

- [15] Crystal data for **2**: $C_{16}H_{23}B_{11}$, $M_r = 334.25$, monoclinic, $P2_1/n$, $a = 7.345(2)$, $b = 17.393(4)$, $c = 14.786(3)$ Å, $\beta = 99.28(2)^\circ$, $V = 1864.2(8)$ Å³, $Z = 4$, $\rho_{\text{calcd}} = 1.191$ Mg m⁻³, $\mu = 0.058$ mm⁻¹, $F(000) = 696$. 4355 data collected, 3268 independent reflections ($R_{\text{int}} = 0.0336$), $R_1 = 0.0462$, $wR_2 = 0.1081$ for data with $I > 2\sigma(I)$, $S = 1.033$, largest peak 0.140 and deepest hole -0.225 e Å⁻³.^[14]
- [16] R. G. Parr, W. Yang, *Density-Functional Theory of Atoms and Molecules*, OUP, New York, **1989**. Calculations used the ADF1999 program^[17–19] with the BP86 functional and incorporated a treatment of relativistic effects. A double- ζ plus polarization STO basis set for all atoms and the frozen core approximation was applied (C, B: 1s).
- [17] E. J. Baerends, D. E. Ellis, P. Ros, *Chem. Phys.* **1973**, 2, 41.
- [18] G. te Velde, E. J. Baerends, *J. Comput. Phys.* **1992**, 99, 84.
- [19] C. F. Guerra, J. G. Snijders, G. te Velde, E. J. Baerends, *Theor. Chem. Acc.* **1998**, 99, 391.
- [20] G. M. Sheldrick, SHELXTL Version 5.1, Bruker AXS Inc., Madison, Wisconsin, **1999**.

Giant Rings



Macrocyclic Synthesis by Olefin Metathesis on a Nanosized, Shape-Persistent Tricationic Platinum Template**

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Macrocyclic compounds are widely used as preorganized host molecules for the selective binding of specific guests.^[1] Commonly, these guests are monometallic cations or small

polar molecules, such as urea. An alternative possibility is to assemble a given set of molecules around a metal center^[2] or molecular pattern^[3,4] and then couple the molecules to one host–guest complex. In this reaction sequence the metal center or molecular pattern functions as template.^[5] In a number of recent reports the latter strategy has been used for the synthesis of catenanes and knots,^[6] and of molecular wires imbedded in an alkane double helix.^[7] In these reactions, host and guest often become irreversibly integrated in an assembly with novel molecular properties.

In a recent study, we prepared a series of shape-persistent multimetallic compounds which can be easily converted into the corresponding multicationic species.^[8] The cationic sites in the trication of **1** (see Scheme 1) used in the present study are fixed in a two-dimensional space and are at the corners of a triangle with edges of 1.75 nm.^[8b] The NCN pincer platinum cations bind new ligands exclusively *trans* to C_{ipso} along the pseudo C_2 axis of the molecule ($C_4-C_{\text{ipso}}\text{-Pt}$). Accordingly, binding of pyridine ligands provides a special molecular arrangement having the planes of the tris(phenylene)benzene core and the pyridine ligands coplanar. It turns out that of the combinations ECE pincer ligand/metal/pyridine (E: N, S; metal: palladium, platinum) the NCN pincer platinum pyridine complexes are the kinetically most stable ones.^[9] Moreover, the NCN-Pt complexes are the least active catalysts for the isomerization of α -olefins (see below). This makes the trication of **1** an ideal template for interconnecting the pyridine rings at the *ortho* or *meta* positions thereby forming a large tris(pyridyl) macrocyclic compound around the trication.

Here we report the selective linking of 2,6-bis(dec-9-enyloxy)pyridine substituents by alkene metathesis to form a 69-membered tris(pyridyl) macrocycle. Its detachment occurs by addition of nucleophiles, for example, Cl^- . The trisolefinic macrocycle could be hydrogenated and subsequently recoordinated to the tricationic template. This sequence (Scheme 1) provides a new approach to the selective synthesis of large-ring macrocyclic hosts which have as the only preorganization a precise atom connectivity pattern.

2,6-Bisolefin-substituted pyridines **2a,b** were prepared from 9-decen-1-ol and 2,6-dibromopyridine or 2,6-bis(chloromethyl)pyridine, respectively. The template precursor **1** (1 mmol) was reacted in CH_2Cl_2 with three equivalents of either **2a** or **2b** in the presence of suspended AgBF_4 to give the tricationic compounds **3a** or **3b**, respectively, in quantitative yields. A prolonged reaction time (30 min to 16 h) is necessary because of the poor solubility of AgBF_4 in CH_2Cl_2 . The compounds **3** undergo alkene metathesis in the presence of the first-generation Grubbs catalyst, $[\text{Cl}_2(\text{Cy}_3\text{P})_2\text{Ru}=\text{CHPh}]$ (5 mol % per pyridine ligand), leading to the tricationic tris-platinum heteromacrocyclic complexes **4**. The alkene metathesis reactions were performed under high dilution (1×10^{-3} M) to prevent intermolecular olefin metathesis polymerization. Easy detachment of the newly formed macroheterocycle from the tricationic template was possible by reacting **4** with an aqueous NaCl solution, affording free macrocycle **5a** or **5b** and the neutral template precursor **1**. In fact, pure **1** was obtained quantitatively and could be reused in subsequent experiments.

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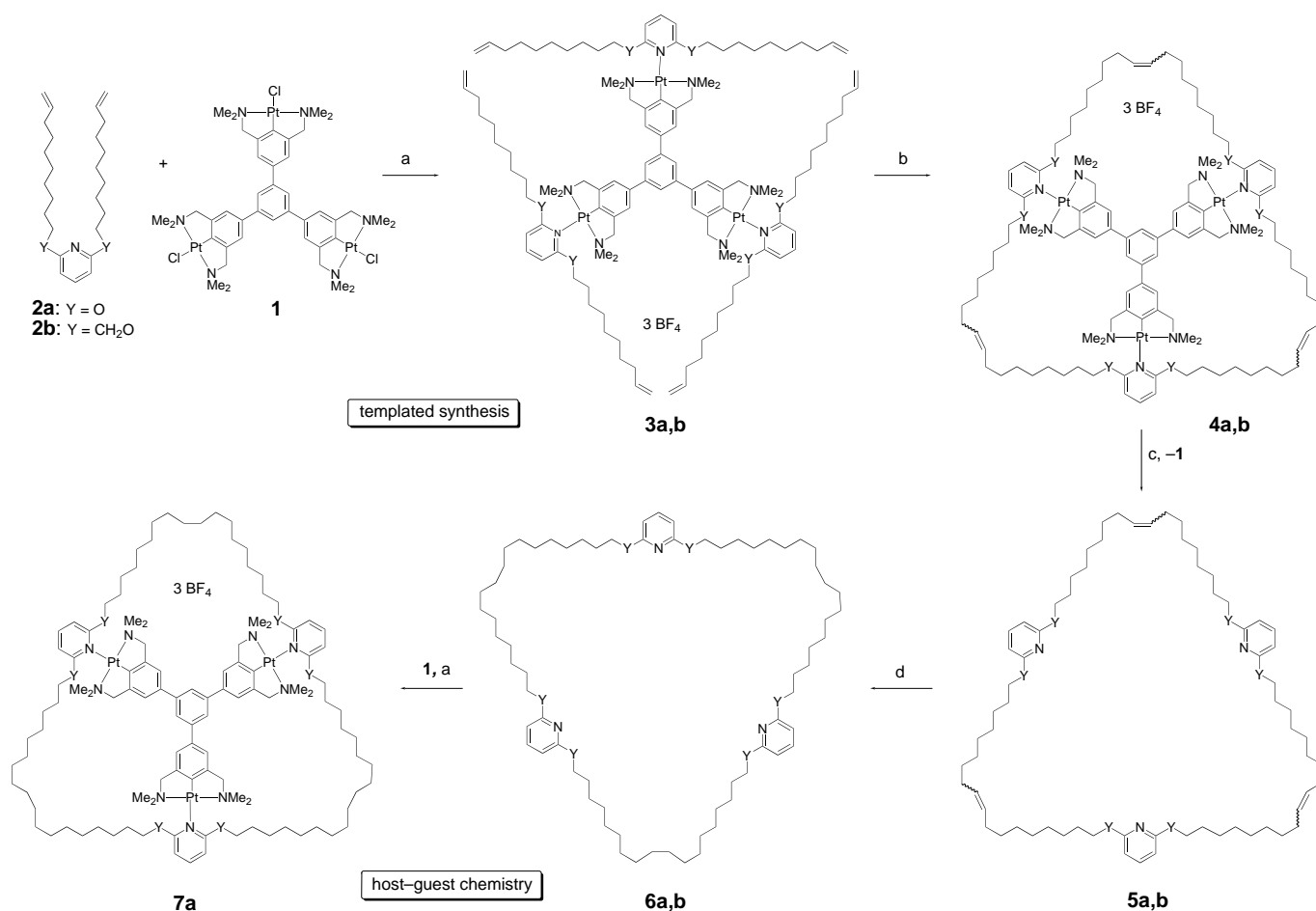
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Scheme 1. a) AgBF₄, CH₂Cl₂; b) [Cl₂(PCy₃)₂Ru=CHPh] 5 mol%, CH₂Cl₂; c) NaCl, H₂O/CH₂Cl₂; d) H₂, Pd/C.

The macroheterocycles **5** were isolated by preparative thin-layer chromatography (TLC) in 67 (**5a**) and 44% (**5b**) yield. Some mono-pyridine macrocycles and linear oligomers were also formed as by-products. In an attempt to increase the reaction rate and to decrease the amount of catalyst, the more active second-generation Grubbs catalyst, [Cl₂(PCy₃)(IMes)Ru=CHPh], IMes = 1,3-bis(2,4,6-trimethylphenyl)-4,5-dihydroimidazol-2-ylidene, was used in the metathesis reaction of **3b**. However, this led to a dramatic decrease in yield of macrocycle **5b** (20%), while large amounts of oligomers were formed. These findings point to the occurrence of secondary cross- and ring-opening metathesis polymerization (ROMP) reactions.

As **5a** and **5b** were formed as mixtures of *cis/trans* trisolefinic heteromacrocycles, for analysis purposes they were hydrogenated over Pd/C in CH₂Cl₂ thus providing the alkane macrocycles **6a** (99%) and **6b** (80%).^[10] In the case of **5b**, some hydrogenolysis of the benzylic ether bond was observed as a side reaction.^[11] It should be noted that according to mass spectrometry both saturated compounds **6** contain macrocycles having one CH₂ group less as small impurities. These macrocycles are most likely formed through cross metathesis of an α -olefinic substituent with a β -olefinic one, which was formed by a prior metal-catalyzed isomer-

ization reaction. Unfortunately, it was not possible to separate these macrocycles from the desired products by TLC.

The macrocycles **6**, which are very flexible and non-preorganized (e.g., by conformational preferences in the connecting alkanediyl chains), were further studied as hosts for highly preorganized nanosized trimetallic guests such as **1**. The reaction of **6a** with **1** gave—after work-up with acetone—complex **7a** in almost quantitative yield (96%). Characterization comprised NMR spectroscopy, elemental analysis and electrospray mass spectrometry.^[10] The mass and isotopic pattern in the experimental spectrum was identical to that in the calculated spectrum for the tricationic complex **7a**.

Definite proof for the reattachment to **1** and the perfect cyclic structure of **6a** was provided by an X-ray structure determination of **7a** (with tetraphenylborate as counter anion). This salt was obtained by reaction of **7a** with NaBPh₄ in acetone. The molecular geometry and some selected distances and angles are given in Figure 1.^[12] The central benzene ring of the template is substituted at positions 1, 3, and 5 with pincer-platinum moieties, each at a different twist angle (the dihedral angles between the planes of the central ring and the pincer aryl rings range from 25.6(3) to 85.1(5)°). The macrocyclic tris(pyridyl) ligand is ligated through its pyridine N atoms to the three peripheral metal centers *trans*

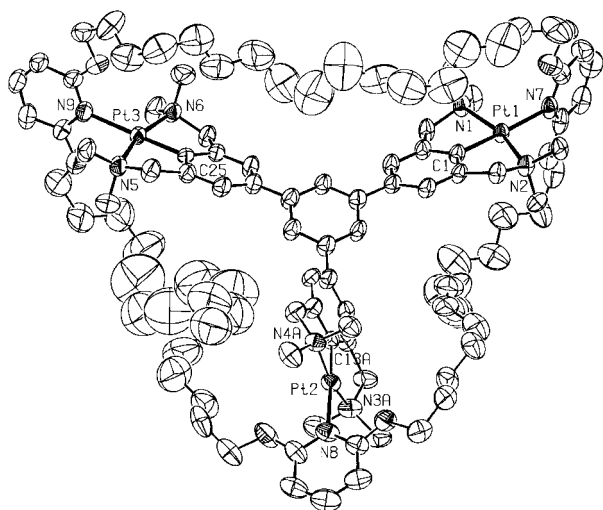


Figure 1. ORTEP representation of the cation in complex **7a**. The hydrogen atoms have been omitted for clarity. Only the major conformation of each of the disordered groups is shown. Selected bond lengths [Å] and angles [°]: Pt1–C1 1.910(5), Pt1–N1 2.104(4), Pt1–N2 2.087(4), Pt1–N7 2.191(4), Pt2–C13A 1.916(5), Pt2–N3A 2.094(6), Pt2–N4A 2.071(5), Pt2–N8 2.192(4), Pt3–C25 1.929(5), Pt3–N5 2.090(4), Pt3–N6 2.093(4), Pt3–N9 2.183(5); C1–Pt1–N1 81.72(18), C1–Pt1–N2 81.19(18), N1–Pt1–N7 94.71(15), N2–Pt1–N7 102.39(15), C1–Pt1–N7 176.32(17), N1–Pt1–N2 162.86(16), C13A–Pt2–N3A 80.4(2), C13A–Pt2–N4A 81.8(2), N3A–Pt2–N8 98.4(2), N4A–Pt2–N8 99.5(2), C13A–Pt2–N8 176.87(19), N3A–Pt2–N4A 161.8(3), C25–Pt3–N5 82.24(19), C25–Pt3–N6 81.33(19), N5–Pt3–N9 96.92(17), N6–Pt3–N9 99.55(17), C25–Pt3–N9 178.3(2), N5–Pt3–N6 163.49(18).

to C_{ipso} of the framework. The pyridine rings of the ligand are nearly perpendicular to the $PtCN_3$ ((NCN)–Pt–N(py)) coordination planes (84.3(4)–89.8(3)°), and are linked at the 2- and 6-positions by saturated $O(CH_2)_{18}O$ bridges to form a 69-membered macrocycle.

In conclusion, this report demonstrates the possibility of synthesizing large polynuclear heteromacrocycles by metathesis of olefin-substituted pyridines in the coordination sphere of symmetric, shape-persistent multimetallic templates. In addition, these multimetallic templates are quantitatively recovered. Currently, this template-directed synthesis is applied in the selective and high-yield synthesis of large heteroatomic crown ether rings.

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- [1] a) E. C. Constable, *Coordination Chemistry of Macrocyclic Compounds*, Academic, San Diego, CA, **1999**; b) L. F. Lindoy, *The Chemistry of Macrocyclic Ligand Complexes*, Cambridge University Press, Cambridge, UK, **1992**.
- [2] E. B. Bauer, J. Ruwwe, J. M. Martín-Alvarez, T. B. Peters, J. C. Böhlring, F. A. Hampel, S. Szafert, T. Lis, J. A. Gladysz, *Chem. Commun.* **2000**, 2261–2262, and references therein.
- [3] a) J. A. Harnisch, R. J. Angelici, *Inorg. Chim. Acta* **2000**, 300–302, 273–279; b) H. L. Anderson, J. K. M. Sanders, *J. Chem. Soc. Perkin Trans. 1* **1995**, 29, 2223–2229, and references therein.
- [4] For ring-closing reactions using dynamic combinatorial libraries see a) E. Stulz, Y.-F. Ng, S. M. Scott, J. K. M. Sanders, *Chem.*

Commun. **2002**, 524–525; b) S. L. Roberts, R. L. E. Furlan, G. R. L. Cousins, J. K. M. Sanders, *Chem. Commun.* **2002**, 938–939, and references therein.

- [5] For general references on templated synthesis see a) N. V. Gerbeleu, V. B. Arion, J. Burgess, *Template Synthesis of Macrocyclic Compounds*, Wiley-VCH, Weinheim, **1999**; b) F. Diederich, P. J. Stang, *Templated Organic Synthesis*, Wiley-VCH, Weinheim, **1999**.
- [6] a) M. Weck, B. Mohr, J.-P. Sauvage, R. H. Grubbs, *J. Org. Chem.* **1999**, 64, 5463–5471; b) G. Rapenne, C. Dietrich-Buchecker, J.-P. Sauvage, *J. Am. Chem. Soc.* **1999**, 121, 994–1001.
- [7] J. Stahl, J. C. Böhlring, E. B. Bauer, T. B. Peters, W. Mohr, J. M. Martín-Alvarez, F. Hampel, J. A. Gladysz, *Angew. Chem.* **2002**, 114, 1951–1957; *Angew. Chem. Int. Ed.* **2002**, 41, 1872–1876.
- [8] a) H. P. Dijkstra, M. D. Meijer, J. Patel, R. Kreiter, G. P. M. van Klink, M. Lutz, A. L. Spek, A. J. Canty, G. van Koten, *Organometallics* **2001**, 20, 3159–3168; b) H. P. Dijkstra, C. A. Kruithof, N. Ronde, R. van de Coevering, D. J. Ramon, D. Vogt, G. P. M. van Klink, G. van Koten, *J. Org. Chem.* **2002**, ASAP; c) I. P. Beletskaya, A. V. Chuchurjukin, H. P. Dijkstra, G. P. M. van Klink, G. van Koten, *Tetrahedron Lett.* **2000**, 41, 1081–1085.
- [9] H. P. Dijkstra, A. Chuchuryukin, B. M. J. M. Suijkerbuijk, G. P. M. van Klink, A. M. Mills, A. L. Spek, G. van Koten, *Adv. Synth. Catal.* **2002**, 344, 771–780.
- [10] NMR spectroscopic, mass spectrometric and elemental analysis data are available as Supporting Information.
- [11] Use of PtO_2 ^[11a] as hydrogenation catalyst or of a nitrogen-containing base as inhibitor for the side reaction^[11b] might increase the yield of **6b**. a) H. Pettersson-Fasth, S. W. Riesinger, J. E. Bäckvall, *J. Org. Chem.* **1995**, 60, 6091–6096; b) H. Sajiki, K. Hirota, *Tetrahedron* **1998**, 54, 13981–13996.
- [12] $C_{111}H_{174}N_9O_6Pt_3 \cdot 3(C_{24}H_{20}B)$, $M_r = 3273.49$, triclinic, $P\bar{1}$ (No. 2), $a = 18.9296(1)$, $b = 20.6363(1)$, $c = 22.4100(2)$ Å, $\alpha = 80.4058(3)$, $\beta = 86.3821(3)$, $\gamma = 76.7954(3)^\circ$, $V = 8400.66(10)$ Å³, $Z = 2$, $\rho_{\text{calcd}} = 1.294$ g cm^{−3}; 2219 refined parameters, 3563 restraints, $R(F) = 0.0517$ [$I > 2\sigma(I)$], $wR(F^2) = 0.1357$, $S = 1.04$, $\Delta\rho_{\text{max}}/\Delta\rho_{\text{min}} = 1.92/−1.49$ e Å^{−3}. CCDC 185367 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/contents/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; or deposit@ccdc.cam.ac.uk).