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One-Pot Synthesis of a bis-Pocket Corrole through a 14-fold Bromination Reaction

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A one-pot protocol, effecting 14-fold bromination with elemental bromine, has afforded copper β-octabromo-meso-tris(2,6-dibromo-3,5-dimethoxyphenyl)corrole, a new bis-pocket metalcorrole. The Cu complex underwent smooth demetalation under reductive conditions, affording the free corrole ligand, which in turn could be readily complexed to MnIII and AuIII. A single-crystal X-ray structure was obtained for the MnIII complex.

bis-Pocket porphyrins and corroles afford sterically protected environments that may potentially stabilize high-valent transition metal-oxo, -imido, and -nitrido intermediates.[1–6] Of the wide variety of such ligands reported, porphyrins and corroles with 2,6-disubstituted meso-aryl groups are among the more easily accessible. Even so, the syntheses of such corroles rarely proceed in yields higher than 10%. Thus, condensation of pyrrole and the appropriate 2,6-disubstituted benzaldehyde provides 5,10,15-tris(2',6'-dichlorophenyl)corrole[7] in 9% yield and meso-trimesitylcorrole[8] and 5,10,15-tris(2',4',6'-tri phenylph eny l)corrole[9] each in 7% yield. Recently, a dipyrromethane–aldehyde condensation led to 5,10,15-tris(2',6'-dibromophenyl)corrole in 11% yield.[10] Bhyrappa and co-workers reported an elegant, if serendipitous, solution to the problem of low yields involving the direct bromination of copper 5,10,15,20-tetrakis(3',5'-dimethoxyphenyl)porphyrin with elemental bromine, which resulted in the hexadecabromobis-pocket complex copper 2,3,7,8,12,13,17,18-octabromo-5,10,15,20-tetrakis(2',6'-dibromo-3',5'-dimethoxyphenyl)porphyrin in nearly 80% yield.[10] Reported herein is an analogous protocol for the smooth 14-fold bromination of copper 5,10,15-tris(3',5'-dimethoxyphenyl)corrole, Cu[Tm,m'MeOPC] (1), affording the copper 2,3,7,8,12,13,17,18-octabromo-5,10,15-tris(2',6'-dibromo-3',5'-dimethoxyphenyl)corrole, Cu[Br14Tm,m'MeOPC] (1-Br14).

Exposure of readily accessible Cu[Tm,m'MeOPC] (1) to an excess of elemental bromine in chloroform yielded the bis-pocket complex Cu[Br14Tm,m'MeOPC] (1-Br14) in yields of over 55% and quantities of > 100 mg per batch, with clear indications that the synthesis could be scaled up further.[11] The tetradecabromocorrole product was contaminated with trideca- and dodecabrominated impurities (as inferred from mass spectrometric analysis), which fortunately could be readily removed by overnight recrystallization from chloroform/methanol. To our satisfaction, 1-Br14 underwent smooth reductive demetalation with anhydrous FeCl3 and concentrated H2SO4, affording the free-base ligand H1[Br14Tm,m'MeOPC] (2-Br14) in 77% yield.[12, 13] To demonstrate its utility as a transition-metal ligand, 2-Br14 was used to synthesize its AuIII[14] (3-Br14) and MnIII[15, 16] (4-Br14) complexes, which proceeded in good yields. A high-quality single-crystal X-ray structure was obtained for the MnIII complex 4-Br14·H2O (Figure 2 and Table 1), providing conclusive proof of composition and structure for the unusual 14-fold brominated complex. An attempt at rhenium insertion, however, led to a mixture of partially debrominated products Re[Br14,Tm,m'MeOPC(O) (n < 14), presumably reflecting the inability of the sterically hindered macrocycle to adopt the domed conformation observed for ReO corroles.[17]

Electrochemical (Figure 3) and UV/Vis (Figure 4) measurements (see Table 2 for select data) showed that 14-fold bromination has a substantial impact on the electronic character Cu[Tm,m'MeOPC] (1) and Au[Tm,m'MeOPC] (3). The most significant effect is an upshift of approximately 500 mV of both the oxidation and reduction potentials of the two metalcorroles. These upshifts are significantly higher than the 300–350 mV effect of β-octabromination on the oxidation and reduction potentials of Cu triarylcorroles,[12] but similar to those observed for other corrole derivatives.[18] Interestingly, 14-fold bromination of 1 engenders a significantly smaller redshift (ca. 15 nm).

Figure 1. Synthesis of 1-Br14.
of the Soret maximum than β-octabromination does for Cu triarylcorroles (ca. 27 nm).\[12\] Unfortunately, our attempts to relate these observations to the molecular structures of 1-Br14 and 3-Br14 were thwarted by our inability to grow X-ray quality crystals of either compound. A few speculative, explanatory remarks, however, may still be entertained. Copper corroles are inherently saddled as a result of a specific Cu(d$_x^2$-$d_y^2$)–corrole(p$_z$) orbital interaction.\[19-21\] Octabromination considerably enhances the saddling.\[19b,21\] The 27 nm Soret redshift resulting from octabromination of Cu triarylcorroles is thought to reflect both the direct electronic effect of the bromine atoms and the enhanced saddling.\[19b,21\] The six ortho bromine atoms in 1-Br14 presumably result in somewhat diminished saddling relative to regular Cu β-octabromo-meso-triarylcorroles, which would explain the reduced Soret redshift of 1-Br14 relative to 1. Whether

Table 1. Selected X-ray data for 4-Br14·H$_2$O.

<table>
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<tr>
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<td>Unique reflections</td>
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<tr>
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<tr>
<td>S (GooF) all data</td>
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</tr>
<tr>
<td>Max/min res. Dens. [e/Å$^3$]</td>
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</tr>
</tbody>
</table>

Figure 2. X-ray structure of 4-Br$_{14}$H$_2$O. Selected distances (Å): Mn(1)-N(1) 1.918(4), Mn(1)-N(2) 1.936(4), Mn(1)-N(3) 1.931(4), Mn(1)-N(4) 1.918(4), and Mn(1)-O(7) 2.182(4).

Figure 3. Cyclic voltammograms in CH$_2$Cl$_2$ (V vs. SCE).

4-Br$_{14}$ and other transition-metal derivatives of the new bis-pocket corrole exhibit improved catalytic properties has not been examined herein and remains a key question for the future.\[22\]

Experimental Section

Materials

All reagents and solvents were obtained from Sigma Aldrich and used as purchased, unless otherwise noted. Dimethylformamide was dried and stored over 4 Å molecular sieves under argon. The metal salts Au(OAc)$_3$, Cu(OAc)$_2$·4H$_2$O, and Mn(OAc)$_2$·4H$_2$O were obtained from Merck. Pyrrole was passed over a short column of basic alumina (Merck, 1 cm width, ca. 5 cm height) to remove brownish impurities and stored at –20 °C. Silica gel 60 (0.04–0.063 mm particle size; 230–400 mesh, Merck) was used for flash chromatography. Silica gel 60 preparative thin-layer chromato-
a glassy carbon working electrode, a platinum wire counter electrode, and a saturated calomel reference electrode (SCE). Tetra(n-buty)ammonium perchlorate, recrystallized twice from absolute ethanol and dried in a desiccator for at least 2 weeks, was used as the supporting electrolyte. The reference electrode was separated from the bulk solution by a fritted-glass bridge filled with a solvent/supporting electrolyte mixture. The anhydrous dichloromethane solutions were purged with argon for at least 5 min prior to measurements and an argon blanket was maintained over the solutions all through the measurements. All potentials were referenced to the SCE and a scan rate of 100 mVs$^{-1}$ was used. $^1$H NMR spectra (400 MHz) were recorded in CDCl$_3$ (referenced to 7.26) at 298 K on a Varian Inova spectrometer. High-resolution electrospray- ionization (HR-ESI) mass spectra were recorded from methanolic solution on an LTQ Orbitrap XL spectrometer. Elemental analyses were obtained from Atlantic Microlabs, Inc. In general, the Br$_4$ derivatives failed to yield satisfactory elemental analyses; whether the high degrees of bromination lead to interference in the analyses remains uncertain at this point. Proof of composition and purity of these compounds, thus, came from fully assigned $^1$H NMR spectra, thin-layer chromatography, and, in one case (4-Br$_3$), also from single-crystal X-ray structure analysis.

**Synthesis of Free-Base 5,10,15-tris(3',5'-Dimethoxyphenyl)-corrole**

In a slight modification of a literature protocol,$^{[1]}$ 3,5-dimethoxybenzaldehyde (5 mmol, 831 mg) and pyrrole (10 mmol, 697 µL) were dissolved in 200 mL MeOH, followed by slow addition of water (200 mL) and of 37 % HCl (4.25 mL) under vigorous stirring. The reaction mixture was stirred overnight at room temperature, extracted with CHCl$_3$, washed twice with distilled water, once with saturated aqueous NaHCO$_3$, dried over Na$_2$SO$_4$ and filtered. The filtrate was diluted to 300 mL, followed by addition of p-chloranil (1.23 g), and refluxed for 1 h. The reaction mixture was then washed three times with NaHCO$_3$ (aq), dried over Na$_2$SO$_4$ and filtered; the filtrate was rotary-evaporated to dryness. The residue was dissolved in a minimal amount of 1:1 n-hexane/CH$_2$Cl$_2$ and chromatographed on silica gel with the same solvent mixture to flush out fast-eluting impurities and subsequently with 1:2 and 1:3 n-hexane/CH$_2$Cl$_2$ to elute the bluish-green free-base corrole, which partially overlapped with and was followed by a reddish brown impurity. All fluorescent fractions were combined and evaporated to dryness. Treatment of the residue with cold, 3:1 n-hexane/CH$_2$Cl$_2$, sonication, and filtering afforded the desired corrole as a bluish solid. Yield: 206 mg (17 %). Analytical data were consistent with literature data.$^{[21]}

**Synthesis of Copper 5,10,15-tris(3',5'-Dimethoxyphenyl)-corrole (1)**

The procedure used was adapted from the literature.$^{[11]}$ Free-base 5,10,15-meso-tris-(3,5-dimethoxyphenyl)corrole (40 mg) and Cu-(OAc)$_2$·4H$_2$O (40 mg) was added to a 100 mL round-bottom flask equipped with a stirrer bar, dissolved in 25 mL of pyridine and stirred for 30 min at room temperature. The solvent was then removed through rotary evaporation and the resulting residue dissolved in a minimum volume of 1:2 n-hexane/CH$_2$Cl$_2$. Flash chromatography (silica gel, n-hexane/CH$_2$Cl$_2$ 1:1, then 2:3) yielded the target compound as a brownish red fraction. Yield: 37 mg (85%). UV/Vis (CH$_2$Cl$_2$): $\lambda_{max}$ [ε $\times 10^{4}$ (M$^{-1}$ cm$^{-1}$)] (nm): 415 (8.0), 539 (0.8). $^1$H NMR (400 MHz, chloroform-d) $\delta$ 7.88 (d, $J = 4.2$ Hz, 2H, β-pyrrolic), 7.69 (d, $J = 4.2$ Hz, 2H, β-pyrrolic), 7.42 (d, $J = 4.4$ Hz, 2H, β-pyr-
A procedure was adapted from the literature as follows: free-base 5,10,15-meso-tris(3,5′-dimethoxyphenyl)corrole (40 mg, 0.057 mmol) and Au(OAc)₃ (70 mg, 0.188 mmol, 3.3 equiv) were added to a 10 mL glass-vial equipped with a stirrer bar, dissolved in 5 mL of pyridine, and stirred for 22 h at room temperature. After rotary evaporation of the solvent, the resulting solids were dissolved in a minimum volume of CH₂Cl₂. Flash chromatography (silica gel, 1:1 n-hexane/CH₂Cl₂ gradually changing to pure CH₂Cl₂) afforded the title compound as the first red fraction. Yield: 8 mg (15%). UV/Vis (CH₂Cl₂): λ max (e × 10⁻⁴ (M⁻¹ cm⁻¹)) (nm): 418 (12.8), 530 (0.6), 561 (2.4), 572 (2.6). 1H NMR (400 MHz, chloroform-d): δ 9.22 (d, J = 4.3 Hz, 2H, β-pyrrolic), 9.14 (d, J = 4.8 Hz, 2H, β-pyrrolic), 8.97 (d, J = 4.4 Hz, 2H, β-pyrrolic), 8.90 (d, J = 4.9 Hz, 2H, β-pyrrolic), 7.48 (d, J = 2.4 Hz, 4H, 5, 15-methoxy), 7.38 (d, J = 2.4 Hz, 2H, 10-), 6.91–6.86 (m, 3H, 5, 10,15-p), 4.00 (s, 12H, 5,15-methoxy), 3.97 (s, 6H, 10-methoxy). MS (HR-ESI) m/z 900.2213 (M+,1), calcd 900.2212; Anal calcd for CH₃₅N₃O₆Au: C 81.04, H 3.92, N 6.22. Found (%): C 81.72, H 3.84, N 6.19.

Synthesis of Copper β-Octabromo-5,10,15-tris(2′,6′-Dibromo-3′,5′-dimethoxyphenyl)corrole (1-Br₄)

A procedure was adapted from the literature as follows:¹¹ Copper corrole 1 (85 mg, 0.051 mmol) was dissolved in CHCl₃ (30 mL) in a round-bottom flask equipped with a magnetic stirrer bar. To the stirred reaction mixture at room temperature, was added bromine (296 µL, 52.5 equivalents) dissolved in CHCl₃ (12 mL) with a dropping funnel over a period of 30 min. After an additional 1 h of stirring, pyridine (561 µL, 63 equivalents) dissolved in CHCl₃ (12 mL) was added with a dropping funnel over a period of 15 min. The reaction mixture was stirred at room temperature overnight, shaken with 20 mL of 20% w/v aqueous sodium metabisulfite, dried over MgSO₄ and filtered. The filtrate was evaporated to dryness and the residue was flash-chromatographed (silica, n-hexane/CH₂Cl₂ 1:1, then 1:2 and 1:3). The target compound 1-Br₄ eluted as a red band (yellowish when diluted). Yield: 15 mg (90%). UV/Vis (CH₂Cl₂): λ max (e × 10⁻⁴ (M⁻¹ cm⁻¹)) (nm): 436 (13.4), 509 (0.5), 546 (1.2), 585 (5.2). 1H NMR (400 MHz, chloroform-d) δ 7.04–7.01 (m, 3H, 5,10,15-), 4.12 (s, 12H, 5,15-methoxy), 4.11 (s, 6H, 10-methoxy). MS (HR-ESI) m/z 2018.0030 (M⁺), calcd 2018.0066.

Synthesis of Manganese β-Octabromo-5,10,15-tris(2′,6′-Dibromo-3′,5′-dimethoxyphenyl)corrole (4-Br₄)

In an adaptation of literature procedures, free-base 2-Br₄ (15 mg, 0.00825 mmol) and Au(OAc)₃ (13 mg, 0.033 mmol, 4 equiv) were dissolved in pyridine (6 mL) and stirred overnight at room temperature. The reaction mixture was rotary-evaporated to dryness, dissolved in a minimum volume of CH₂Cl₂, and flash-chromatographed (silica gel, n-hexane/CH₂Cl₂ 1:1, then 1:2 and 1:3). The target compound 3-Br₄ eluted as a red band (yellowish when diluted). Yield: 15 mg (90%). UV/Vis (CH₂Cl₂): λ max (e × 10⁻⁴ (M⁻¹ cm⁻¹)) (nm): 436 (13.4), 509 (0.5), 546 (1.2), 585 (5.2). 1H NMR (400 MHz, chloroform-d) δ 7.04–7.01 (m, 3H, 5, 10, 15-p), 4.15 (s, 12H, 5, 15-methoxy), 4.13 (s, 6H, 10-methoxy). MS (HR-ESI) m/z 2043.9221 (M⁺+K⁺), calcd 2043.9191.

X-ray Structure Determination

X-ray data for 4-Br₄·H₂O were collected on beamline 11.3.1 at the Advanced Light Source, Lawrence Berkeley National Laboratory. Samples were mounted on MiTeGen® kapton loops and placed in a 100(2) K nitrogen cold stream provided by an Oxford Cryostream 800 Plus low-temperature apparatus on the goniometer head of a Bruker D8 diffractometer equipped with a PHOTON100 CMOS detector operating in shutterless mode. Diffraction data were collected by using synchrotron radiation monochromated using sili-

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con(111) to a wavelength of 0.7749(1) Å. An approximate full-
sphere of data was collected by using a combination of phi and
omega scans with scan speeds of 1 s per degree for the phi scans,
and 1 and 3 s per degree for the omega scans at 2θ = 0 and −45,
respectively. The structures were solved by intrinsic phasing
(SHELXT) and refined by full-matrix least squares on $F^2$ (SHELXL-
2014). All non-hydrogen atoms were refined anisotropically. Hydro-
gen atoms were geometrically calculated and refined as riding
atoms. Additional crystallographic information has been summar-
ized in Table 1 and the crystal structure reported herein has been
deposited to the Cambridge Crystallographic Data Centre.[24]

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Department of Energy under Contract No. DE-AC02-05CH11231.

Conflict of Interest

The authors declare no conflict of interest.

Keywords: bis-pocket corrole · bromination · complex
synthesis · copper · X-ray diffraction

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[24] CCDC 1507046 contains the supplementary crystallographic data for this
paper. These data can be obtained free of charge from The Cam-
bridge Crystallographic Data Centre.

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