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Design and Synthesis of Tridentate Facially Chelating Ligands of the [2.*n*.1]-(2,6)-Pyridinophane Family

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Received February 28, 2003

Syntheses are reported for tripyridine macrocycles **2** and **3** and some of their alkyl derivatives. The macrocycles are designed to stabilize to various extents coordinated d^8 metal precursors and d^6 alkane oxidative addition products (Pt^{IV}), therefore allowing favorable kinetics and thermodynamics of (e.g., Pt^{II}) the cleavage of substrate H−C(sp^3) bonds. Both the Chichibabin protocol and oxidative coupling of carbanions by copper(I) iodide were used for the macrocyclization step. Crystal structures of singly and doubly protonated **2** establish atom connectivity in the macrocycle, and reveal structural features which are obscured in solution NMR by rapid proton migration.

Introduction

Alkane activation with transition-metal complexes leading to their alkyl hydrido derivatives (oxidative addition) has been actively studied for more than 20 years.[1,2]

$$\mathrm{LM} + \mathrm{Alk\text{-}H} \rightarrow \mathrm{LM(R)H} \qquad (1)$$

This transformation, involving relatively inert organic compounds, is considered as a key step in some current[3−11] and potential direct C(sp^3)−H bond functionalizations. It is known that the reactivity of a metal able to split alkane CH bonds is strongly dependent on the metal atom ligand environment L. In particular, cyclopentadienyls[1,2,12] and some facially chelating ligands such as hydridotris(pyrazolyl)borates, Tp,[13−16] and tacn[17,18] stabilize, both kinetically and thermodynamically, d^6 metal alkyl hydrides, e.g., those containing Ir^{III},[1,2,19] Rh^{III},[12,18] and Pt^{IV}.[13−16] Related d^8 metal precursors are very reactive and usually unseen in reaction mixtures.[20,21] In contrast, monodentate ligands disfavor alkane addition to d^8 metal species (eq 1).[22] This structural origin of these experimental observations is illustrated in Figure 1. At the same time some applications of d^6 metal alkyl hydrides for catalytic alkane functionalization may require LM(R)H to be of some intermediate stability under catalytic reaction conditions. Thus, despite the knowledge that ligands play a critical role in controlling the reactiv-

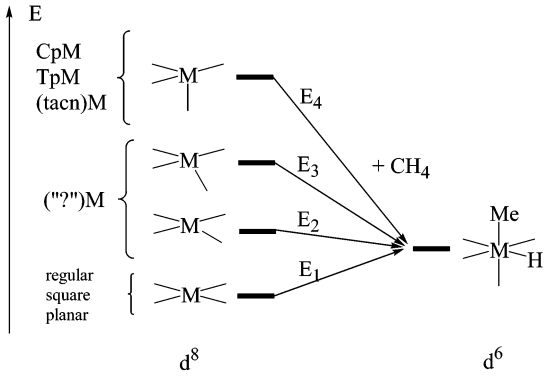

FIGURE 1. Qualitative relation between the degree of out-of-plane deformation of a d^8 precursor coordination unit and the thermodynamics of methane addition.

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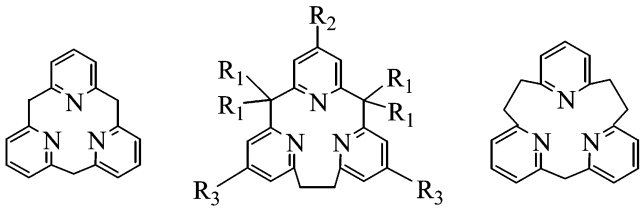
10.1021/jo034268v CCC: $25.00
Published on Web 05/14/2003

ity of metal complexes, particular ligands allowing only intermediate stabilization of products of eq 1 have not been developed. This need can be potentially met by a macrocyclic ligand whose ring size is subject to systematic variation.

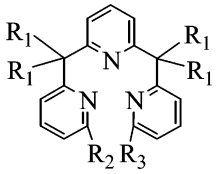
Recently, we developed an approach to ligand and complex design for alkane oxidative addition/reductive elimination to control the kinetics and thermodynamics of eq 1.[23] The main idea of our approach is to affect these parameters by stabilizing/destabilizing a d^6 alkane addition product/related d^8 metal precursor by changing the degree of ligand preorganization to octahedral and/or square planar coordination unit geometry.

Such well-known ligands as Cp, Tp, and tacn stabilize the addition product so well that *catalytic* application of related alkyl hydrides becomes questionable (E_4 in Figure 1). To get d^6 LM(R)H complexes of some intermediate stability (E_2 and E_3 in Figure 1), we introduced recently macrocyclic [*n*.*m*.1]-(2,6)-pyridinophane ligands **1**−**3** of various macrocycle sizes.[24−27]

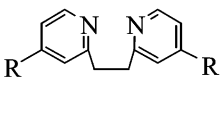
Rigid and chemically robust pyridine residues help constrain the ligand while the bridges bring some flexibility to the macrocycle. All of the macrocycles are expected to be small enough to prohibit all three nitrogen atoms from coplanar arrangement with the metal, as would be needed for stabilization of a d^8 metal species.



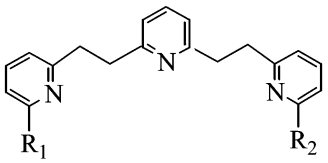
1 $R_1=R_2=R_3=H$, **2** **3**
R_1=Me, $R_2=R_3=H$, **Me_4-2**
$R_1=R_3=H$, $R_2=Bu^t$, **^{t}Bu-2**
$R_1=H$, $R_2=R_3=Bu^t$, **^{t}Bu$_3$-2**



$R_1=R_2=R_3=H$, **4**
R_1,R_2=H, R_3=Me, **Me-4**
R_1=H, R_2,R_3=Me, **Me_2-4**
$R_1=R_2=R_3$=Me, **Me_6-4**

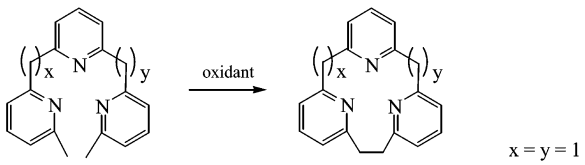


R=H, **5**
R=Me, **Me_2-5**



R_1, R_2=H, **6**
R_1=Me, R_2=H **Me-6**
R_1, R_2=Me, **Me_2-6**

SCHEME 1



The smallest macrocycle of the [*n*.*m*.1] series, [1.1.1]-(2,6)-pyridinophane, **1**, is highly preorganized to octahedral geometry of LM(R)H compounds and allows the highest degree of d^6 metal alkyl hydride stabilization in the series of complexes formed with [*n*.*m*.1]-(2,6)-pyridinophanes. One or two longer alkanediyl bridges in larger macrocycles **2** and **3** should permit an octahedral geometry of a metal coordination unit and destabilize an LM(R)H species. In contrast to the pyridinophanes, their nonmacrocyclic analogue tripyridine **4** is flexible[28] and expected to accommodate both *square planar* d^8 precursors and *octahedral* d^6 alkane addition products. Thus, it should have almost no effect on the thermodynamics of alkane addition as compared with regular square planar compounds.

According to literature precedents,[29] the synthesis of these target macrocyclic ligands could be challenging. Recently, we reported simple synthetic routes to two [2.1.1]-(2,6)-pyridinophanes, **2** and **Me_4-2**.[24] In this work we report detailed *improved* synthetic routes to them and to three more macrocycles, **^{t}Bu-2**, **^{t}Bu$_3$-2**, and the important new **3**, as well as characterization of these five [2.*n*.1]-(2,6)-pyridinophanes (n = 1, 2).

Results and Discussion

Synthetic Approaches to the Tripyridine Macrocycles. There are published studies on the synthesis of some derivatives of the unknown parent **1**.[29] The known compounds of this family bear various combinations of oxo and alkoxy substituents at bridging carbons due to features of the synthetic method employed. This substitution pattern affects dramatically their coordination behavior. No compounds of the families of **2** or **3** were known before our work.

In this work we considered several synthetic routes to the target species **2** and **3** including nonmacrocyclic di- and tripyridines as key precursors. The following routes were explored: (i) Oxidative coupling of 6′,6″-dimethyl-substituted tripyridines (Scheme 1).[24] One ethylene bridge is formed in the course of the coupling. [2.*x*.*y*]-Pyridinophanes might be obtained by this method. (ii) Condensation of α-methylpyridines with pyridine fragments with an unsubstituted α-carbon atom (Scheme 2). Single condensation of the corresponding nonmacrocyclic

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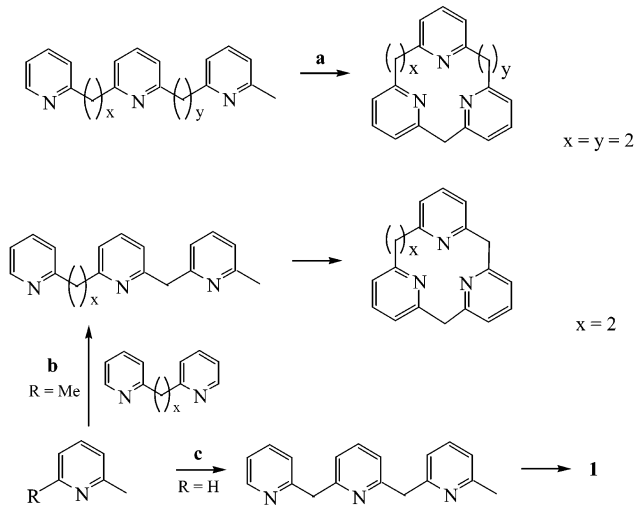
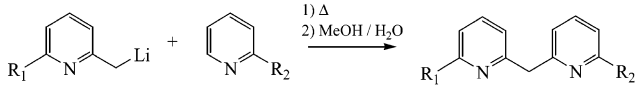
SCHEME 2



6′-methyl-substituted tripyridines might afford [*x*.*y*.1]-pyridinophanes (Scheme 2a). Double condensation of a dipyridine and the anion of 2,6-dimethylpyridine might lead to [*x*.1.1]-pyridinophanes (Scheme 2b).[24] Triple condensation of 2-methylpyridine could lead to [1.1.1]-pyridinophane (Scheme 2c). In the two latter cases, the corresponding nonmacrocyclic tripyridine intermediates are required.

To form two pyridine residues methylene bridged as needed in Scheme 2, we chose the Chichibabin-type[30−33] condensation as a key tool:



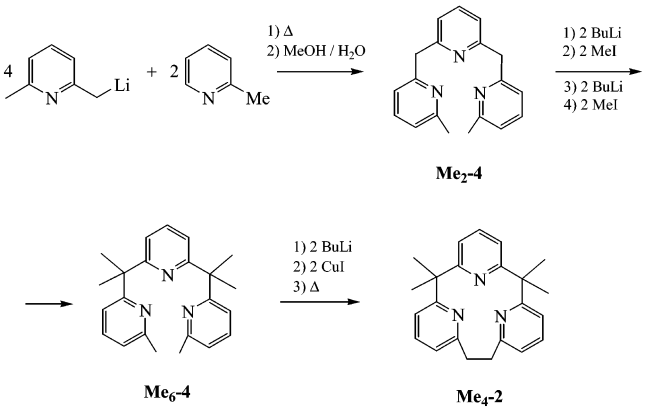
Detailed density functional theory (DFT) analysis of the thermodynamics of this reaction and application for the synthesis of nonmacrocyclic tripyridines have been reported.[33]

To prepare ethanediyl-bridged compounds (see below), we used an oxidative coupling of 2-pyridylmethyl carbanions with copper iodide (macrocycle **Me$_4$-2**) or 1,2-dibromoethane (nonmacrocyclic dipyridines **5**) or condensation of pyridinecarboxylic acid esters with 2-pyridylmethyl carbanions followed by reduction of the carbonyl functions (nonmacrocyclic tripyridines **6**).

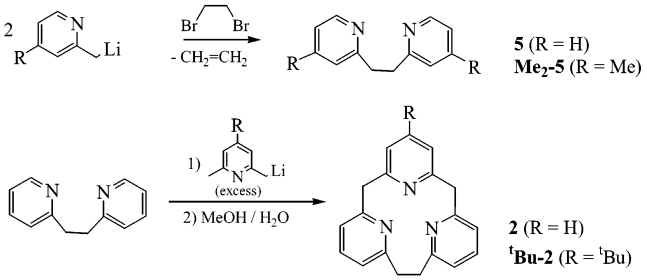
Synthesis of 9,9,16,16-Tetramethyl-[2.1.1]-(2,6)-pyridinophane, Me$_4$-2. Coupling of 2-pyridylmethyl carbanions with copper(I) salts to produce 1,2-bis(2-pyridyl)ethanes has been reported previously.[34,35] This reaction was used at a final stage, leading to the macrocycle **Me$_4$-2** here (Scheme 3).

The key precursor, tripyridine **Me$_2$-4**, can be prepared in a one-pot two-step condensation of 2-methylpyridine with 2 equiv of 6-methyl-2-pyridylmethyllithium (LiLut)

SCHEME 3



SCHEME 4



in a 50% yield.[24,33] The driving force of this condensation is the formation of a salt of a stronger CH acid, **Me$_2$-4**, and liberation of the less acidic 2,6-dimethylpyridine. The much higher acidity of the methylenic groups of the tripyridine **Me$_2$-4** than that of its methyl groups (evidenced by the fact that successful monodeprotonation of **Me$_2$-4** can be readily performed with potassium *tert*-butoxide in THF solution) requires alkylation of methylene groups to allow formation of a dianion required for the macrocyclization. Necessary alkylation has been achieved by two sequential double-deprotonation (*n*-butyllithium)/double-methylation (methyl iodide) procedures in glyme solution in almost quantitative yield.

The resulting 2,6-bis(6-methyl-2-pyridyl-2-propyl)-pyridine, **Me$_6$-4**, has been doubly deprotonated with *n*-butyllithium in glyme and cyclized with copper(I) iodide to give tetramethyl-substituted macrocycle **Me$_4$-2** in 30% yield.[24] It is significant that the use of 1,2-dibromoethane, also known as a coupling reagent for 2-pyridylmethyllithium compounds,[36] instead of copper(I) iodide gave no macrocycle. Thus, organocuprates must be important intermediates in the synthesis described. Since "intermolecular" coupling might lead to higher molecular weight oligomers, we attempted the reaction in 3 times more diluted solutions. As a result of the *dilution* we *increased* the yield of the macrocycle to 50%.

Synthesis of [2.1.1]-(2,6)-pyridinophane, 2. Macrocyclization of 1,2-bis(2-pyridyl)ethanes **5** and carbanions derived from 2,6-dimethylpyridines, including double Chichibabin C−C coupling, allowed us to synthesize two [2.1.1]-pyridinophanes, **2** and **^{t}Bu-2**, in good yields (Scheme 4).

The key precursor for the synthesis of the macrocycles is 1,2-bis(2-pyridyl)ethane, **5**, which can be prepared in

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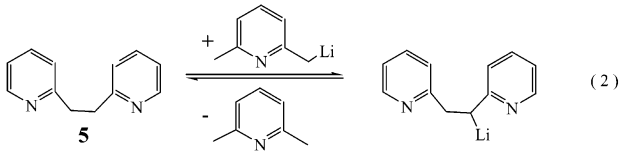
85% isolated yield by coupling 2 mol of 2-pyridylmethyllithium with 1,2-dibromoethane.[36] The last step of the synthesis is the double condensation of the dipyridine **5** with excess LiLut.[24] The number of equivalents of LiLut is very important and has been *optimized in this work*. A 2 equiv sample is necessary by stoichiometry, leading to free macrocycle **2** and 2 mol of lithium hydride. Two acidic methylene bridges in **2** consume an extra 2 equiv of LiLut. Thus, the amount of the latter reagent increases up to 4 equiv.

Finally, taking into account that the acidity of the ethylene bridge in the precursor **5** should be comparable to that of 2,6-dimethylpyridine (eq 2), we increased the



(2)

amount of LiLut. The best yield of the macrocycle **2**, 60% as a crude isolated compound, could be obtained with 4.5−5 equiv of LiLut. Due to expected easy deprotonation of the precursor **5** and the related nonmacrocyclic tripyridine resulting from single condensation (Scheme 2b), the concentration of these electrophilic components is suppressed, and as a result, the final C−C forming step of the macrocyclization requires high temperature.

Synthesis of More Lipophilic Alkylated [2.1.1]-(2,6)-Pyridinophanes. (a) 12-*tert*-Butyl-[2.1.1]-(2,6)-pyridinophane, ^{t}Bu-2. To develop even more lipophilic pyridinophanes, such as **^{t}Bu-2** and **^{t}Bu$_3$-2**, and to evaluate the generality of the synthetic path to the macrocycles **2**, we tried to use 2,4,6-trimethylpyridine instead of 2,6-dimethylpyridine in a condensation with the dipyridine **5**. This attempt did not lead to the desired 12-methyl-substituted macrocycle presumably due to the high relative acidity of the methyl group at the *para*-carbon of methylpyridines[37] and involvement of this carbanionic center in condensation. Similarly, 1,2-bis(4-methyl-2-pyridyl)ethane, **Me$_2$-5**, used instead of the parent compound **5** in a condensation with 2,6-dimethylpyridine did not lead to macrocycle, presumably for the same reason. Under such circumstances reagents possessing groups not bearing acidic CH bonds in an α-position to a pyridine ring such as *tert*-butyl or phenyl might be suitable for the synthesis of (poly)substituted analogues of **2**. Indeed, when 4-*tert*-butyl-2,6-dimethylpyridine was used instead of 2,6-dimethylpyridine, the corresponding **^{t}Bu-2** was obtained in 50% yield (Scheme 4).

(b) Synthesis of 5,12,19-Tri-*tert*-butyl-[2.1.1]-(2,6)-pyridinophane, ^{t}Bu$_3$-2. Two additional *tert*-butyl groups could be introduced into the remaining nonsubstituted pyridine rings of the compound **^{t}Bu-2** at the *para*-carbons using reaction of excess *tert*-butyllithium in benzene to produce **^{t}Bu$_3$-2** in almost quantitative yield (Scheme 5).

Attempted Synthesis of 1. Our attempts to observe triple C−C self-coupling of 2-pyridylmethyllithium to give macrocycle **1** were unsuccessful. The main product of the condensation is its nonmacrocyclic precursor, 2-(6-methyl-2-pyridylmethyl)-6-(2-pyridylmethyl)pyridine (Scheme 2c).[33] A possible reason for the failure of this approach to produce macrocycle **1** is the suppressed acidity of its dianion and therefore insufficient gain in acidity in the course of the macrocyclization step. A planar structure of trianion **1** would result in better charge delocalization, but might be destabilized by significant repulsive interactions between three nitrogen lone pairs, were they to point to the center of the anion. In contrast to anions derived from the smallest macrocycle **1**, the dianion derived from compound **2** is not planar according to DFT calculations due to the flexibility of its ethylene bridge (Figure 2). Thus, significant N/N lone pair repulsions are avoided in this case.

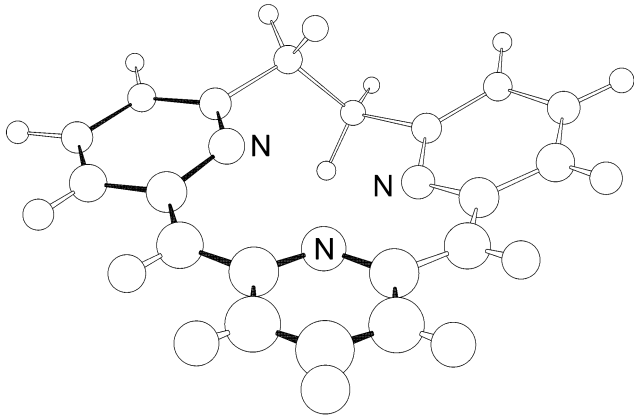
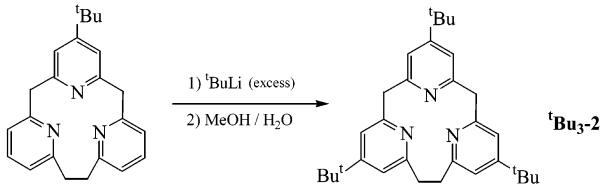


FIGURE 2. DFT-optimized structure for the doubly deprotonated [2,1,1]-(2,6)-pyridinophane dianion.

SCHEME 5



Synthesis of [2.2.1]-(2,6)-Pyridinophane, 3. For the synthesis of this tripyridine we chose macrocyclization of precursor **Me-6**. The most efficient way found to this precursor is shown in Scheme 6.

The dimethyl ester of 2,6-pyridinedicarboxylic acid was treated with a mixture of 2 equiv of 2-pyridylmethyllithium and 2 equiv of 6-methyl-2-pyridylmethyllithium to produce the bisenol **Me-7** shown as the main product (40%). Consecutive treatment of the ester with 1 or 2 equiv of 2-pyridylmethyllithium first and then with 2 equiv of 6-methyl-2-pyridylmethyllithium gave mainly the corresponding nonmethylated bisenol **7**. The dimethylated homologue **Me$_2$-7** was observed as the main product with the opposite order of addition of these reagents. Presumably, reaction of the intermediate monoester with a second organolithium species occurs faster than reaction of the diester with the first one. The resulting mixture of bisenols was reduced with hydrazine hydrate in a 50% yield to a mixture of tripyridines **6**, **Me-6**, and **Me$_2$-6**, with **Me-6** as the major component. The mixture was transformed into the macrocycle **3** in a yield of 30%.

Mono- and Diprotonated Macrocycle 2. Protonation of the pyridinophane **2** with 1 or 2 equiv of triflic

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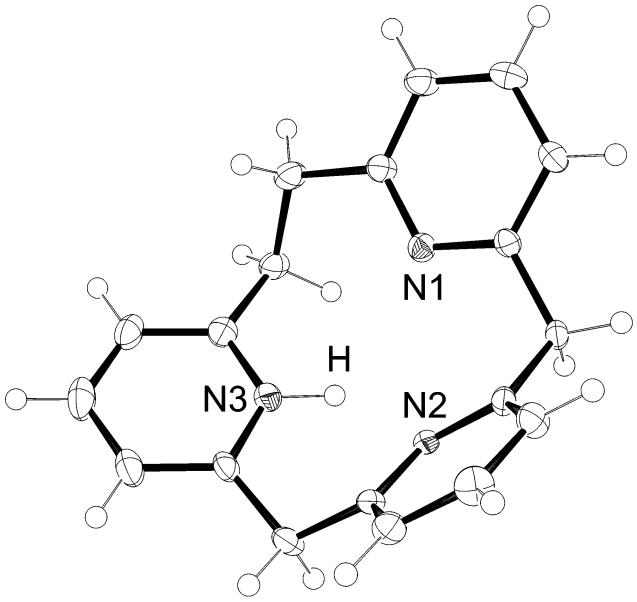
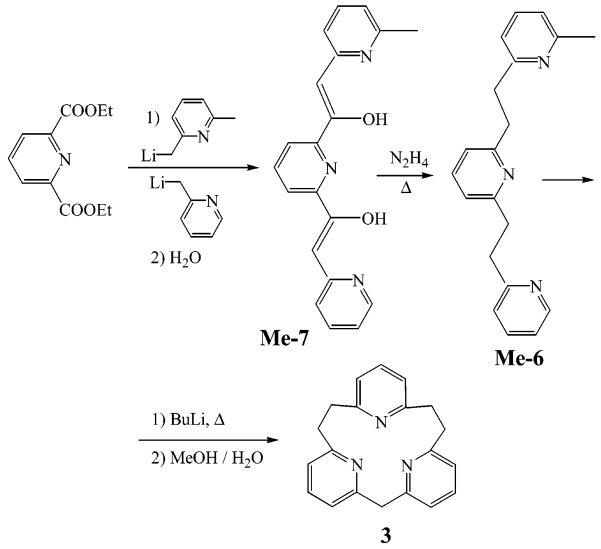


FIGURE 3. ORTEP plot (thermal ellipsoids are given at the 50% probability level) of (**2**)H^+ in its triflate salt.

SCHEME 6



acid led to the corresponding salts. The solid-state structure of each has been established by X-ray diffraction (Figures 3 and 4).

The monoprotonated pyridinophane cation is bowl-shaped with the N−H bond and nitrogen lone pairs directed toward one point. The proton is bound to the nitrogen of one of two symmetry-related rings of the starting pyridinophane (Figure 3) with N(3)−H, N(1)−H, and N(2)−H distances of 1.00, 2.54, and 2.12 Å, respectively. Oxygen atoms of the triflate anion have no close contacts with the proton (2.38 Å and longer). The "bowl" has no elements of symmetry due to the preferred gauche conformation of the ethylene-containing fragment of (**2**)H^+. Analysis of crystal packing shows that the unique ring of **2** is partially "immersed" into the bowl belonging to a closely situated layer of (**2**)H^+, therefore avoiding too much empty space and gaining van der Waals interactions. In dichloromethane solution at room temperature the proton of (**2**)HOTf migrates rapidly

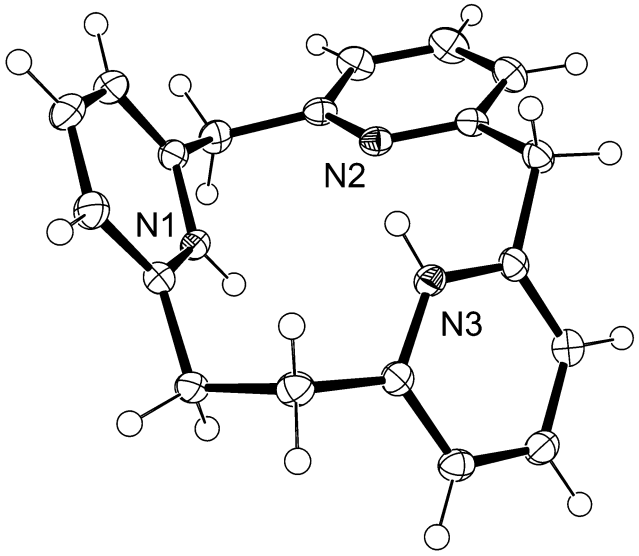


FIGURE 4. ORTEP plot (thermal ellipsoids are given at the 50% probability level) of (**2**)H_2^{2+} in its triflate salt.

between nitrogen atoms so that the cation shows, in both ^1H and ^{13}C NMR spectra, a set of sharp signals characteristic of a species with mirror symmetry.

In contrast to the monoprotonated compound, the dication derived from double protonation of **2** is characterized by orientation of two N−H bonds to the opposite sides of the NNN plane due to repulsion between these positively charged fragments (Figure 4). The third nitrogen lone pair vector lies in the NNN plane, and the ion has idealized C_2 symmetry. Oxygen atoms of the triflate anion have near van der Waals contacts with the protons (1.922 and 1.979 Å).

Macrocycle 2 in Hydrocarbon CH Bond Activation. According to X-ray structure determination, the dichloropalladium(II) complex derived from the macrocycle **Me$_4$-2** is highly preorganized for oxidative addition.[24] We found that (**2**)PtR_2H^+ salts exhibit room temperature alkane (R = Me, Ph)[25,26] and arene (R = Me)[26] CH bond activation chemistry, while the cationic complex (**2**)$PtMeH_2^+$ is able to exchange methyl for another alkyl or aryl ligand derived from the appropriate hydrocarbon.[27]

Summary and Conclusions

Simple and effective pathways to [2.*m*.1]-(2,6)-pyridinophanes are presented here. Using ab initio and DFT calculations to better understand the structure−reactivity relationship and thus to design ligands able to provide metal complexes with desired properties is an attractive guide to experiment.[23] New macrocyclic ligands [2.*m*.1]-(2,6)-pyridinophanes (L) have been designed to achieve an "intermediate" degree of stability and reactivity of d^6 metal alkyl hydrido complexes LMR_2H: neither excessively unstable (E_1 in Figure 1), producing species too unreactive toward alkane CH bonds, nor too stable (E_4 in Figure 1) and thus reluctant to produce a reactive transient LMR. At the moment it has already been demonstrated that [2.1.1]-(2,6)-pyridinophane is effective in the case of alkane oxidative addition to platinum(II) complexes.[25,26] The problem of controlling the reactivity

of transition-metal complexes by a carefully chosen ligand environment has multiple solutions, and the pyridinophanes are only one of them. However, the pyridinophanes synthesized here permit further modification, allowing enhanced lipophilicity or hydrophilicity, but also chirality. Extension of their coordination chemistry to other transition elements than Pt and Pd may also be productive.

Experimental Section

General Procedures and Methods. All manipulations with organolithium compounds were carried out under purified argon using standard Schlenk techniques. Solvents were dried and distilled following standard protocols and stored in gastight bulbs under argon. All reagents for which a synthesis is not given are commercially available and were used as received without further purification. All NMR solvents were dried, vacuum-transferred, and stored in an argon-filled glovebox. ^{1}H and ^{13}C NMR spectra were recorded at 400 MHz (^{1}H) and 100.6 MHz (^{13}C). NMR chemical shifts are reported in parts per million and referenced to residual solvent resonance peaks.

Computations. Theoretical calculations in this work have been performed using the DFT method,[38] specifically functional PBE,[39] implemented in an original program package, "Priroda".[40,41] In PBE calculations, relativistic Stevens−Basch−Krauss (SBK) effective core potentials (ECPs)[42−44] optimized for DFT calculations have been used. The basis set was 311-split for main group elements with one additional polarization p-function for hydrogen, and two additional polarization d-functions for elements of higher periods. Full geometry optimization was performed without constraints on symmetry. For all species under investigation, frequency analysis has been carried out. All minima have been checked for the absence of imaginary frequencies.

9,9,16,16-Tetramethyl-[2.1.1]-(2,6)-pyridinophane, $C_{23}H_{25}N_3$, Me_4-2. To a 300 mL Schlenk flask equipped with a magnetic stirring bar and filled with argon was added 2,6-bis[2-(6-methyl-2-pyridyl)-2-propyl]pyridine, **Me_6-4** (3.43 g, 10 mmol; see below), and glyme (200 mL). The flask was cooled to 0 °C in an acetone−liquid nitrogen bath, and an *n*-butyllithium solution in hexane (10 M, 2.0 mL, 20 mmol) was added dropwise with stirring. After the addition of *n*-butyllithium was complete, the resulting dark red solution was stirred at −10 °C for 1 h. The reaction mixture was cooled to −60 °C, and copper(I) iodide (3.90 g, 20 mmol) was added with stirring in one portion. After 30 min of stirring at −50 °C the mixture was allowed to warm slowly to room temperature and then heated under reflux for 2 h. Precipitation of metallic copper was observed. After cooling, a saturated aqueous solution of potassium hydroxide (2.6 g) was added to the mixture with intensive stirring to precipitate dissolved lithium salts. The resulting liquid was decanted, dried over solid potassium hydroxide, and fractionally distilled first at ambient pressure and then under vacuum: yield of crude tetramethyl-[2.1.1]-(2,6)-pyridinophane 1.7 g (50%); bp 165−170 °C at 0.13 Torr (bp 170−175 °C at 0.12 Torr).[24] After complete solidification, the crude product was recrystallized from *n*-heptane: colorless needles (1.0 g); mp 139 °C (lit.[24] mp 138−139 °C); ^{1}H NMR (C_6D_6, 22 °C) δ 1.60 (s, 12H, CH_3), 2.95 (s, 4H, CH_2), 6.54 (dd, J = 7.6 Hz, 0.9 Hz, 2H, *meta*-CH), 6.77 (dd, J = 7.9 Hz, 0.8 Hz, 2H, *meta*-CH), 6.92 (d, J = 7.8 Hz, 2H, *meta*-CH), 7.03 (t, J = 7.8 Hz, 2H, *para*-CH), 7.21 (t, J = 7.8 Hz, 1H, *para*-CH); ^{13}C NMR (C_6D_6, 22 °C) δ 27.64 (CH_3), 38.59 (C_2H_4), 47.87 (CMe_2), 115.26, 116.47, 119.69 (*meta*-C), 135.31 (2C, *para*-C), 135.86 (1C, *para*-C), 159.19, 167.29 (*ortho*-C, two overlapping peaks); HRMS *m*/*z* found 343.20550, calcd 343.20484, $C_{23}H_{25}N_3$. Anal. Calcd for $C_{23}H_{25}N_3$: C, 80.4; H, 7.34; N, 12.2. Found: C, 80.3; H, 7.28; N, 12.1.

2,6-Bis(6-methyl-2-pyridylmethyl)pyridine, $C_{19}H_{19}N_3$, Me_2-4. The product has been synthesized in 70% yield according to the published procedure:[24] white crystals; mp 68−68.5 °C; bp 173−178 °C at 0.15 Torr; ^{1}H NMR (22 °C, C_6D_6) δ 2.31 (s, 6H, CH_3), 4.31 (s, 4H, CH_2), 6.47 (d, J = 7.6 Hz, 2H, C(5′)H), 6.86 (d, J = 7.8 Hz, 4H, C(3′)H, C(3,5)H), 6.92 (m, 1H, C(4)H), 6.94 (t, J = 7.7 Hz, 2H, C(4′)H); ^{13}C NMR (C_6D_6, 22 °C) δ 24.32 (CH_3), 47.62 (CH_2), 120.46, 121.10 (C(3′), C(5′), C(3,5)), 136.21 (C(4′)), 136.54 (C(4)), 157.90, 159.49, 159.61 (C(2, 6), C(2′), C(6′)); HRMS *m*/*z* found 289.15664, calcd 289.15790, $C_{19}H_{19}N_3$. Anal. Calcd for $C_{19}H_{19}N_3$: C, 78.9; H, 6.62; N, 14.5. Found: C, 78.9; H, 6.58; N, 14.3.

Deprotonation of Me_2-4 with Potassium *tert*-Butoxide. This compound can be readily deprotonated with potassium *tert*-butoxide in tetrahydrofuran solution. In a 5 mL flask filled with argon were added 28.9 mg of **Me_2-4** (0.010 mmol), 1.0 mL of tetrahydrofuran, and then a solution of 11.2 mg of potassium *tert*-butoxide (0.010 mmol) in 1.0 mL of tetrahydrofuran. A deep red color developed immediately. In 15 min the mixture was taken to dryness under vacuum. The residue dissolved in THF-d_8 showed no ^{1}H NMR signals in the region of 1 ppm characteristic of the *tert*-butyl group.

2,6-Bis[2-(6-methyl-2-pyridyl)-2-propyl]pyridine, $C_{23}H_{27}N_3$, Me_6-4. This compound has been synthesized according to the published procedure:[24] colorless liquid; bp 165−170 °C at 0.13 Torr; ^{1}H NMR (C_6D_6, 22 °C) δ 1.93 (s, 12H, CH_3), 2.35 (s, 6H, CH_3), 6.51 (d, J = 7.8 Hz, 2H, C(5′)H), 6.83 (vd, J = 7.8 Hz, 4H, C(3,5,3′)H), 6.96 (m, 1H, C(4)H), 6.97 (t, J = 7.8 Hz, 2H, C(4′)H); ^{13}C NMR (CD_2Cl_2, 22 °C) δ 24.97 (py-CH_3), 28.60 ($C(CH_3)_2$), 48.37 ($C(CH_3)_2$), 118.11, 118.81, 120.17 (*meta*-C), 135.96 (C(4′)), 136.11 (C(4)), 156.87, 166.18, 167.35 (C(2,6), C(2′), C(6′)); HRMS *m*/*z* found 345.22131, calcd 345.22049, $C_{23}H_{27}N_3$.

[2.1.1]-(2,6)-Pyridinophane, $C_{19}H_{17}N_3$, 2. To a 300 mL Schlenk flask equipped with a Teflon valve and filled with purified argon were added 50 mL of diethyl ether and 2,6-lutidine (24 mL, 0.20 mol) distilled over calcium hydride. The flask was then placed into an ice bath, and *n*-butyllithium solution in hexane (10 M, 20.0 mL, 0.20 mol) was added dropwise with stirring. The resulting dark red solution was left at ambient temperature for 1 h. Diethyl ether was removed in a vacuum, and 1,2-bis(2-pyridyl)ethane (7.4 g, 0.040 mol) dissolved in toluene (75 mL) was added; the color turned to yellow-black. The flask was immersed for 24 h into a silicon oil bath heated to 170 °C. The mixture finally turned dark red. Then the flask was cooled, and methanol (12 mL) was added to decompose lithium hydride. After addition of water (16 mL) and careful shaking, a yellow-brown liquid could be easily separated by decantation from a white precipitate of lithium hydroxide. The liquid was fractionally distilled, first at ambient pressure to recover lutidine and then under vacuum: yield of crude [2.1.1]-(2,6)-pyridinophane 7.0 g (60%); bp 190−195 °C at 0.26 Torr (bp 190−200 °C at 0.2 Torr).[24] Solidification of the crude product can be accelerated by addition of 2 mL of *n*-pentane. Brown crystals were filtered off, recrystallized from 3:7 benzene−*n*-heptane mixture, and washed with a 1:1 *n*-heptane−diethyl ether mixture: colorless prisms (3.5 g); mp 143 °C (lit.[24] mp 142−143 °C); ^{1}H NMR (C_6D_6, 22 °C) δ 3.01 (s, 4H, C_2H_4), 3.91 (s, 4H, CH_2), 6.52 (d, J = 7.8 Hz, 2H, *meta*-CH), 6.53 (d, J = 7.7 Hz, 2H, *meta*-CH), 6.60 (d, J = 7.8 Hz, 2H, *meta*-CH), 6.97 (t, J = 7.6 Hz, 1H, *para*-CH), 6.98 (t, J =

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7.7 Hz, 2H, *para*-CH); ^{13}C NMR (CD_2Cl_2, 22 °C) δ 39.09 (C_2H_4), 45.64 (CH_2), 119.97, 120.62, 120.77 (*meta*-C), 136.29 (2C, *para*-C), 136.36 (1C, *para*-C), 158.27, 158.87, 160.82 (*ortho*-C); HRMS (EI) *m*/*z* found 287.14128, calcd 287.14225, $C_{19}H_{17}N_3$. Anal. Calcd for $C_{19}H_{17}N_3$: C, 79.4; H, 5.96; N, 14.6. Found: C, 79.3; H, 5.98; N, 14.5.

1,2-Bis(2-pyridyl)ethane, $C_{12}H_{12}N_2$, 5. A 250 mL two-neck flask equipped with a magnetic stirbar, condenser with an argon inlet tube, and serum cap was filled with argon. In the flask were placed 150 mL of dry THF and 15 mL (0.15 mol) of dry 2-picoline. The stirred solution was cooled in an ice bath, and then slowly 16.0 mL of a 10 M butyllithium solution in hexane (0.16 mol) was added with a syringe. The resulting mixture of a dark red color was removed from the bath and allowed to stay at room temperature. In 1 h the flask was put into an acetone bath and cooled to −60 °C. A solution of 6.5 mL (0.075 mol) of 1,2-dibromoethane in 10 mL of THF was added with a syringe while the temperature was maintained in the range of −50 to −60 °C. When the addition was complete, the mixture turned light red. The flask was allowed to warm slowly to room temperature (3 h). Then a saturated aqueous solution of potassium hydroxide (20 g) was added to the stirred mixture. The flask was cooled and shaken carefully. The resulting almost colorless liquid was decanted from a precipitate of lithium hydroxide and potassium bromide and dried overnight over solid potassium hydroxide. After removal of the solvent and distillation under vacuum pure 1,2-bis(2-pyridyl)ethane was obtained (12 g, 85%) as a slightly yellow liquid which solidified easily: bp 110 °C at 0.2 mmHg; mp 48 °C (lit.[35] mp 49−50 °C); ^{1}H NMR ($CDCl_3$, 22 °C) δ 3.19 (s, 4H, C_2H_4), 7.05 (ddd, J = 7.7 Hz, 4.9 Hz, 1.0 Hz, 2H, C(5)H), 7.07 (dd, J = 7.8 Hz, 0.8 Hz, 2H, C(3)H), 7.50 (dt, J = 7.8 Hz, 1.9 Hz, 2H, C(4)H), 8.50 (m, 2H, C(6)H); ^{13}C NMR ($CDCl_3$, 22 °C) δ 38.23 (CH_2), 121.26, 123.13 (C(3), C(5)), 136.42 (C(4)), 149.40 (C(6)), 161.21 (C(2)).

1,2-Bis(4-methyl-2-pyridyl)ethane, $C_{14}H_{16}N_2$, Me_2-5. A similar procedure as for the synthesis of 1,2-bis(2-pyridyl)-ethane was used. After removal of solvent and distillation under vacuum pure 1,2-bis(4-methyl-2-pyridyl)ethane was obtained (7 g, 30%) as a slightly yellow easily solidified liquid: bp 150 °C at 0.25 mmHg; mp 51 °C; ^{1}H NMR ($CDCl_3$, 22 °C) δ 2.49 (s, 6H, Me), 2.84 (s, 4H, C_2H_4), 6.85 (d, J = 5.2 Hz, 2H, C(5)H), 6.91 (s, 2H, C(3)H), 8.35 (d, J = 5.2 Hz, 2H, C(6)H); ^{13}C NMR ($CDCl_3$, 22 °C) δ 24.50 (CH_3), 35.89 (CH_2), 121.03, 123.48 (C(3), C(5)), 149.28 (C(6)), 150.40 (C(2), C(4)); HRMS *m*/*z* found 212.13051, calcd 212.13135, $C_{14}H_{16}N_2$.

[2.1.1]-(2,6)-Pyridinophane Monotriflate, $C_{20}H_{18}F_3N_3O_3S$, (2)HOTf. To a 5 mL flask were added 14.4 mg of [2.1.1]-(2,6)-pyridinophane (0.0050 mmol), 1.0 mL of dichloromethane, and then slowly 7.5 mg of triflic acid (0.0050 mmol) dissolved in 0.3 mL of dichloromethane. The solution was layered with 0.2 mL of diethyl ether and left for 1 day. Crystals suitable for X-ray analysis were obtained: total yield 21 mg (96%); ^{1}H NMR (CD_2Cl_2, 22 °C) δ 3.54 (s, 4H, C_2H_4), 4.41 (s, 4H, CH_2), 7.35 (d, J = 7.8 Hz, 2H, *meta*-CH), 7.38 (d, J = 7.8 Hz, 2H, *meta*-CH), 7.39 (d, J = 7.8 Hz, 2H, *meta*-CH), 7.81 (t, J = 7.8 Hz, 1H, *para*-CH), 7.86 (t, J = 7.8 Hz, 2H, *para*-CH), NH proton not seen; ^{13}C NMR (CD_2Cl_2, 22 °C) δ 33.46 (C_2H_4), 41.25 (CH_2), 122.62, 123.23, 123.80 (*meta*-C), 140.36 (1C, *para*-C), 141.19 (2C, *para*-C), 155.28, 155.77, 158.51 (*ortho*-C).

[2.1.1]-(2,6)-Pyridinophane Ditriflate, $C_{21}H_{19}F_6N_3O_6S_2$, (2)$(HOTf)_2$. To a 5 mL flask were added 14.4 mg of [2.1.1]-(2,6)-pyridinophane (0.0050 mmol), 1.0 mL of dichloromethane, and then slowly 15.0 mg of triflic acid (0.010 mmol) dissolved in 0.6 mL of dichloromethane. The solution was layered with 0.2 mL of diethyl ether and left for 1 day. Crystals suitable for X-ray analysis were obtained: total yield 28 mg (95%); ^{1}H NMR (CD_2Cl_2, 22 °C) δ 3.68 (br s, 4H, C_2H_4), 4.45 (s, 4H, CH_2), 7.24 (br d, J = 6.8 Hz, 2H, *meta*-CH), 7.63 (br d, J = 6.8 Hz, 2H, *meta*-CH), 7.73 (br t, J = 7.0 Hz, 1H, *para*-CH), 7.90 (br d, J = 6.8 Hz, 2H, *meta*-CH), 8.39 (br t, J = 6.8 Hz, 2H, *para*-CH), NH protons not seen.

Attempt To Prepare 12-Methyl-[2.1.1]-(2,6)-pyridinophane. The experiment was set up similarly to that for the synthesis of **2**. 2,4,6-Trimethylpyridine (28 mL, 0.20 mol) was used instead of 2,6-lutidine. After 24 h of heating at 170 °C the reaction mixture was worked up. No characteristic signals of the methylene bridges of the [2.1.1] macrocycle in the region of 4.1 ppm were observed.

Attempt To Prepare 5,19-Dimethyl-[2.1.1]-(2,6)-pyridinophane. The experiment was set up similarly to that for the synthesis of **2**. 1,2-Bis(4-methyl-2-pyridyl)ethane (8.5 g, 0.040 mol) was used instead of 1,2-bis(2-pyridyl)ethane. After 24 h of heating at 170 °C the reaction mixture was worked up. No characteristic signals of the methylene bridges of the [2.1.1] macrocycle in the region of 4.1 ppm were observed.

12-*tert*-Butyl-[2.1.1]-(2,6)-pyridinophane, $C_{23}H_{25}N_3$, ^{t}Bu-2. The experiment was set up similarly to that for the synthesis of **2**. 4-*tert*-Butyl-2,6-dimethylpyridine (36 mL, 33.7 g, 0.20 mol) was used instead of 2,6-lutidine. After 24 h of heating at 185 °C the reaction mixture was worked up. The resulting liquid was fractionally distilled first under a water aspirator pump vacuum to recover 4-*tert*-butyl-2,6-dimethylpyridine (25 mL) and then under a high vacuum: yield of crude 12-*tert*-butyl-[2.1.1]-(2,6)-pyridinophane 7.0 g (50%); bp 200−210 °C at 0.2 Torr. The crude product was dissolved in 70 mL of refluxing *n*-heptane. Yellow crystals were filtered off the cooled mixture, recrystallized from *n*-heptane three times, and washed with diethyl ether: colorless crystals (3.5 g); mp 142−143 °C; ^{1}H NMR ($CDCl_3$, 22 °C) δ 1.26 (s, 9H, CH_3), 3.17 (s, 4H, C_2H_4), 4.10 (s, 4H, CH_2), 6.86 (dd, J = 0.9 Hz, 7.6 Hz, 2H, *meta*-CH), 6.95 (s, 2H, *meta*-CH), 6.96 (dd, J = 1.0 Hz, 7.6 Hz, 2H, *meta*-CH), 7.39 (t, J = 7.6 Hz, 2H, *para*-CH); ^{13}C NMR ($CDCl_3$, 22 °C) δ 30.92 (CH_3), 34.76 (CMe_3), 38.81 (C_2H_4), 46.04 (CH_2), 117.30, 120.86, 121.01 (*meta*-C), 136.47 (2C, *para*-C), 158.47, 158.72 (*ortho*-C), 160.11 (1C, *para*-C), 160.31 (*ortho*-C); HRMS (EI) *m*/*z* found 343.20480, calcd 343.20484, $C_{23}H_{25}N_3$.

5,12,19-Tri-*tert*-butyl-[2.1.1]-(2,6)-pyridinophane, $C_{31}H_{41}N_3$, ^{t}Bu$_3$-2. To a 300 mL Schlenk flask equipped with a magnetic stirring bar and filled with argon were added 3.43 g of 12-*tert*-butyl-[2.1.1]-(2,6)-pyridinophane (10.0 mmol), 60 mL of benzene, and slowly, with stirring, 60 mL of a 1.7 M solution of *tert*-butyllithium in *n*-pentane (100 mmol). The resulting mixture was heated at 120 °C for 22 h. The flask was cooled, and a mixture of 4 mL of methanol and 5 mL of water was added slowly with a syringe to decompose excess *tert*-butyllithium and to precipitate lithium hydroxide. The mixture was filtered and dried with solid potassium hydroxide. The resulting benzene solution was reduced to 15 mL, and transferred to a short column filled with 50 mL of silica. The column was washed with 100 mL of benzene. The main portion of the target compound was obtained using 100 mL of a THF−CH_2Cl_2 (1:4 by volume) mixture as an eluent: combined yield of 5,12,19-tri-*tert*-butyl-[2.1.1]-(2,6)-pyridinophane 4.5 g (98%). The middle fraction (2.5 g) contained the most pure product: yellow crystals; mp 78 °C; ^{1}H NMR ($CDCl_3$, 22 °C) δ 1.24 (s, 18H, $C(CH_3)_3$), 1.28 (s, 9H, $C(CH_3)_3$), 3.19 (s, 4H, C_2H_4), 4.16 (s, 4H, CH_2), 6.87 (d, J = 1.9 Hz 2H, *meta*-CH), 6.92 (d, J = 1.9 Hz, 2H, *meta*-CH), 6.97 (s, 2H, *meta*-CH); ^{13}C NMR ($CDCl_3$, 22 °C) δ 30.84 (CH_3, ^{t}Bu), 30.90 (CH_3, central ^{t}Bu), 34.62 (C, ^{t}Bu), 34.76 (C, central ^{t}Bu), 38.46 (C_2H_4), 45.97 (CH_2), 117.62, 117.89, 118.33 (*meta*-C), 158.21, 158.71, 159.97, 160.07 (two overlapping signals) (*ortho*- and *para*-C); HRMS (EI) *m*/*z* found 455.32825, calcd 455.33005, $C_{31}H_{40}N_3$.

Attempt To prepare [1.1.1]-(2,6)-Pyridinophane, 1, Leading to 2-(6-Methyl-2-pyridylmethyl)-2-(2-pyridylmethyl)pyridine, Me-4. To a 300 mL Schlenk flask equipped with a Teflon valve and filled with purified argon were added 50 mL of diethyl ether and 2-picoline (20 mL, 0.20 mol) distilled over calcium hydride. The flask was then placed into an ice bath, and an *n*-butyllithium solution in hexane (10 M, 20.0 mL, 0.20 mol) was added dropwise with stirring. The resulting dark red solution was left at ambient temperature for 1 h. Diethyl ether was removed in a vacuum, and toluene

(75 mL) was added. The flask was immersed for 8 h into a silicon oil bath heated to 170 °C. The mixture finally turned dark red. Then the flask was cooled, and methanol (12 mL) was added to decompose lithium hydride. After addition of water (16 mL) and careful shaking a yellow-brown liquid could be easily separated by decantation from a white precipitate of lithium hydroxide. The liquid was fractionally distilled first at ambient pressure to recover 2-picoline and then under vacuum: yield of **Me-4** 4.6 g (50% on *n*-butyllithium); bp 169−171 °C at 0.7 Torr; ^{1}H NMR (22 °C, $CDCl_3$) δ 2.51 (s, 3H, CH_3), 4.28 (s, 2H, CH_2), 4.31 (s, 2H, CH_2), 6.95 (d, J = 7.7 Hz, 2H, C(3′,5′)H), 7.00 (d, J = 7.7 Hz, 1H, C(3)H), 7.02 (d, J = 7.7 Hz, 1H, C(5)H), 7.09 (dd, J = 7.7 Hz, 4.8, 1H, C(5″)H), 7.22 (dd, J = 7.7 Hz, 0.9 Hz, 1H, C(3″)H), 7.42 (t, J = 7.7 Hz, 1H, C(4′)H), 7.46 (t, J = 7.7 Hz, 1H, C(4)H), 7.55 (dt, J = 1.8 Hz, 7.7 Hz, 1H, C(4″)H), 8.48−8.54 (m, 1H, C(6″)H); HRMS (EI) *m*/*z* found 275.13685, calcd 275.142247, $C_{18}H_{17}N_3$.

2,6-Bis[1-hydroxy-2-(2-pyridyl)vinyl]pyridine, $C_{19}H_{15}N_3O_2$, 7. To a 250 mL Schlenk flask equipped with a magnetic stirring bar and filled with argon were added 100 mL of anhydrous tetrahydrofuran and 20 mL of 2-picoline (0.20 mol). The flask was immersed into an ice bath, and an *n*-butyllithium solution in hexane (10 M, 20.0 mL, 0.20 mol) was added dropwise with stirring. After the addition of *n*-butyllithium was complete, the resulting dark red solution of 2-pyridylmethyllithium was left to stand for 1 h. The solution was added via Teflon cannula to a stirred mixture of diethyl 2,6-pyridinedicarboxylate (11.3 g, 0.050 mol) or corresponding dimethyl ester (9.9 g, 0.050 mol) and anhydrous tetrahydrofuran (100 mL), and the resulting mixture was added to a 500 mL Schlenk argon-filled flask in the course of 30 min. The resulting mixture was stirred and cooled with an ice bath and then allowed to warm to room temperature for 1 h. Methanol (100 mL) and water (140 mL) were added to precipitate yellow lithium salt of the target bisenol. The precipitate was collected and treated with acetic acid (6.0 g, 0.10 mol) dissolved in 140 mL of water with heating until it melted completely. The mixture was ice-cooled; the red-yellow crude bisenol filtered off and washed with water: yield of the crude product 11 g (70%). After recrystallization from ethanol 8 g of pure compound was obtained: bright yellow crystals; mp 144 °C.

In acetone solution approximately 10% of the compound exists presumably as a monoenol tautomer. Addition of a drop of D_2O to the solution led to slow disappearance of both ketone CH_2 (4.76) and enol −CH═ (7.08) signals: ^{1}H NMR (acetone-d_6, 22 °C) δ 2.80 (br s, OH), 7.08 (s, 2H, ═CH−), 7.23 (ddd, J = 7.4 Hz, 5.2 Hz, 1.1 Hz, 2H, C(5′)H), 7.41 (vd, J = 8.0 Hz, 2H, C(3′)H), 7.86 (dt, J = 7.8 Hz, 1.6 Hz, 2H, C(4′)H), 7.92 (m, 2H, C(3)H), 8.02 (m, 1H, C(4)H), 8.51 (vd, J = 5.2 Hz, 1H, C(6′)H); ^{1}H NMR (acetone-d_6, 22 °C) (monoenol) δ 4.76 (s, CH_2); ^{13}C NMR (acetone-d_6, 22 °C) δ 96.27 (═CH−), 119.84, 120.01, 122.81 (C(3), C(3′), C(5′)), 137.94 (C(4′)), 137.99 (C(4)), 145.53 (C(6′)), 152.92, 158.71, 160.94 (C(2), C(2′), C−OH); ^{13}C NMR (acetone-d_6, 22 °C) (monoenol) δ 120.21, 121.54, 121.66, 123.03 (2C), 124.59 (C(3), C(5), C(3′), C(5′), C(3″), C(5″)), 136.35, 138.52 (*para*-C); IR (Nujol): 2500−3300 (br, OH···N), 1700 (weak), 1644, 1602, 1549 cm^{-1}; HRMS (EI) *m*/*z* found 317.11680, calcd 317.11643, $C_{19}H_{15}N_3O_2$.

2,6-Bis[1-hydroxy-2-(6-methyl-2-pyridyl)vinyl]pyridine, $C_{21}H_{19}N_3O_2$, Me_2-7. The same procedure as for 2,6-bis-[1-hydroxy-2-(2-pyridyl)vinyl]pyridine was used, with 23 mL of 2,6-lutidine (0.20 mol) instead of 2-picoline: yield of the crude product 14.7 g (85%). After recrystallization from ethanol 11 g of pure compound was obtained: yellow crystals; mp 168 °C; ^{1}H NMR (acetone-d_6, 22 °C) δ 2.56 (s, 6H, Me), 2.80 (br s, OH), 7.03 (s, 2H, ═CH−), 7.06 (d, J = 7.6 Hz, 2H, C(5′)H), 7.19 (d, J = 8.0 Hz, 2H, C(3′)H), 7.72 (t, J = 7.8 Hz, 2H, C(4′)H), 7.91 (m, 2H, C(3)H), 7.99 (m, 1H, C(4)H); ^{1}H NMR (acetone-d_6, 22 °C) (monoenol) δ 4.72 (s, CH_2); ^{13}C NMR (acetone-d_6, 22 °C) δ 96.38 (═CH−), 119.44, 119.69, 119.84 (C(3), C(3′), C(5′)), 137.90 (C(4)), 138.16 (C(4′)), 153.00, 154.68, 158.08, 161.11 (C(2,6), C(2′), C(6′), C−OH); IR (Nujol): 2500−3300 (br, OH···N), 1635, 1599, 1552 cm^{-1}; HRMS (EI) *m*/*z* found 345.14609, calcd 345.14773, $C_{21}H_{19}N_3O_2$.

2-[1-Hydroxy-2-(6-methyl-2-pyridyl)vinyl]-6-[1-hydroxy-2-(2-pyridyl)vinyl] pyridine, $C_{20}H_{17}N_3O_2$, Me-7. The same procedure as for 2,6-bis[1-hydroxy-2-(2-pyridyl)vinyl]pyridine was used, with a mixture of 10 mL of 2-picoline (0.10 mol) and 11.6 mL of 2,6-lutidine (0.10 mol) instead of pure 2-picoline: yield of a mixture of three homologous compounds 16 g (90%). According to MS determination, the ratio of nonmethylated **7**, monomethylated **Me-7**, and dimethylated Me_2-**7** bisenols was almost statistical, 1:2:1. In the case of consecutive introduction of (1) 2-pyridylmethyllithium (0.10 mol) solution first and then 6-methyl-2-pyridylmethyllithium (0.10 mol) or (2) 6-methyl-2-pyridylmethyllithium (0.10 mol) solution first and then 2-pyridylmethyllithium solution (0.10 mol), this ratio was correspondingly much in favor of **7** or Me_2-**7**. Data for **Me-7**: ^{1}H NMR (acetone-d_6, 22 °C) δ 2.56 (s, 3H, Me), 2.82 (br s, OH), 7.04 (s, 1H, ═CH−), 7.06 (d, J = 7.8 Hz, 1H, C(5′)H), 7.07 (s, 1H, ═CH−), 7.18 (d, J = 7.8 Hz, 1H, C(3′)H), 7.20 (dd, J = 7.8 Hz, 5.2 Hz, 1H, C(3″)H), 7.39 (d, J = 7.8 Hz, 1H, C(5″)H), 7.72 (t, J = 7.8 Hz, 1H, C(4′)H), 7.84 (t, J = 7.8 Hz, 1H, C(4″)H), 7.91 (m, 2H, C(3)H), 7.99 (m, 1H, C(4)H), 8.49 (vd, J = 5.0 Hz, 1H, C(6″)H); HRMS (EI) *m*/*z* found 331.13104, calcd 331.13208, $C_{20}H_{17}N_3O_2$.

2,6-Bis[2-(2-pyridyl)ethyl]pyridine, $C_{19}H_{19}N_3$, 6. To a 250 mL argon-filled Schenk flask were added 15.5 g of bisenol **7** (0.050 mol) and 60 mL of hydrazine hydrate. The mixture was heated in a silicon oil bath at 170 °C. In 26 h the flask was cooled and a mixture of two almost colorless liquids extracted three times with 30 mL portions of chloroform. The chloroform extract was dried over solid potassium hydroxide. After removal of the solvent the residue was distilled in a high vacuum. The fraction collected in the interval 188−193 °C at 0.25 mmHg contained pure tripyridine **6**: yellow solid; yield 7 g (50%); mp 59 °C; ^{1}H NMR (acetone-d_6, 22 °C) δ 3.19 (vs, 8H, CH_2), 6.89 (d, J = 7.7 Hz, 2H, C(3)H), 7.06 (m, 2H, C(5′)H), 7.08 (dd, J = 7.9 Hz, 1.2 Hz, 2H, C(3′)H), 7.39 (t, J = 7.7 Hz, 1H, C(4)H), 7.52 (dt, J = 7.7 Hz, 1.9 Hz, 2H, C(4′)H), 8.52 (ddd, J = 4.8 Hz, 1.9 Hz, 1.1. Hz, 2H, C(4)H); ^{13}C NMR (acetone-d_6, 22 °C) δ 38.23, 38.37 (CH_2), 120.45, 121.23, 123.17 (C(3), C(3′), C(5), C(5′)), 136.36 (C(4′)), 136.65 (C(4)), 149.40 (C(6′)), 160.64, 161.46 (C(2), C(6), C(2′)); HRMS (EI) *m*/*z* found 289.15688, calcd 289.15790, $C_{19}H_{19}N_3$.

2-[2-(6-Methyl-2-pyridyl)ethyl]-6-[2-(2-pyridyl)ethyl]-pyridine, $C_{20}H_{21}N_3$, Me-6. To a 250 mL argon-filled Schenk flask were added 16.5 g of a 1:2:1 mixture of bisenols **7**, **Me-7**, and Me_2-**7** (0.050 mol) and 60 mL of hydrazine hydrate. The mixture was heated in a silicon oil bath at 170 °C. In 26 h the flask was cooled and a mixture of two almost colorless liquids extracted three times with 30 mL portions of chloroform. The chloroform extract was dried over solid potassium hydroxide. After removal of the solvent the residue was distilled in a high vacuum. The fraction collected in the interval 190−220 °C at 0.2 mmHg contained mainly a mixture of tripyridines **6**, **Me-6**, and Me_2-**6** in the ratio 3:4:2: yellow solid; yield 7 g (50%); HRMS (EI) *m*/*z* (intensity, reference) 289.15688, $C_{19}H_{19}N_3$ (3, **6**), 303.17255, $C_{20}H_{21}N_3$ (4, **Me-6**), 317.18841, $C_{21}H_{23}N_3$ (2, Me_2-**6**). Data for **Me-6**: ^{1}H NMR (acetone-d_6, 22 °C) δ (selected peaks) 2.48 (s, 3H, Me), 3.09−3.28 (m, 8H, CH_2), 8.48 (vd, J = 4.9 Hz, 1H, C(6″)H); ^{13}C NMR (acetone-d_6, 22 °C) δ 24.72 (CH_3), 38.44, 38.51 (CH_2), 119.25, 120.41 (several overlapping peaks), 120.74 (C(3), C(3′), C(3″), C(5), C(5′), C(5″)), 149.42 (C(6″)), 157.90 (C(6′)), 136.35, 136.60, 136.65 (C(4), C(4′), C(4″)), 160.62, 160.84, 161.48 (C(2), C(6), C(2′), C(2″)).

[2.2.1]-(2,6)-Pyridinophane, $C_{20}H_{19}N_3$, 3. To a 100 mL Schlenk flask equipped with a Teflon valve and filled with argon were added 60 mL of diethyl ether and 6.06 g of a 3:4:2 mixture of tripyridines **6**, **Me-6**, and Me_2-**6** (approximately 20 mmol). The flask was placed into an ice bath, and an *n*-butyllithium solution in hexane (10 M, 6.1 mL, 61 mmol) was added dropwise with stirring. The resulting black solution was left at ambient temperature for 1 h. Diethyl ether was removed

in a vacuum, and dry toluene (75 mL) was added. The flask was immersed for 24 h into a silicon oil bath heated to 180 °C. The flask was cooled, and methanol (3 mL) was added to decompose lithium hydride. After addition of water (4 mL) and careful shaking, a brown liquid could be easily separated by decantation from a white precipitate of lithium hydroxide. The liquid was fractionally distilled first at ambient pressure, to remove toluene, and then under a vacuum: yield of crude [2.1.1]-(2,6)-pyridinophane 0.90 g (30%); bp 190−200 °C at 0.3 Torr. The crude product slowly solidified. White crystals were filtered off, washed with diethyl ether, and recrystallized twice from *n*-heptane: colorless prisms (0.30 g); mp 174−175 °C; ^{1}H NMR ($CDCl_3$, 22 °C) δ 3.09 (m, 8H, C_2H_4), 4.03 (s, 2H, CH_2), 6.72 (d, J = 7.8 Hz, 2H, *meta*-CH), 6.95 (d, J = 7.8 Hz, 2H, *meta*-CH), 7.02 (d, J = 7.8 Hz, 2H, *meta*-CH), 7.21 (t, J = 7.7 Hz, 1H, *para*-CH), 7.45 (t, J = 7.7 Hz, 2H, *para*-CH); ^{13}C NMR (CD_2Cl_2, 22 °C) δ 37.38, 37.56 (C_2H_4), 46.05 (CH_2), 119.45, 121.00, 121.10 (*meta*-C), 136.04 (1C, *para*-C), 136.22 (2C, *para*-C), 158.81, 159.55, 160.15 (*ortho*-C); HRMS (EI) *m*/*z* found 301.15877, calcd 301.15790, $C_{20}H_{19}N_3$.

Acknowledgment. This work was supported by the Department of Energy. A.N.V. is on leave from the Chemical Faculty, Kazan State University, Kazan, Russia. This work has been made possible in part due to support from the Russian Foundation for Basic Research (Grant No. 01.03.32692).

Supporting Information Available: ^{1}H and ^{13}C NMR spectra of compounds **2**−**7** and crystallographic data for (**2**)-HOTf and (**2**)$(HOTf)_2$. This material is available free of charge via the Internet at http://pubs.acs.org.

JO034268V