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Construction of supramolecular multi-component assemblies by using allosteric interactions

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ABSTRACT

Supramolecular complexes between two cavity-appended porphyrin hosts and three bifunctional guests are described. The host with a single cavity exclusively forms dimers with the bifunctional guests, while the double cavity host yields tetramers and higher order assemblies. The role of allosteric interactions in the binding and assembly process is highlighted.

1. Introduction

Cooperative interactions are common in nature; they are, for instance, employed to influence the composition and function of hierarchical, self-assembled systems such as the tobacco mosaic virus, and also to transfer information, like in the binding of oxygen to haemoglobin.[1–4] Cooperative interactions also play a critical role in gene transcription; for instance, cyclic AMP has a strong cooperative effect on the binding of the gene transcription regulating cAMP receptor protein (CRP) to DNA.[5] Chemists have recognised that utilising cooperative interactions might also help in the construction of functional nanoscale objects. In the past decades this type of interaction has received increasing attention and a myriad of self-assembled structures that employ cooperative effects have been developed.[6,7]

Cooperative effects have been widely used and studied in the field of supramolecular chemistry and are interesting tools to control the properties of host–guest systems[8] and polymers.[9] Allosterism is a special case of cooperativity,[10] in the sense that a binding event at one site in a multivalent system like a biomolecule[11,12] or synthetic host[13] causes a discrete, reversible alteration in the structure at a remote binding site. Allosteric interactions can be both positive and negative in nature, and can act between a host and identical guests (homotropic allosterism) or between a host and different types of guests (heterotropic allosterism).

In previous research in our group a number of cavity-appended porphyrin hosts that display allosteric binding behaviour have been developed.[14–17] The most extensively studied host molecule is the monocavity-appended zinc porphyrin **ZnMC**, which is depicted in Figure 1 together with its allosteric binding behaviour. It was found that **ZnMC** can bind viologen molecules with high binding constants. The addition of a nitrogen-donor ligand that is too bulky to fit inside the cavity, like 4-*tert*-butyl-pyridine (**tbpy**), results in a positive heterotropic allosteric effect, which is demonstrated by an increase in binding constant between dimethylviologen (**V**) and **ZnMC** (Fig. 1b). Vice versa, an increase in binding constant between **tbpy** and **ZnMC** was observed upon the addition of viologen molecules to a mixture of the host and the axial ligand.

In the double cavity analogue of **ZnMC** and **ZnDC**, the interactions are even more complicated (Fig. 2). For the binding of viologens, this double cavity porphyrin system shows highly negative allosteric binding. The free base host molecule has the ability to bind two dimethylviologen molecules, but the association constant for the second binding (K_a=5×10^4 M^{-1}) is considerably lower than for the first binding event (K_a=7×10^7 M^{-1}). A combination of NMR studies and computational modelling indicated that this lower binding was not due to electronic repulsion between the two guests, but the result of conformational changes in the host molecule.[15]

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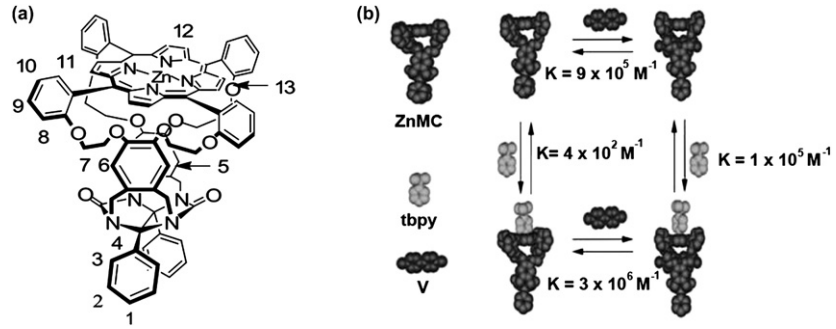

Figure 1. (a) Structure of porphyrin host **ZnMC**, together with the relevant proton numbering. (b) Schematic representation of the allosteric binding properties of this compound.

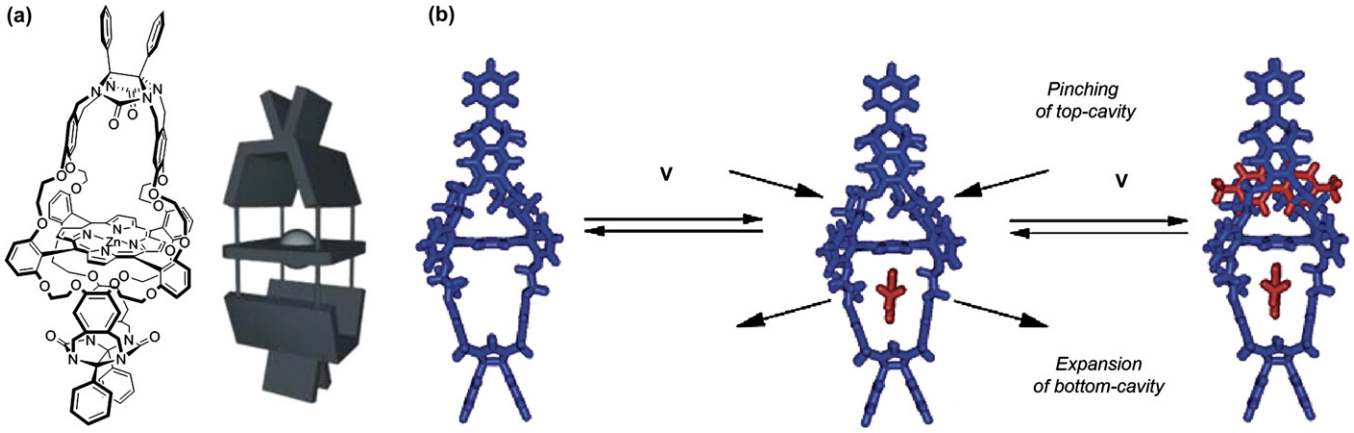

Figure 2. (a) **ZnDC** and its schematic representation. (b) Negative homotropic allosteric binding behaviour of **DC**.

As a continuation of this research we describe here attempts to construct more complex self-assembled allosteric assemblies based on bifunctional viologen and pyridine guests, and both **ZnMC** and **ZnDC** as hosts. The ultimate goal of this research is to generate materials of which both the architecture and the properties can be influenced by allosteric interactions.

2. Results and discussion

2.1. Synthesis

To study allosteric assembly three different bifunctional guests were synthesised, one containing two pyridine moieties (**PyPy**), another one containing two viologen moieties (**VV**) and a third one containing one pyridine and one viologen moiety (**VPy**) (Fig. 3).

Bis-pyridine bifunctional guest **PyPy** was synthesised by a straightforward reaction of suberoyl chloride with 3-amino-pyridine (yield 73% after recrystallisation). An amide bond linker was chosen because it was found to increase the binding of the pyridine guest in **ZnMC** due to the formation of a weak hydrogen bond with one of the carbonyl groups in the cavity of the host.[14]

For the synthesis of diviologen bifunctionalised guest **VV**, 1,10-dibromodecane was reacted with an excess of 4,4′-bipyridine to give an α,ω-bis-bipyridyl-functionalised decane. This compound was then treated with iodomethane, after which anion exchange was carried out by dissolving the compound in a hot aqueous solution of ammonium hexafluorophosphate. Upon cooling, the desired product **VV** precipitated as the tetrakis-hexafluorophosphate salt in a yield of 28%.

Viologen-pyridine bifunctionalised guest **VPy** was prepared from 9-bromo-1-nonanol, which was converted into 9-bromononanoic acid by oxidation with CrO_3 and then into an acid chloride using standard conditions. The latter compound was subsequently reacted with 3-aminopyridine to yield the corresponding amide. In order to prevent cyclisation and oligomerisation, this amide was treated with an excess of mono-methylated bipyridine at room temperature.

2.2. Self-assembled complexes based on ZnMC

The association constants of the complexes between the three guest molecules and the host **ZnMC** were determined by UV–vis and fluorescence spectroscopy (Table 1). All association constants were calculated assuming independent (non-cooperative) binding of the separate binding moieties of the guest molecules.

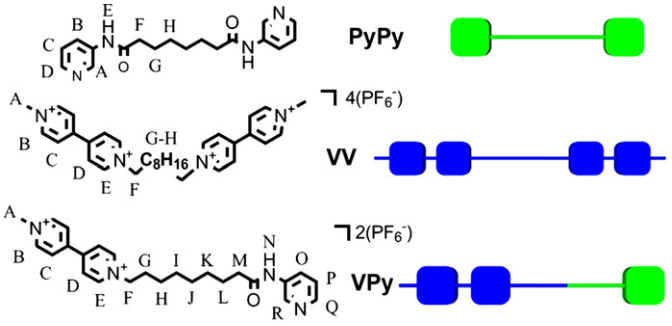

Figure 3. The bifunctional guests used in this study and their proton assignment (left). Schematic representation of the guest molecules (right).