Multivalent Oligomacrocyclic Hosts as Key-Compounds for Multiply Interlocked Architectures

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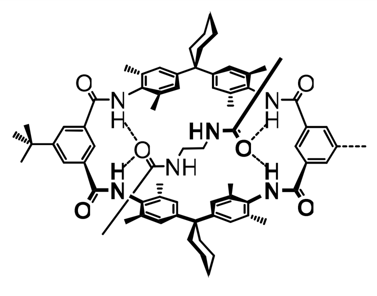
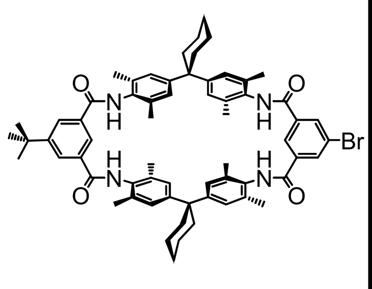
I. Introduction

The tetralactam macrocycles (or wheels) **1a** und **1b** can be easily functionalized by cross-coupling reactions to yield flexible or rigid branched multimacrocyclic hosts[1].

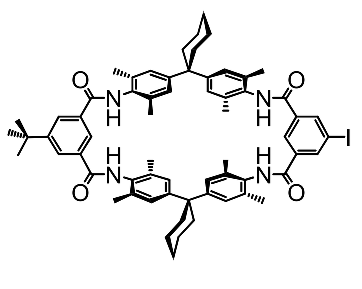
Additionally, several tetralactam macrocycles can be connected with each other or with a central spacer and also metal-coordination sites like phenanthroline or bipyridine can be attached to the macrocycles.



These molecules allows to build a variety of multiply interlocked architectures by threading axles through the macrocycles via H-bonding and connect them with each other or to other linkers.



1a



1b

[1] B. Baytekin, S.S. Zhu, B. Brusilowskij, J. Illigen, J. Ranta, J. Huuskonen, K. Rissanen, L. Kaufmann, C.A. Schalley, *Chem. Eur. J.* **2008**, 14, 10012 – 10028.

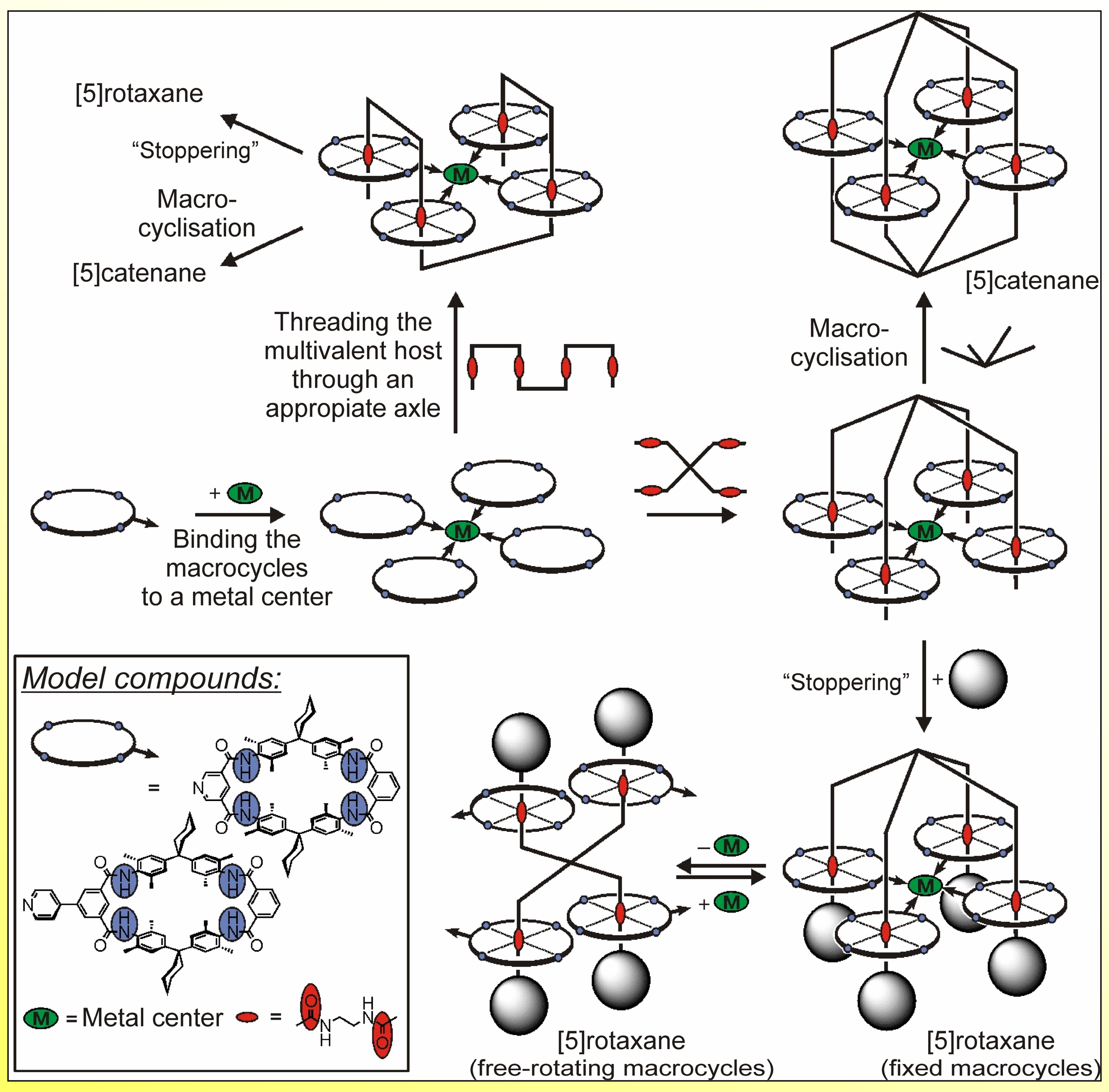
II. Motivation

The aim of this project is the synthesis, characterisation and application of a great variety of components (different metals, macrocycles, axles, spacers and linkers, components with different functionalities,…) for:

- → Generating architectures with different features (for example flexibility)
- → Metal-directed self-assembly of macrocycles and rotaxanes to obtain multivalent hosts and precursors
- → Analysing the relationship between structural units and features
- → Better understanding of multivalency

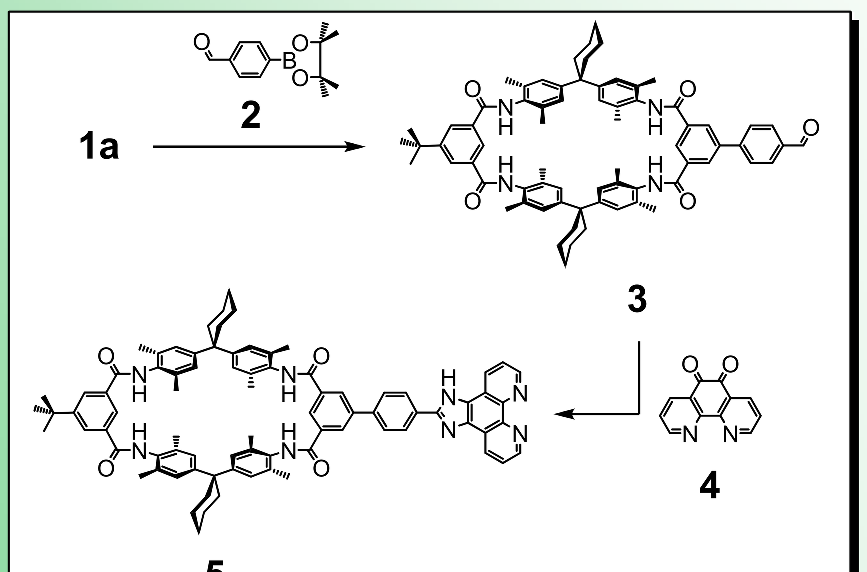
(Multivalency = host-guest interactions existing simultaneously between two or more binding sites)

The concept of multivalency[2] is important, which allows supramolecular chemists to potentate many weak bonds and therefore increase the binding strength enormously. This could lead to a higher efficiency of rotaxanes and catenanes preparation with new topologies and functions. The application of such topological architectures could revolutionize the rare field of molecular machines.



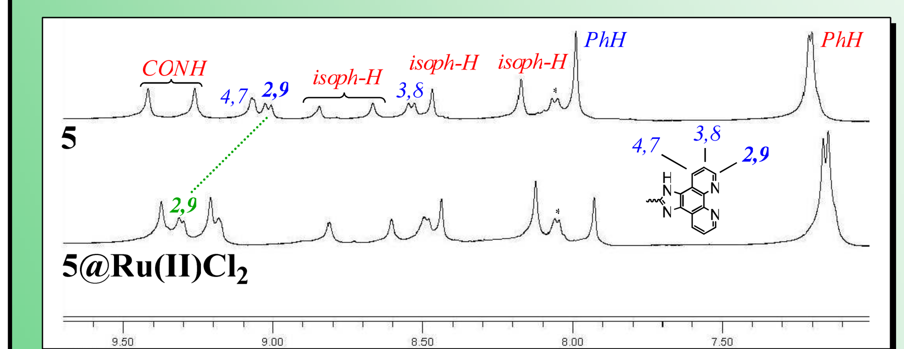
[2] For resent reviews, see: A. Mulder, J. Huskens, D. N. Reinhoudt, *Org. Biomol. Chem.* **2004**, *2*, 3409 -3424; b) M. Mammen, S.-K. Chio, G. M. Whitesides, *Angew. Chem.* **1998**, *110*, 2908 - 2953; *Angew. Chem. Int. Ed.* **1998**, *37*, 2754 – 2794.

III. Synthesis and Metal Directed Self-Assembly of Phenanthroline Wheel



Ligand-decorated macrocycles can be used to form metal complexes with different geometries of the wheels around the metal centers.

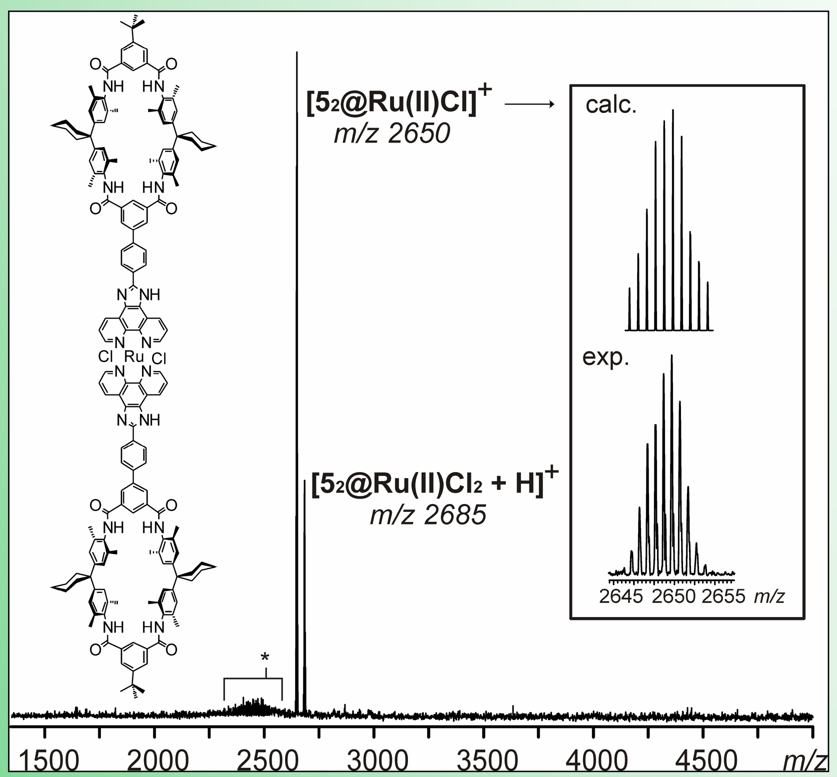
These complexes further can be used for example as multivalent hosts for multivalent guests by the controlled self-assembly of macrocycles.

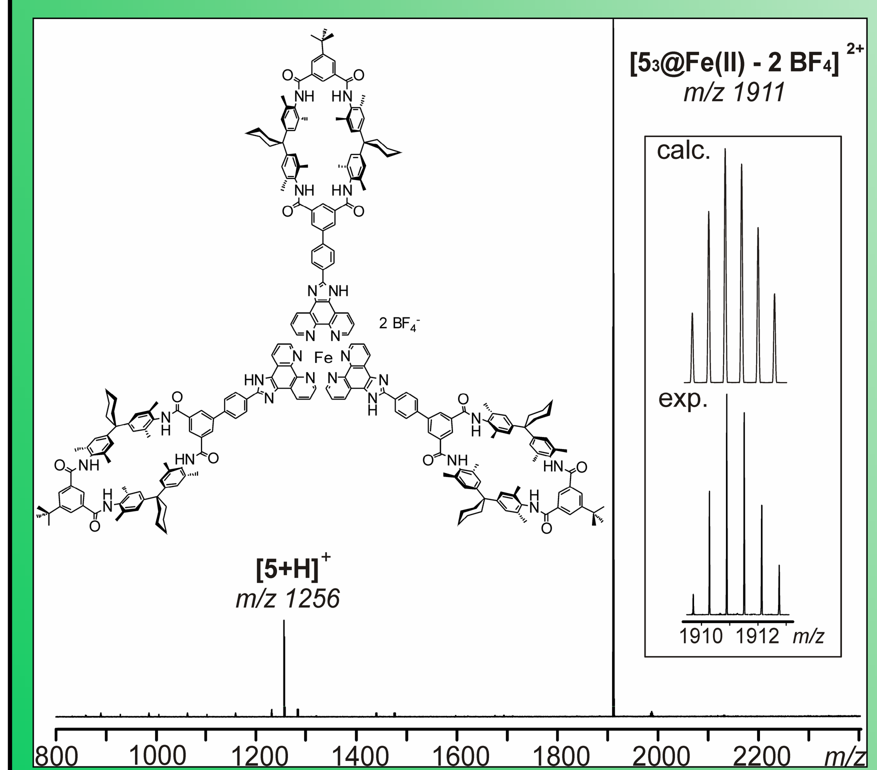


The new phenanthroline wheel **5** can non-covalently coordinate to metals like Ru(II), Fe(II), Cu(I), Pd(II),… by the two coordination sites of the phenanthroline unit.

5 was synthesized from the bromo wheel **1a** via Suzuki coupling with the pinacol boronic ester **2** yielding the aldehyde wheel **3** in the first step. The second step is a imidazole synthesis with **4** in presence of NH_4OAc und AcOH[3].

Afterwards, the phenanthroline wheel **5** was exploited for the synthesis of the divalent host **5_2@Ru(II)Cl_2** and the trivalent host **5_3@Fe(II)$(BF_4)_2$**.



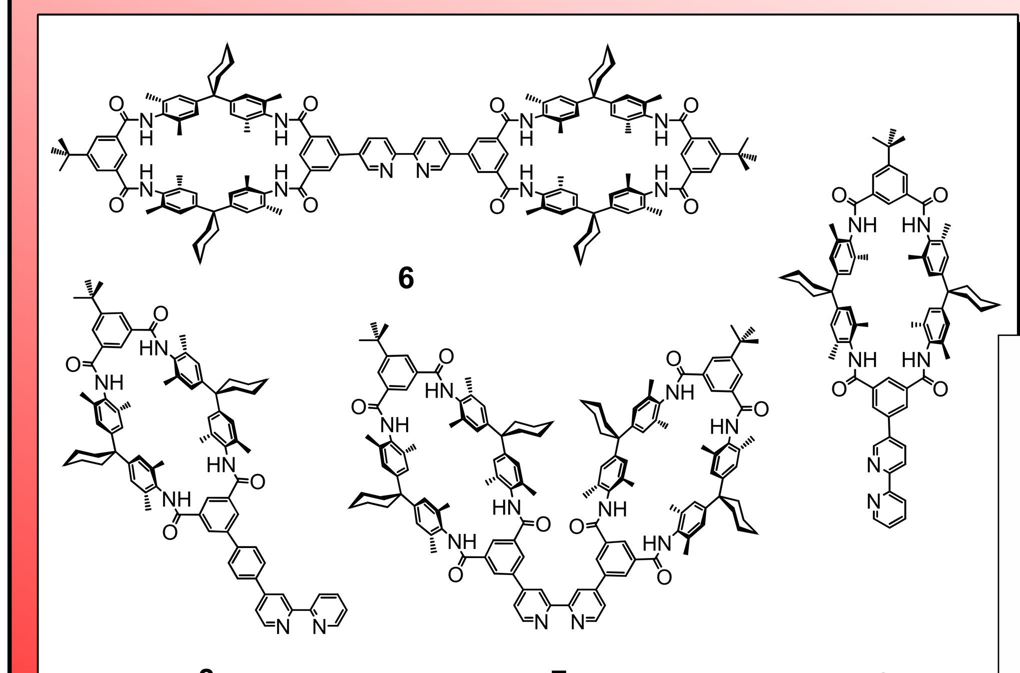


The ^{1}H-NMR spectrum of **5_2@Ru(II)Cl_2** shows in comparison with the ^{1}H-NMR spectrum of **5** a large downfield shift of the phenanthroline protons at the positions 2 and 9.

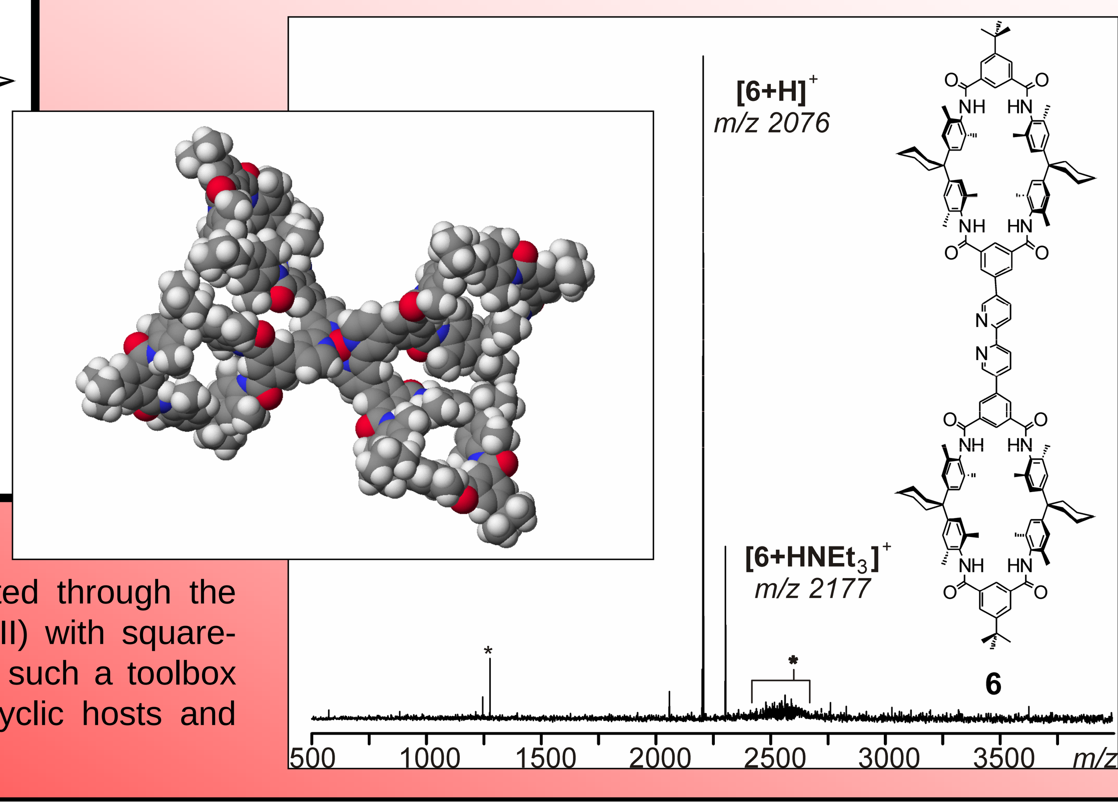
The FT-ICR-MS spectrum of **5_2@Ru(II)Cl_2** shows $[5@Ru(II)Cl]^+$ as the main peak and a smaller peak, which can be assigned to $[5_2@Ru(II)Cl_2 + H]^+$. The FT-ICR-MS spectrum of **5_3@Fe(II)$(BF_4)_2$** shows the doubly charged complex without counter anions as the main peak and a small amount of the free ligand **5**.

[3] E.A. Steck, A. R. Day, *J. Am. Chem. Soc.* **1943**, *65*, 452-456.

IV. 2,2'-Bipyridine-based multimacrocyclic Hosts



Modification of the wheels **1a** and **1b** at the 5-position of the isophthaloyl units via Suzuki coupling with several 2,2'-bipyridine blocks results in an easily accessible toolbox consisting of differently functionalized macrocycles for multiply interlocked architectures.

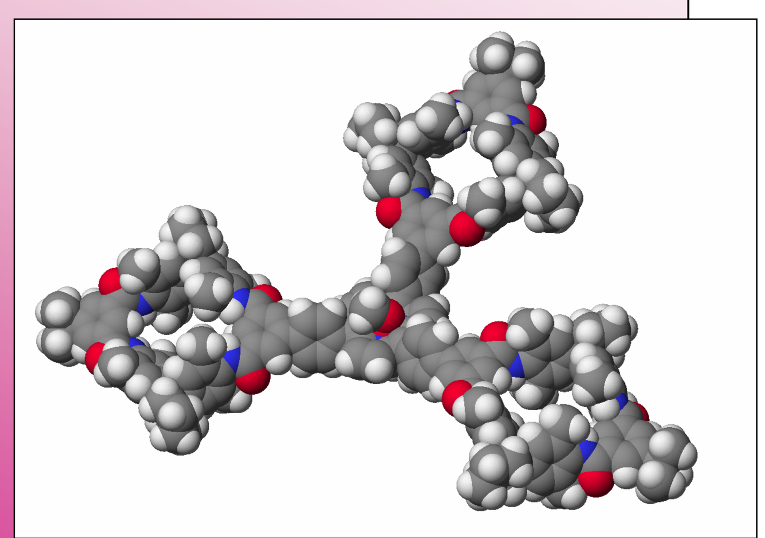


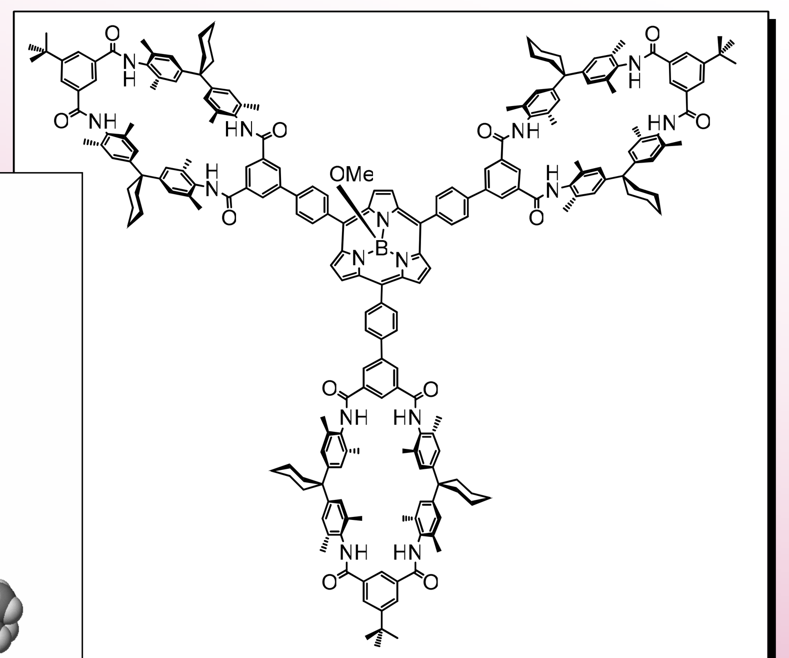
The degree of the substitution (one or two wheels connected through the bipyridine) or the type of the metal center, for example Pd(II) with square-plane or Cu(I) with tetrahedral coordination sphere complete such a toolbox and allows a straightforward access to a variety of macrocyclic hosts and interlocked architectures from the same precursors.

V. Rigid branched multimacrocyclic hosts

The synthesis of the trivalent host **10** as an example for a rigid branched multimacrocyclic host, where tetralactam macrocycles are connected to a central piece, which is not metal-based, is planned.

Herein, the central piece can have photoactive properties, which allows to study the intratoxane energy transfer or to build light-switchblade molecular machines[4].



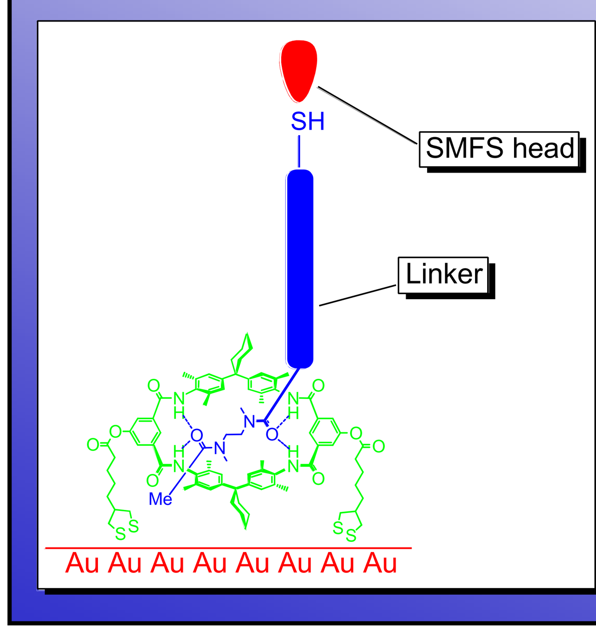


10

[4] V. Balzani, A. Credi, F. M. Raymo, J. F. Stoddart, *Angew. Chem.*, **2000**, *112*, 3484-3530; *Angew. Chem. Int. Ed.*, **2000**, *39*, 3348-3391.

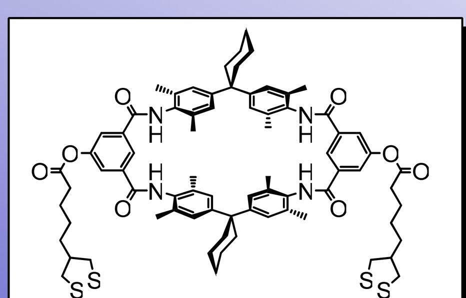
VI. Hosts for SMFS-Measurements

AFM-based single-molecule force spectroscopy (SMFS) appears to be suitable to address interaction forces from the single-molecule perspective, which have traditionally been assessed by ensemble thermodynamics[5].

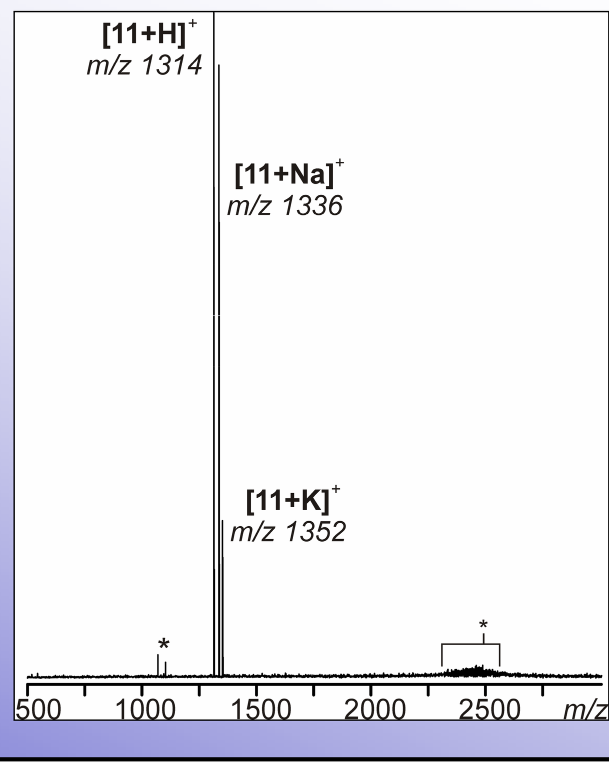


Attaching lipoic acid to the tetralactam macrocycle yields the dilipoic acid wheel **11**, which can be bound to an Au surface. With a multivalent molecule on the SMFS head containing one or more diamide binding sites, the interaction forces between wheel and axle can be measured.

[5] For resent reviews, see: a) W. Zhang, X. Zhang, *Prog. Polym. Sci.* **2003**, *28*, 1271-1295; b) A. Jahnhoff, M. Neitzert, Y. Oberdorfer, H. Fuchs, *Angew. Chem. Int. Ed.* **2000**, *39*, 3213 – 3237.



11



VII. Conclusion/Outlook

As it is shown in here, the wheels **1a** and **1b** are very important for the design of multivalent building blocks and multiply interlocked architectures.

The phenanthroline wheel **5** and the 2,2'-bipyridine-based multimacrocyclic hosts **6 - 9** can be used for the preparation of a variety of flexible branched multimacrocyclic hosts with several metal centers. Also, rigid branched multimacrocyclic hosts with different features like photoactivity are possible.

Gold surfaces can easily be coated with the dilipoic acid wheel **11**, which allows SMFS measurements to examine the individual host-guest interactions, are planned.

Acknowledgments

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