_3$CN/EtOAc (1:1) to give pure **2b** (0.57 g, 76%). $^1$H NMR (300 MHz, [D$_6$]DMSO, 25°C): $\delta$ = 9.17 (d, $^3J$(H,H) = 6.5 Hz, 4H; H$_o$), 8.49 (d, $^3J$(H,H) = 6.5 Hz, 4H; H$_m$), 4.43 (s, 6H; NCH$_3$), 4.40 (t, $^3J$(H,H) = 6.6 Hz, 4H; CH$_2$O), 1.79 (m, 4H; CH$_2$CH$_2$O), 1.49 ppm (m, 4H; CH$_2$CH$_2$CH$_2$O); HR-ESI-MS: *m/z* calcd for $C_{20}H_{26}N_2O_4^{2+}$: 179.09408; found: 179.09427 $[M-2I]^{2+}$.

**Ditopic guest with 1,6-hexanediol spacer 2b***: $NH_4PF_6$ (0.45 g, $2.78\times10^{-3}$ mol) was added to a solution of **2b** (0.56 g, $9.26\times10^{-3}$ mol) in water (10 mL). The mixture was stirred at RT for 1 h. Vacuum filtration afforded pure **2b*** (0.53 g, 88%). $^1$H NMR (300 MHz, [D$_6$]DMSO, 25°C): $\delta$ = 9.11 (d, $^3J$(H,H) = 6.5 Hz, 4H; H$_o$), 8.45 (d, $^3J$(H,H) = 6.5 Hz, 4H; H$_m$), 4.39 (s, 6H; NCH$_3$), 4.37 (t, $^3J$(H,H) = 6.5 Hz, 4H; CH$_2$O), 1.75 (m, 4H; CH$_2$CH$_2$O), 1.45 ppm (m, 4H; CH$_2$CH$_2$CH$_2$O); $^{31}$P NMR (162 MHz, [D$_6$]DMSO, 25°C): $\delta$ = −141.2 ppm (s, PF$_6$); HR-ESI-MS: *m/z* calcd for $C_{20}H_{26}N_2O_4^{2+}$: 179.09408; found: 179.09375 $[M-2PF_6]^{2+}$.

**Ditopic guest with PEG spacer 2c**: $CH_3I$ (0.32 mL, $5.06\times10^{-3}$ mol) was added to a solution of **IVc** (2.06 g, $1.16\times10^{-3}$ mol) in acetonitrile (10 mL). The reaction mixture was stirred at reflux overnight. The solvent was removed in vacuo and the crude product was taken up with diethyl ether (3×20 mL) to give pure **2c** (1.86 g, 81%). $^1$H NMR (300 MHz, CDCl$_3$, 25°C): $\delta$ = 9.52 (d, $^3J$(H,H) = 6.5 Hz, 4H; H$_o$), 8.51 (d, $^3J$(H,H) = 6.0 Hz, 4H; H$_m$), 4.73 (s, 6H; NCH$_3$), 4.58 (t, $^3J$(H,H) = 4.9 Hz, 4H; CH$_2$OCC(O)), 3.68 (m, 4H; CH$_2$CH$_2$OC(O)), 3.69–3.58 ppm (m, 116H; O(CH$_2$CH$_2$O)$_{29}$); HR-ESI-MS: *m/z* calcd for $C_{80}H_{146}N_2O_{36}^{2+}$: 855.48222; found: 855.48242 $[M-2I]^{2+}$.

CCDC-787200 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

## Acknowledgements

This work was supported by the EC through the Project BION (ICT-2007-213219) and the Project FINELUMEN (PITN-GA-2008-215399). Financial support from INSTM to F.T. is gratefully acknowledged. We thank the Centro Interfacoltà di Misure "G. Casnati" of the University of Parma for the use of NMR and HR ESI-MS facilities, and Prof. J. de Mendoza from ICIQ in Tarragona (Spain) for ITC facilities. Finally we acknowledge Dr. R. Mendichi and A. Giacometti of CNR in Milano (Italy) for the use of SLS instrument.

[1] a) L. B. Brunsveld, B. J. B. Folmer, E. W. Meijer, R. P. Sijbesma, *Chem. Rev.* **2001**, *101*, 4071–4097; b) *Supramolecular Polymers*, 2nd ed. (Ed.: A. Ciferri), Francis & Taylor, New York, **2005**;

c) G. B. W. L. Ligthart, O. A. Scherman, R. P. Sijbesma, E. W. Meijer, *Macromolecular Engineering: Precise Synthesis, Materials, Properties, Applications* (Eds.: K. Matijaszewski, Y. Gnanou, L. Liebler), Wiley-VCH, Weinheim, **2007**, pp. 351–398.

[2] a) J.-M. Lehn in *Supramolecular Science: Where It Is and Where It Is Going* (Eds.: R. Ungaro, E. Dalcanale), Kluwer Academic Publishers, Dordrecht, **1999**, pp. 287–304; b) J.-M. Lehn, *Chem. Eur. J.* **1999**, *5*, 2455–2463; c) J.-M. Lehn, *Prog. Polym. Sci.* **2005**, *30*, 814–831; d) T. F. A. de Greef, E. W. Meijer, *Nature* **2008**, *453*, 171–173.

[3] B. J. B. Folmer, R. P. Sijbesma, R. M. Versteegen, J. A. J. van der Rijt, E. W. Meijer, *Adv. Mater.* **2000**, *12*, 874–878.

[4] L. Zang, Y. Che, J. S. Moore, *Acc. Chem. Res.* **2008**, *41*, 1596–1608.

[5] J. D. Hartgerink, E. Beniash, S. I. Stupp, *Science* **2001**, *294*, 1684–1688.

[6] a) P. Cordier, F. Tournilhac, C. Soulie-Ziakovic, L. Lieber, *Nature* **2008**, *451*, 977–980; b) S. Burattini, H. M. Colquhoun, J. D. Fox, D. Friedmann, B. W. Greenland, P. J. F. Harris, W. Hayes, M. E. Mackay, S. J. Rowan, *Chem. Commun.* **2009**, 6717–6720.

[7] T. Park, S. C. Zimmerman, *J. Am. Chem. Soc.* **2006**, *128*, 11582–11590.

[8] F. Wang, J. Zhang, X. Ding, S. Dong, M. Liu, B. Zheng, S. Li, L. Wu, Y. Yu, H. W. Gibson, F. Huang, *Angew. Chem.* **2010**, *122*, 1108–1112; *Angew. Chem. Int. Ed.* **2010**, *49*, 1090–1094.

[9] R. M. Yebeutchou, F. Tancini, N. Demitri, S. Geremia, R. Mendichi, E. Dalcanale, *Angew. Chem.* **2008**, *120*, 4580–4584; *Angew. Chem. Int. Ed.* **2008**, *47*, 4504–4508.

[10] a) H. Hofmeier, U. S. Schubert, *Chem. Commun.* **2005**, 2423–2432; b) M. J. Serpe, S. L. Craig, *Langmuir* **2007**, *23*, 1626–1634; c) T. F. A. De Greef, M. M. J. Smulders, M. Wolffs, A. P. H. J. Schenning, R. P. Sijbesma , E. W. Meijer, *Chem. Rev.* **2009**, *109*, 5687–5754.

[11] Hydrophobic interactions: a) cyclodextrins: A. Harada, Y. Takashima, H. Yamaguchi, *Chem. Soc. Rev.* **2009**, *38*, 875–882; b) cucurbiturils: U. Rauwald, O. A. Scherman, *Angew. Chem.* **2008**, *120*, 4014–4017; *Angew. Chem. Int. Ed.* **2008**, *47*, 3950–3953.

[12] Calixarenes: a) T. Haino, Y. Matsumoto, Y. Fukazawa, *J. Am. Chem. Soc.* **2005**, *127*, 8936–8937; b) S. Pappalardo, V. Villari, S. Slovak, Y. Cohen, G. Gattuso, A. Notti, A. Pappalardo, I. Pisagatti, M. F. Parisi, *Chem. Eur. J.* **2007**, *13*, 8164–8173; c) Rebek's polycaps represent a special case, in which hydrogen-bonding polymerization is driven by guest encapsulation: R. K. Castellano, D. M. Rudkevich, J. Rebek, Jr., *Proc. Natl. Acad. Sci. USA* **1997**, *94*, 7132–7137.

[13] Fullerenes: G. Fernández, E. M. Perz, L. Sanchez, N. Martin, *Angew. Chem.* **2008**, *120*, 1110–1113; *Angew. Chem. Int. Ed.* **2008**, *47*, 1094–1097.

[14] a) M. Miyauchi, A. Harada, *J. Am. Chem. Soc.* **2004**, *126*, 11418–11419; b) R. K. Castellano, J. Rebek, Jr., *J. Am. Chem. Soc.* **1998**, *120*, 3657–3663; c) K. Ohga, Y. Takashima, H. Takahashi, Y. Kawaguchi, H. Yamaguchi, A. Harada, *Macromolecules* **2005**, *38*, 5897–5904.

[15] E. Biavardi, G. Battistini, M. Montalti, R. M. Yebeutchou, L. Prodi, E. Dalcanale, *Chem. Commun.* **2008**, 1638–1640.

[16] B. Gadenne, M. Semeraro, R. M. Yebeutchou, F. Tancini, L. Pirondini, E. Dalcanale, A. Credi, *Chem. Eur. J.* **2008**, *14*, 8964–8971.

[17] a) A. Cooper, C. M. Johnson in *Microscopy, Optical Spectroscopy, and Macroscopic Techniques* (Eds.: C. Jones, B. Mulloy, A. H. Thomas), Humana Press, Totowa, **1994**, pp. 137–150; b) F. P. Schmidtchen in *Analytical Methods in Supramolecular Chemistry* (Ed.: C. A. Shalley), Wiley-VCH, Weinheim **2007**, pp. 55–78.

[18] Typical concentrations in ITC titrations for host and guest were 0.3–0.5 and 4–8 mM, respectively. In this low concentration regime, only oligomeric species can form, since the average polymerization degree for supramolecular structures is directly proportional to the concentration. It follows that the association constants reported here correspond to an average value for the formation of 1:1 oligomers (not truly polymeric materials).

[19] a) L. Pirondini, E. Dalcanale, *Chem. Soc. Rev.* **2007**, *36*, 695–706; b) M. Melegari, M. Suman, L. Pirondini, D. Moiani, C. Massera, F. Ugozzoli, E. Kalenius, P. Vainiotalo, J.-C. Mulatier, J.-P. Dutasta, E. Dalcanale, *Chem. Eur. J.* **2008**, *14*, 5772–5779.

[20] a) A. Einstein, *Ann. Phys.* **1906**, *324*, 289–306; b) M. E. Cates, *Macromolecules* **1987**, *20*, 2289–2296.

[21] R. Abbel, C. Grenier, M. J. Pouderoijen, J. W. Stouwdam, P. E. L. G. Leclere, R. P. Sijbesma, E. W. Meijer, A. P. H. J. Schenning, *J. Am. Chem. Soc.* **2009**, *131*, 833–843.

[22] R. De Zorzi, B. Dubessy, J.-C. Mulatier, S. Geremia, L. Randaccio, J.-P. Dutasta, *J. Org. Chem.* **2007**, *72*, 4528–4531.

[23] The tetraphosphonate cavitand used as model is compound **3** reported in reference [9].

[24] For a different cavitand homopolymer exhibiting a similar concentration and temperature behavior, see: F. Tancini, E. Rampazzo, E. Dalcanale, *Aust. J. Chem.* **2010**, *63*, 646–652.

Received: August 4, 2010
Published online: December 1, 2010