Communication

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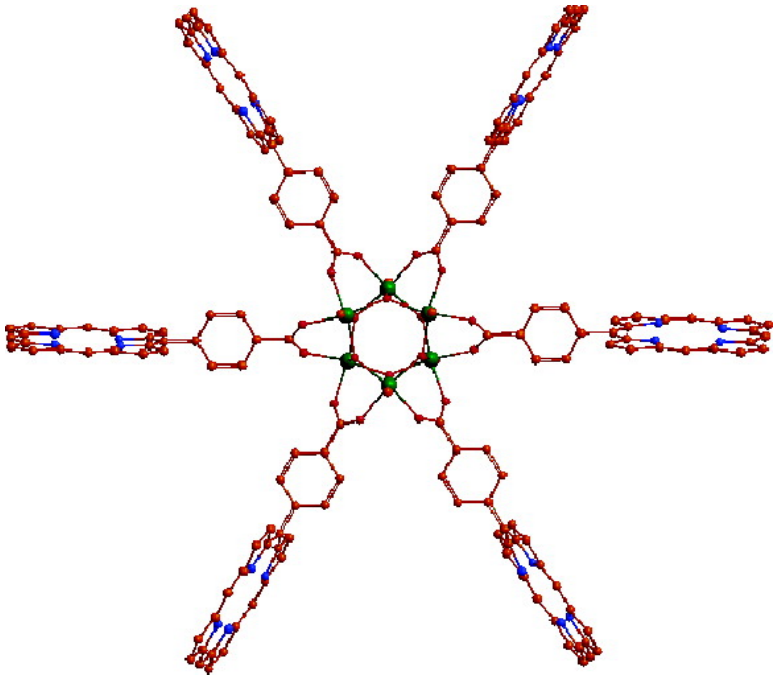

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A Lipophilic Hexaporphyrin Assembly Supported on a Stannoxane Core

Vadapalli Chandrasekhar,*,† Selvarajan Nagendran,† Ramachandran Azhakar,† Murugaeson Ravi Kumar,† Alagar Srinivasan,† Kallol Ray,† Tavarekere K. Chandrashekar,*,† C. Madhavaiah,† Sandeep Verma,*,† U. Deva Priyakumar,‡ and G. Narahari Sastry*,‡

Department of Chemistry, Indian Institute of Technology−Kanpur, Kanpur-208016, India, and Indian Institute of Chemical Technology, Hyderabad-500007, India

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Functionalized dendrimers containing metalated sites in the periphery have emerged as an attractive class of compounds in recent years.[1] This is in view of the promise of some of these compounds as homogeneous catalysts while retaining the advantages of the heterogeneous systems. Such a possibility stems from an accurate control of the number of active sites and separation of the catalyst from the reaction mixture by techniques such as ultrafiltration.[1] Among the various ligands that can be anchored on a dendrimeric surface, tetrapyrrolic porphyrins offer several advantages in the form of (i) a highly stable, planar, tetra-coordinating macrocyclic coordination environment and (ii) tunable redox and electronic properties.[2] Synthesis of multi-porphyrin arrays has hitherto been carried out with a view to utilizing such assemblies in optoelectronic devices or for harvesting light.[3−7] Recently a multiporphyrin assembly supported on a central benzene ring has been reported.[8]

We wished to build multi-porphyrin arrays, utilizing short synthetic steps, where the individual porphyrin units retain their porphyrinic character and can be used as macrocyclic coordinating ligands. Importantly, we wished to impart favorable solubility properties to such an assembly.[9] In a completely radical and unprecedented synthetic strategy, we chose to utilize the *organostannoxane approach* for the construction of a hexaporphyrin assembly. Accordingly, we report the synthesis and characterization of novel lipophilic free-base and Cu(II)-metalated hexaporphyrin assemblies **3** and **4**, which are supported on a central drumlike stannoxane core. The application of the hexacopper assembly **4** as an artificial nuclease is also reported. Quantum chemical calculations were employed to obtain the optimized geometry and to ascertain whether the stannoxane core is amenable for building the multiporphyrin array. In modeling the stannoxane core, the PM3 method appears to perform better than AM1 when compared to more reliable B3LYP calculations (see Supporting Information).[10] Therefore, the PM3 method was chosen to obtain the optimized geometry of **3**, which reveals that all six porphyrin units are disposed perpendicular to the stannoxane core, substantiating that the synthesis of the hexaporphyrin **3** is sterically viable (Figure 1).

In accordance with the results of the theoretical calculations, the reaction of *n*-butyl stannonic acid **1** with 5-(4-carboxyphenyl)-10,15,20-tritolyl-21,23*H*-porphyrin (H_2TTP−COOH, **2**) in a 1:1 stoichiometry afforded a bright violet-colored compound identified as **3** (eq 1). Remarkably, this synthesis is a *one-step* procedure, which is quite unprecedented for this family of compounds. Second, there was no need for any chromatographic purification of **3**. Also, in contrast to the poor to modest yields reported for many multiporphyrin compounds, **3** has been isolated in about 89% yield. Last and importantly, **3** is highly soluble in many common organic solvents, including dichloromethane, chloroform, carbontetrachloride, benzene, toluene, etc.

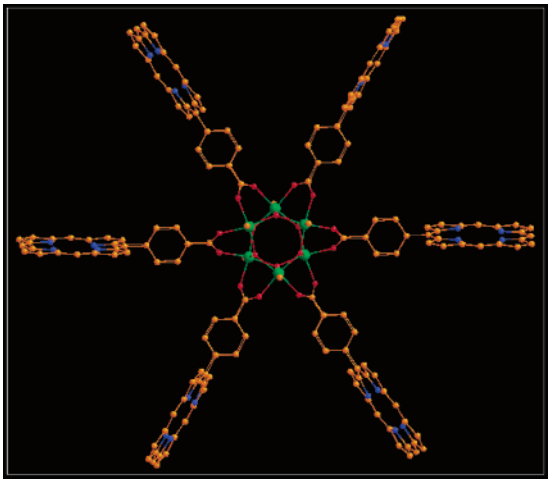

Figure 1. PM3-optimized geometry of the model compound $[CH_3Sn(O)OC(O)H_2Por]_6$ (Por = 5-(4-carboxyphenyl)-21,23*H*-porphyrin). Hydrogen atoms have been omitted. Color scheme: green, tin; red, oxygen; orange, carbon; blue, nitrogen. (See Supporting Information for computational details).

$$6\ \underset{\mathbf{1}}{n\text{-BuSn(O)OH}} + 6\underset{\mathbf{2}}{H_2\text{TTPCOOH}} \xrightarrow[\text{reflux, 6 h}]{C_6H_6} \underset{\mathbf{3}}{[n\text{-BuSn(O)OC(O)H}_2\text{TTP}]_6} \quad (1)$$

The composition of **3** was deduced from a variety of spectroscopic data. This was confirmed by the observation of the molecular ion peak as the base peak at *m*/*e* 5344.69 in its MALDI-TOF mass spectrum. Further, the ^{119}Sn NMR spectrum of **3** showed a sharp singlet at −482.4 ppm. This chemical shift not only confirms the equivalence of all the tins in the drumlike central stannoxane scaffold but also serves as a signature for a hexameric organostannoxane drum containing a Sn_6O_6 core.[11]

The observation of a Soret band (UV−vis) at 419 nm ($\epsilon = 1.75 \times 10^6$ dm^3 mol^{-1} cm^{-1}) and four Q-bands in the region 516−649 nm ($\epsilon \approx 104$) clearly suggests the absence of any strong electronic coupling between the porphyrin units in the hexaporphyrin assembly **3** (see Supporting Information). Furthermore, the fluorescence spectrum of **3** revealed a strong emission band at 653 nm (quantum yield = 0.117 relative to H_2TTP) and a weaker band at 711 nm. The cyclic voltammogram (in dicloromethane using 0.1 M $TBAPF_6$ as supporting electrolyte) of **3** shows a typical porphyrinic behavior, where two quasi-reversible reductions ($^{Red1}E_{1/2} = -1.26$ V, $^{Red2}E_{1/2} = -1.59$ V) and two irreversible/quasi-reversible oxidations (peak potentials at 1.02 and 1.29 V) were observed.

† Indian Institute of Technology−Kanpur.
‡ Indian Institute of Chemical Technology.

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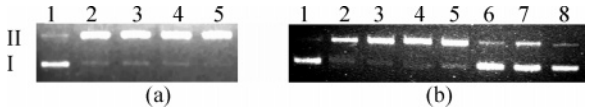

Figure 2. (a) pBR322 cleavage by **4**: lane 1, DNA alone; lanes 2−5, DNA + **4** (5, 10, 20, and 30 min, respectively). (b) pBR322 cleavage by **4** in the presence of hydroxyl and enzymatic scavengers: lane 1: DNA alone; lane 2, DNA + **4**; lanes 3−8, **4** + *t*-BuOH, +D-mannitol, +DMSO, +NaN_3. +SOD, and +catalase, respectively (30 min).

Complete metalation of **3** was accomplished by using $CuCl_2$, as shown in eq 2, to afford the hexacopper porphyrin **4** in 96% yield.

$$\mathbf{3} + 50CuCl_2 + 20Et_3N \xrightarrow[MeOH]{CHCl_3} \underset{\mathbf{4}}{[n\text{-BuSn(O)OC(O)CuTTP}]_6} \quad (2)$$

It is significant to note that the tin core supporting the hexaporphyrin assembly does not undergo any degradation during the metalation. Compound **4** showed a typical metalloporphyrin spectrum with an intense Soret band at 416 nm ($\epsilon = 1.5 \times 10^6$ $dm^3\ mol^{-1}\ cm^{-1}$) and two bands [Q(0,0) and Q(1,0) bands at 540 nm ($\epsilon = 7.7 \times 10^4$ $dm^3\ mol^{-1}\ cm^{-1}$) and 575 nm ($\epsilon = 1.1 \times 10^4$ $dm^3\ mol^{-1}\ cm^{-1}$)]. The EPR spectrum of **4** showed hyperfine and superhyperfine couplings due to copper and nitrogen, respectively, and the EPR parameters [EPR ($CHCl_3$/toluene, 1:1, 77K): $g_{||}$, 2.19; $g_\perp$, 2.02; $A_{||}$(Cu), 186.46 × 10^{-4} cm^{-1}; $A_{||}$(N), 11.65 × 10^{-4} cm^{-1}; $A_\perp$(Cu), 32.64 × 10^{-4} cm^{-1}; $A_\perp$(N), 16.32 × 10^{-4} cm^{-1}] clearly suggest a typical tetragonal symmetry around the Cu(II) ion, similar to that observed for Cu(TPP). The successful high-yield synthesis of **4** prompted us to explore its catalytic utility. Accordingly, the usefulness of hexacopper assembly **4** as an artificial nuclease was studied.

Under the reaction buffer conditions, compounds **3** and **4** are completely insoluble; thus, the present studies constitute a case of heterogeneous catalysis. The nuclease activity of **4** was probed by incubating supercoiled DNA. Interestingly, nearly complete conversion of form **I** to form **II** was observed in 5 min in the presence of **4** (Figure 2a). However, DNA cleavage did not occur in the presence of the free base **3** alone. Interestingly, a monomeric porphyrin−Cu complex, Cu−OMe-TPP, also failed to cleave DNA (see Supporting Information). The rapid DNA cleavage by **4** alone, in the absence of oxidants, is significant. Although many copper complexes are shown to have nuclease activity in the presence of external cooxidants,[12] very few reports are available where copper-(II) complexes promote the DNA cleavage on their own.[13]

It was of interest to probe the nature of reactive species involved. *t*-BuOH, D-mannitol, and DMSO do not affect the cleavage activity of **4** (Figure 2b, lanes 3−5). Considerable inhibition of DNA cleavage in the presence of singlet oxygen quencher NaN_3 suggests the involvement of reactive oxygen species for cleavage (Figure 2b, lane 6). Enzymatic scavengers, SOD, and catalase also retard cleavage reactions, confirming the formation and a possible role of superoxide anion radicals and H_2O_2 in plasmid relaxation (Figure 2b, lanes 7, 8).

Interestingly, **4** was found to be inactive toward protein cleavage. Incubation of lysozyme with **4** for prolonged time periods, either in the presence or in the absence of the external co-oxidant, did not give any cleavage products or higher molecular weight cross-linked products (Figure 3). Thus, **4** can potentially be used for selective removal of nucleic acid contaminants from cell extracts.

In conclusion, we have demonstrated a highly efficient and successful synthetic strategy based on approaches available in organostannoxane chemistry to construct hexaporphyrin assemblies in a single step and in nearly quantitative yields. The lipophilicity

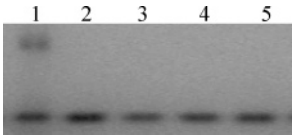

Figure 3. Lysozyme cleavage with **4**: lane 1, molecular weight marker (17 000; 14 200 from top to bottom); lane 2, lysozyme alone; lane 3, lysozyme + **3** + MMPP (48 h); lane 4, lysozyme + **4** (48 h); lane 5, lysozyme + **4** + MMPP (48 h).

of these assemblies will be of considerable advantage in their catalytic applications. In view of the presence of the multi-porphyrin periphery, the photonucleolytic activity of **4** should be interesting. We are currently investigating these possibilities. Also, recently there has been considerable interest in expanded porphyrins.[14,15] We are exploring the utility of adapting the synthetic method described herein for the assembly of multi(expanded)-porphyrin architectures.

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Supporting Information Available: Synthesis of **3** and **4**, spectroscopic and electrochemical plots (Figures S1−S6), and computational details (Scheme S1; Tables S1 and S2). This material is available free of charge via the Internet at http://pubs.acs.org.

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