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Preparation of *N*-Aryl Azacrown Ether Derivatives, Using Arene−Iron Chemistry

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m- or *p*-phenylenediamine and *m*- or *p*-chlorophenyl-substituted azacrown ether derivatives were synthesized through sequential nucleophilic substitution of [(η^5-cyclopentadienyl)(η^6-(*m*- or *p*-dichlorobenzene))]iron hexafluorophosphate by azacrown ethers and cyclohexaamines. Monoarylation is the main reaction for diazacrown ethers. The overall yield from the starting complex is 50−96% for multiple steps.

Introduction

Construction of an arene−nitrogen bond is achievable via several approaches. Traditional aromatic nucleophilic substitution requires strong electron-withdrawing groups on the phenyl ring. Ullmann-type coupling employs harsh reaction conditions. The benzyne mechanism and the $S_{RN}1$ mechanism only afford primary arylamines.[1] The latter two procedures can tolerate very limited functionality on the phenyl ring.

Over the last two decades, transition-metal-catalyzed amination of aryl halides or triflates has been developed and well-studied by several groups.[2,3] Palladium-catalyzed cross-coupling is especially valuable because it shows relatively high compatibility with functional groups and provides medium to high yields depending on the substrates. Starting with aryl polyhalides, symmetrical aryl polyamines can be made.[4]

The transition-metal-mediated S_NAr reaction opens another door to the synthesis of arylamines. Various transition metals have been used to form metal−arene complexes.[5] Complexation with the metal lowers the electron density of the phenyl ring so that nucleophilic attack can occur. The most attractive feature of this method is that sequential nucleophilic substitutions can proceed easily, leading to unsymmetrical phenylenediamine or -triamine. Several *p*-phenylenediamine derivatives have been made via iron− or ruthenium−arene complexes in our laboratory.[6] Ruthenium−arene complexes are stable toward ambient light and air, and are easy to handle, but the demetalation requires UV-light and very low solution concentration. Iron−arene complexes are much more sensitive toward light, which in turn makes the demetalation relatively easy. Moreover the cost of iron is much lower than that of ruthenium.

Direct attachment of azacrown ethers to aromatic rings has been attempted through all the above pathways. Lapouyade et al. made substituted aryl crowns via S_NAr reaction and multistep transformation to the desired functionality.[7] High-pressure S_NAr reaction was adopted to prepare various aryl and heteroaryl crown ethers.[8] Palladium-catalyzed amination has been used to generate some simple aryl crowns.[9]

Previous studies in our laboratory showed that the fluorescence and redox potential of crown-substituted *p*-phenylenediamines respond to metal cations selectively, which makes this type of molecule useful for possible molecular devices.[10] The synthesis was achieved via arene−ruthenium complexes.[11] Here we report more convenient syntheses of *m*- or *p*-phenylenediamine and *m*- or *p*-chlorophenyl-substituted azacrown ether derivatives via arene−iron chemistry.

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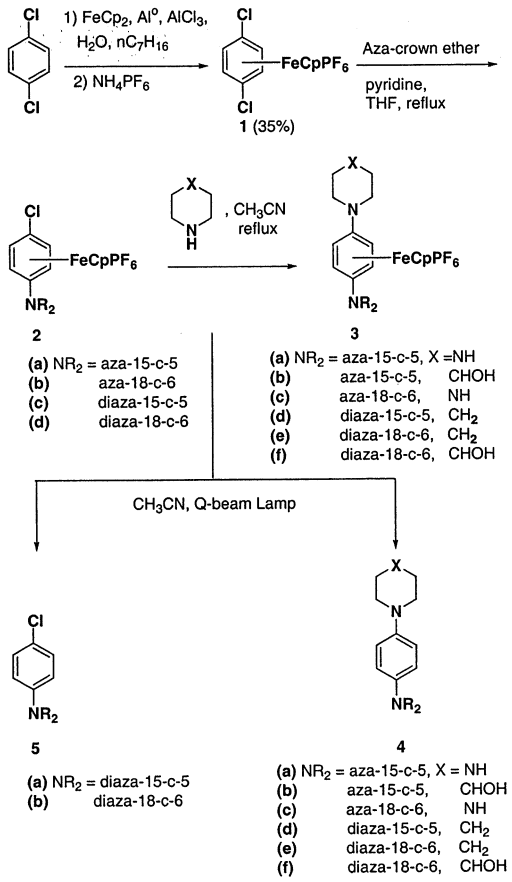
SCHEME 1



Results and Discussion

The major problem for preparation of the requisite dichlorobenzene−iron complexes is low yield and dehalogenation of starting material.[12,13] The best yield previously recorded in our laboratory was around 25%.[14] Careful investigation of reaction conditions in the present study reveals that lower temperature at the beginning improves the yield up to 35% based on added ferrocene (actually excess ferrocence and dichlorobenzene can be recovered after reaction workup). No dehalogenation of dichlorobenzene was observed. Several precautions were taken when carrying out the reaction. The procedure is run under argon or nitrogen atmosphere; ferrocene was sublimed immediately before use; $AlCl_3$ and water were added slowly. The reaction mixture was maintained at 55 °C for several hours after all reagents had been added. During the reaction workup, water was added very slowly to reduce possible damage by heat generated during the hydrolysis of excess $AlCl_3$. The reaction mixture becomes viscous with time and therefore vigorous stirring is needed.

Scheme 1 presents the general procedure for the synthesis of the title compounds (the *m*-chlorophenyl complex precursors to compounds **6** and **7** (Figure 2) are not shown in the scheme).

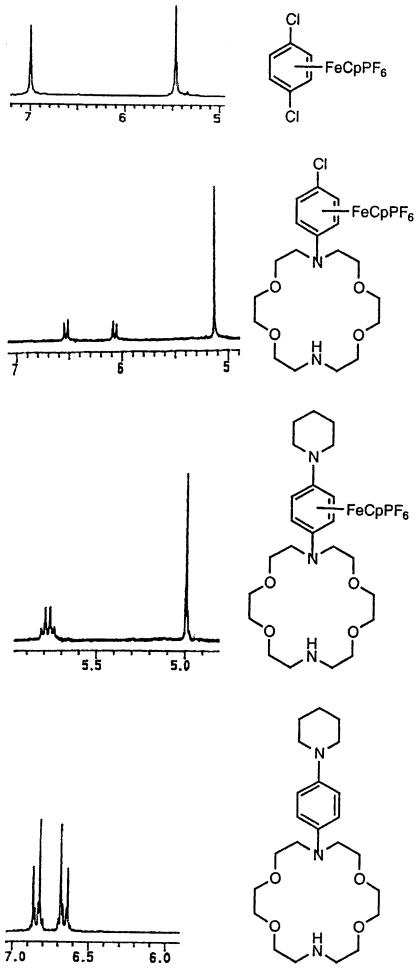


FIGURE 1. ^1H NMR patterns of phenyl and Cp protons at different stages of substitution (in acetone-d_6).

Sequential amination of dichlorobenzene−iron complex **1** with secondary cyclic amines was examined, which included monoazacrown ethers, diazacrown ethers, and cyclohexaamines. Compared with cyclohexaamines, an azacrown ether is a relatively weak nucleophile. Therefore it was attached to the phenyl ring first. Then the second chloride is substituted by a cyclohexaamine. The two steps can be carried out in one pot. The reaction flask should be covered with aluminum foil because this type of iron−arene complex is sensitive even to room light. Both the crown ether and amine are in excess, but the crown ether can be recovered and reused. Different solvents can be used for the reaction: THF, CH_3CN, and CH_2Cl_2 are useful. CH_3CN is usually better for the second step because some amines are more soluble in it. At room temperature, the crown substitution requires around 5 to 9 days for completion, and the cyclohexaamine substitution requires around 2 to 4 days. At reflux temperature, both steps can be completed in several hours to overnight without compromising selectivity, and the overall yield is also high.

Various demetalation procedures have been used in our laboratory.[6,14,15] During this work, we found that irradiation with a 100-W Q-beam halogen lamp worked well for

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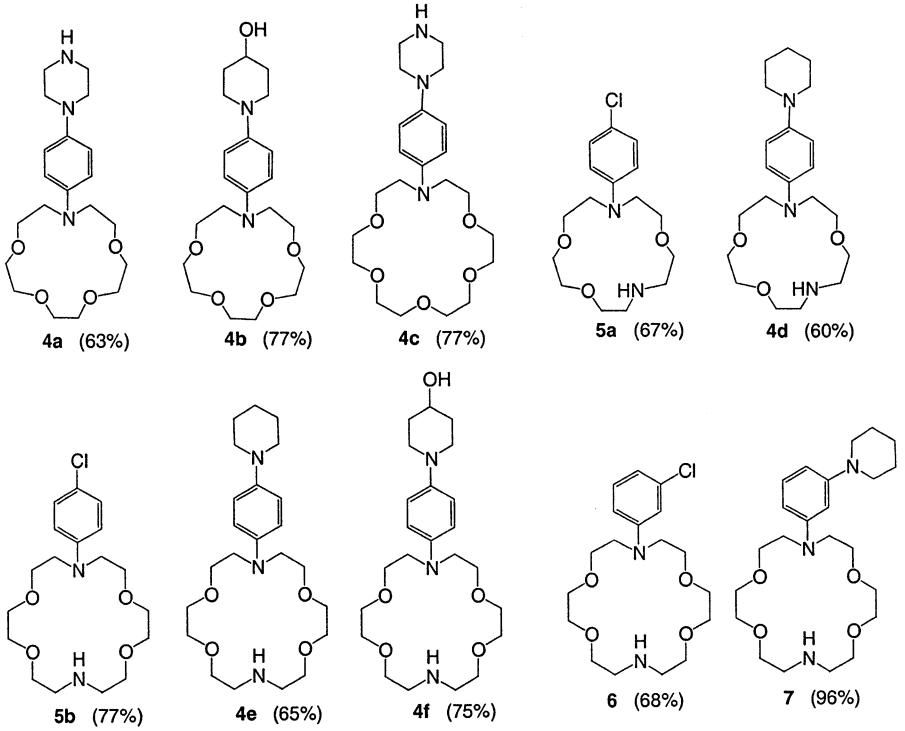

FIGURE 2. *N*-(*m*-/*p*-Chlorophenyl or *m*-/*p*-phenyldiamine)crown ethers (overall yield from dichlorobenzene iron complex).

all the metal complexes. The demetalation was carried out in CH_3CN, and the reaction solution was heated to reflux by the irradiation. With good control, the overall yield from the *m*- or *p*-dichlorobenzene iron complex was 50 to 96% depending on the amine substrates.

All the complexes are yellow to red-orange and oily, and they are soluble in THF, CH_3CN, CH_3COCH_3, and CH_2Cl_2, but insoluble in ethyl ether, hexanes, and ethyl acetate. Generally there is no need to rigorously purify the metal complexes, thereby avoiding exposure of the complex to room light and air. Complexes **2a**, **2b**, and **3b** are stable enough to tolerate flash chromatography on silica gel, but complexes containing a free secondary amine are very polar, therefore difficult to elute from the column. In most cases, washing the crude reaction product with ethyl ether removes most excess crown ether and amine. Purification of the final product was done by flash chromatography on silica gel in the presence of Et_3N.

^{1}H NMR is very useful for monitoring the progress of the sequential reactions. The four phenyl protons show characteristic chemical shifts and splitting patterns at different stages. The five Cp protons always appear as a singlet but with different chemical shifts upon arene substitution. Figure 1 shows ^{1}H NMR of the phenyl and Cp protons for compounds **1**, **2d**, **3e**, and **4e**. Compound **1** shows two singlets: the phenyl proton singlet is at 7.0 ppm, and the Cp singlet is at 5.5 ppm. After one crown ether is attached, the phenyl singlet is split into two doublets at 6.5 and 6.1 ppm; the Cp singlet shifts to higher field at 5.1 ppm. After the second amine is attached, the phenyl proton doublets become an AB quartet and shift to 5.8 ppm; the Cp singlet shifts to around 5.0 ppm. After demetalation the phenyl proton AB quartet shifts to around 6.6 to 6.9 ppm.

Figure 2 shows a selection of the products obtained from the above procedure. All these compounds bear a free amine or a hydroxyl group that can be further manipulated, for example by attaching an electron acceptor moiety to form a donor−acceptor system. Compound **4f** has two open sites for further functionalization. Compounds **4a**−**c** were prepared from monoazacrown ethers. Compounds **4d**−**f**, **5a**,**b**, **6**, and **7** were made from diazacrown ethers. Compounds **6** and **7** were from the *m*-dichlorobenzene iron complex, which is similar to the *p*-dichlorobenzene iron complexes in these reactions. Even though the crown ether is in excess amount, the reaction stops at monosubstitution. Once one chloride is substituted by the crown amine, the phenyl ring is less electrophilic, so it is more difficult for a second crown to attack. It is also noteworthy that selective monoarylation of diazacrown ethers proceeds well. By controlling the amount of crown ether and the reaction time, disubstitution can be avoided. Most of the known diazacrown ether derivatives are substituted symmetrically.[16] For diaza-15-crown-5 derivatives **4d** and **5a** there is no symmetry axis across the two crown amines, which is

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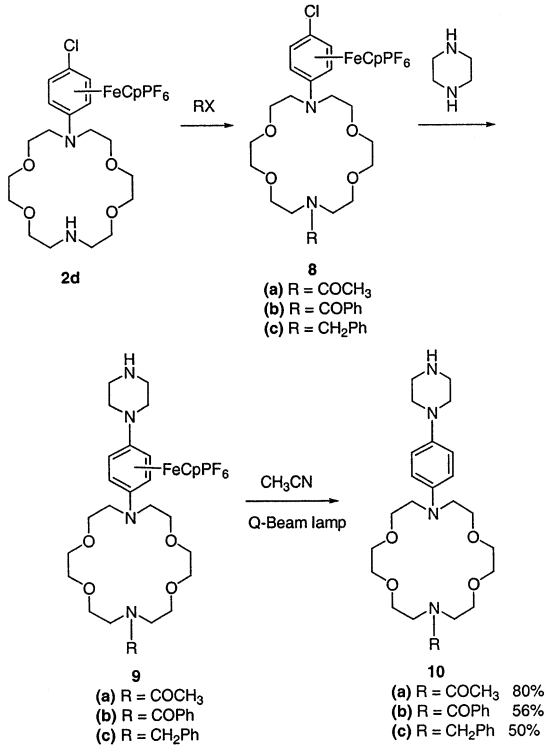
SCHEME 2



different from the monoazacrown ether and *p*-phenyl diaza-18-c-6 derivatives.

Taking advantage of monoarylation of the diazacrown ether, compounds **10a**, **10b**, and **10c** were made in four steps from compound **1** (Scheme 2).[17] After the first amination, the residue is washed with ethyl ether several times to remove excess crown ether. After the second crown amine is attached to R, the product mixture is again washed with ethyl ether and benzene to remove excess RX. Following this procedure can greatly reduce the amount of byproducts.

p-Phenylenediamine derivatives **4a**−**f** and **10a**−**c** become deep blue when treated with UV light or acid, which indicates that they all form the Würster's blue radical cation.[6] **5a**, **5b**, **6**, and **7** do not show the blue color that is consistent with the corresponding aromatic ring being less electron rich.

As mentioned in the Introduction, previous studies have indicated that these compounds can be useful as molecular devices. Detailed studies on the above systems in the synthesis of PET fluorescent chemosensors and molecular switches will be reported elsewhere.

Experimental Section

All reactions were conducted under nitrogen or argon. Reaction flasks except those for demetalation were covered with aluminum foil. Solvents for all reactions were freshly distilled before use: THF over sodium/benzophenone, CH_2Cl_2, CH_3CN, Et_3N and pyridine over CaH_2. All reagents were used as purchased unless otherwise noted. NMR spectra were recorded on 200 or 300 MHz instruments. Chemical shifts are reported in ppm with solvent as the internal reference, and coupling constants are reported in Hz. Only ^1H NMR spectra were obtained for crude metal complexes, and only values for phenyl and Cp protons are reported because of the presence of residual crown ether and amine. The mass for metal complexes is M − PF_6, the mass for molecules containing Cl is reported for ^{35}Cl.

Improved Synthesis of 1. To a 250-mL three-neck round-bottom flask was added *p*-dichlorobenzene (40 g, 272 mmol) and 15 mL of *n*-heptane. The mixture was heated to 55−60 °C until *p*-dichlorobenzene completely melted. Ferrocene (freshly sublimed, 3.14 g, 16.9 mmol), aluminum powder (400 mg, 14.8 mmol), $AlCl_3$ (6 g, 45 mmol), and water (288 μL, 16 mmol) were added sequentially with vigorous stirring. The mixture was held at 55 °C for 8 h, and then heated to 95 °C for 8 h. The dark blue slurry was cooled to room temperature, and 40 mL of water was added slowly, followed by 30 mL of ether. The mixture was stirred for 10 min and partitioned. The aqueous phase was extracted with ether until the ether was almost colorless, and saturated aqueous NH_4PF_6 was added to the aqueous phase dropwise until no further yellow precipitate appeared. The product was filtered off and dried under vacuum (2.4 g, 35%).

[(η^5-Cyclopentadienyl)(η^6-(1-chloro-4-(4,7,10,13-tetraoxa-1-azacyclopentadecyl))benzene)]iron Hexafluorophosphate (2a). To a round-bottom flask was added compound **1** (324 mg, 0.78 mmol) and 1-aza-15-crown-5 (500 mg, 2.3 mmol), and the flask was flushed with argon. Pyridine (1 mL) and THF (10 mL) were added. The resulting mixture was stirred at room temperature for 5 days. The mixture was then filtered through Celite. THF was removed by rotary evaporation, and the red-orange residue was washed with ether (3 × 30 mL). The crude product was divided into two portions and used directly for preparing complex **3a** or **3b**. ^1H NMR (200 MHz, CD_3COCD_3): δ 6.23 (2H, d, J = 6.8), 5.89 (2H, d, J = 6.8), 4.94 (5H, s). HRMS-FAB: calcd for $C_{21}H_{29}O_4NClFe$ 450.1134, found 450.1132.

[(η^5-Cyclopentadienyl)(η^6-(1-piperazino-4-(4,7,10,13-tetraoxa-1-azacyclopentadecyl))benzene)]iron Hexafluorophosphate (3a). To complex **2a** (118 mg) in 4 mL of CH_3CN was added piperazine (3.3 equiv). The mixture was stirred at room temperature for 2 days, then filtered through Celite, and CH_3CN was removed. The dark red residue was washed with ether (40 mL). The crude product was submitted directly to demetalation.^1H NMR (200 MHz, CD_3COCD_3): δ 5.55 (4H, br s), 4.82 (5H, s). HRMS-FAB: calcd for $C_{25}H_{38}O_4N_3Fe$ 500.2212, found 500.2212.

1-Piperazino-4-(4,7,10,13-tetraoxa-1-azacyclopentadecyl)benzene (4a). The crude **3a** from above was dissolved in 40 mL of CH_3CN in a round-bottom flask with condenser and irradiated with a 100-W Q-beam halogen lamp for 4 h. The mixture was filtered through Celite. The solvent was removed by rotary evaporation, and the residue was purified by flash chromatography (silica gel, $CH_2Cl_2/CH_3OH/Et_3N$ 90/5/5, R_f 0.3) to afford **4a** as red oil (48 mg, 63% overall yield from **1**). ^1H NMR (200 MHz, $CDCl_3$): δ 6.85 (2H, d, J = 9.0), 6.48 (2H, d, J = 9.0), 6.18 (1H, br), 3.5−3.8 (20H), 3.0−3.2 (8H, s + t, J = 4.9). ^{13}C NMR (50 MHz, $CDCl_3$): δ 143.2, 141.8, 119.6, 112.4, 71.3, 70.2, 70.0, 69.8, 69.6, 68.8, 67.4, 52.6, 50.6, 48.1, 45.0. HRMS-FAB: calcd for $C_{20}H_{34}O_4N(MH^+)$ 380.2549, found MH^+ 380.2556.

1-Chloro-4-(4,10,13-trioxa-1,7-diazacyclopentadecyl)-benzene (5a). One portion of the above product (157 mg, 0.24 mmol) was dissolved in 35 mL of CH_3CN and irradiated with a 100-W Q-beam halogen lamp for 3 h. The solvent was removed by rotary evaporation, and the residue was purified by flash chromatography (silica gel, acetone/hexanes/Et_3N 1/1/0.1, R_f 0.2), to afford the product as a pale yellow oil (53 mg, 67% yield from **1**). ^1H NMR (200 MHz, $CDCl_3$): δ 7.15 (2H, d, J = 8.8), 6.60 (2H, d, J = 8.8), 4.52 (1H, br), 3.5−3.8 (16H), 3.03 (4H, t, J = 4.7). ^{13}C NMR (50 MHz, $CDCl_3$): δ 146.7, 129.1, 121.4, 113.5, 70.8, 70.1, 69.3, 69.0, 68.4, 67.4, 52.6, 48.3. HRMS-FAB: calcd for $C_{16}H_{26}N_2O_3Cl$ (MH^+) 329.1632, found MH^+ 329.1615.

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1-(4-Hydroxypiperazino)-4-(4,7,10,13-tetraoxa-1-azacyclopentadecyl)benzene (4b). Similar to **4a**. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 6.85 (2H, d, J = 9.1), 6.61 (2H, d, J = 9.1), 3.4−3.7 (22H), 3.4 (2H), 2.69 (2H), 1.9 (2H), 1.6 (2H). ^{13}C NMR (50 MHz, CD_3COCD_3): δ 143.9, 143.3, 120.0, 113.4, 72.0, 71.2, 70.9, 70.8, 69.8, 68.0, 53.4, 50.2, 35.8. HRMS-FAB: calcd for $C_{21}H_{34}O_5N_2$ 394.2468, found 394.2469.

1-(4-Piperazino)-4-(4,7,10,13,16-pentaoxa-1-azacyclopentadecyl)benzene (4c). Similar to **4a**. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 6.84 (2H, d, J = 9.2), 6.67 (2H, d, J = 9.2), 3.4−3.7 (24H), 3.02 (1H, s), 2.91 (8H, s). ^{13}C NMR (50 MHz, CD_3COCD_3): δ 144.5, 143.6, 119.3, 114.0, 71.7, 71.6, 71.5, 69.9, 52.9, 52.6, 47.2. HRMS-FAB: calcd for $C_{22}H_{38}O_5N_3$ (MH^+) 424.2811, found MH^+ 424.2793.

1-Piperidino-4-(4,10,13-trioxa-1,7-diazacyclopentadecyl)benzene (4d). Similar to **4a**. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 6.84 (2H, d, J = 9.0), 6.64 (2H, d, J = 9.0), 3.4−3.7 (16H), 2.94 (4H, t, J = 5.4), 2.70 (4H), 2.2 (1H, br), 1.4−1.7 (6H). ^{13}C NMR (50 MHz, CD_3COCD_3): δ 145.1, 143.6, 119.9, 114.1, 71.9, 71.2, 70.9, 70.4, 70.1, 69.8, 53.9, 53.6, 53.2, 49.7, 49.5, 27.2, 25.2. HRMS-FAB: calcd for $C_{21}H_{36}O_3N_3$ (MH^+) 378.2756, found MH^+ 378.2756.

1-Chloro-4-(4,7,13,16-tetraoxa-1,10-diazacyclooctadecyl)benzene (5b). Similar to **5a**. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.11 (2H, q, J = 9.2), 6.58 (2H, q, J = 9.2), 3.6 (20H), 2.80 (4H, t, J = 4.8), 2.21 (1H, br, s). ^{13}C NMR (200 MHz, $CDCl_3$) δ 146.6, 129.0, 120.6, 112.8, 70.6, 70.5, 70.5, 68.6, 50.8, 49.4. HRMS-FAB: calcd for $C_{18}H_{30}O_4N_2Cl$ (MH^+) 373.1894, found MH^+ 373.1891.

1-Piperidino-4-(4,7,13,16-tetraoxa-1,10-diazacyclooctadecyl)benzene (4e). Similar to **4a**. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 6.84, and 6.65 (2H each, d, J = 9.2), 3.45−3.70 (20H), 2.94 (4H, t, J = 5.3), 2.71 (4H, t, J = 4.8), 1.43−1.7 (6H). ^{13}C NMR (50 MHz, CD_3COCD_3): δ 144.9, 143.7, 120.0, 114.0, 71.5, 71.4, 71.3, 53.3, 52.1, 50.4, 27.2, 25.2. HRMS-FAB: calcd for $C_{23}H_{40}O_4N_3$ (MH^+) 422.3019, found MH^+ 422.3010.

1-(4-Hydroxypiperidino)-4-(4,7,10,13-tetraoxa-1,10-diazacyclooctadecyl)benzene (4f). Similar to **4a**. ^{1}H NMR (300 MHz, C_6D_6): δ 6.92 (2H, d, J = 9.1), 6.61 (2H, d, J = 9.1), 3.2−3.6 (23H), 2.69 (6H), 2.35 (2H, br), 1.8 (2H), 1.7 (2H). ^{13}C NMR (50 MHz, C_6D_6): δ 144.1, 143.3, 119.9, 114.3, 71.1, 70.8, 69.7, 67.7, 52.0, 49.9, 35.5. HRMS-FAB: calcd for $C_{23}H_{40}O_5N_2$ (MH^+) 438.2968, found MH^+ 438.2963.

1-Chloro-3-(1-(4,7,13,16-tetraoxa-1,10-diazacyclooctadecyl))benzene (6). To a round-bottom flask were added [(η^5-cyclopentadienyl)(η^6-1,3- dichlorobenzene)]iron hexafluorophosphate (526 mg, 1.3 mmol) and 1,10-diaza-18-crown-6 (1.0 g, 3.8 mmol). The flask was flushed with argon, then 1 mL of pyridine and 15 mL of CH_2Cl_2 were added. The resulting mixture was heated to reflux overnight. The solution was filtered through Celite, the solvent was removed by rotary evaporation, and the residue was washed with ether (3 × 50 mL). The crude product was divided into two portions and used for preparing **6** and **7**. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 6.4 (2H, br s), 6.28 (1H, br t), 5.95 (1H), 5.11 (5H,s). HRMS-FAB: calcd for $C_{23}H_{34}O_4N_2ClFe$ 493.1556, found 493.1543. One portion of the above complex (406 mg, 0.6 mmol) was dissolved in 30 mL of CH_3CN and irradiated with a 100-W Q-beam halogen lamp for 10 min. The solvent was removed by rotary evaporation, and the residue was purified by flash chromatography (silica gel, CH_2Cl_2/Et_3N/CH_3OH 10/1/1, R_f 0.5) to afford **6** as a yellow oil (152 mg, 68% overall yield from the starting complex). ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.08 (1H, t, J = 8.2), 6.5−6.6 (3H), 3.60 (20H), 2.79 (4H, t, J = 4.8), 2.25 (1H, br). ^{13}C NMR (50 MHz, $CDCl_3$): δ 149.1, 135.2, 130.22, 115.7, 111.4, 109.7, 70.6, 70.5, 50.6, 49.4. HRMS-FAB: calcd for $C_{18}H_{30}O_4N_2Cl$ 373.1894, found MH^+ 373.1900.

1-Piperidino-3-(4,7,13,16-tetraoxa-1,10-diazacyclooctadecyl)benzene (7). One portion of the preceding intermediate (458 mg, 0.67 mmol) was dissolved in 15 mL of CH_3CN and piperidine (10 equiv) was added. The mixture was heated to reflux for 5 h, then cooled and filtered through Celite. CH_3CN was removed by rotary evaporation, and the residue was taken up in acetone and filtered. Excess piperidine and acetone were removed by rotary evaporation. Without further purification, the crude product was submitted directly to demetalation. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 5.94 (1H, t, J = 6.5), 5.79 (1H, s), 5.70 (2H, d, J = 5.4), 4.88 (5H, s). HRMS-FAB: calcd for $C_{28}H_{44}O_4N_3ClFe$ 542.2681, found 542.2661. The product was dissolved in 50 mL CH_3CN, and irradiated with 100 W Q-beam halogen lamp for 35 min. The solvent was removed by rotary evaporation, and the residue was purified by flash chromatography (silica gel, acetone/Et_3N: 15/1, R_f = 0.2), to afford **7** as yellow oil (272 mg, 96% overall yield from the starting complex). ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.12 (1H, t, J = 8.0), 6.35 (1H, dd, J = 8.0, 2.0), 6.31 (1H, d, J = 2.0), 6.24 (1H, dd, J = 8.0, 2.0), 4.64 (2H, s), 3.58 (24H), 2.88 (4H, t, J = 5.8), 1.6 (6H). ^{13}C NMR (50 MHz, $CDCl_3$): δ 154.7, 150.5, 130.4, 106.4, 104.9, 102.1, 71.3, 71.1, 69.9, 68.8, 52.0, 51.7, 49.2, 26.9, 25.4. HRMS−FAB Calculated for $C_{23}H_{40}O_4N_2$ (MH^+) 422.3019; Found MH^+ 422.3011.

[(η^5-Cyclopentadienyl)(η^6-(1-chloro-4-(4,7,13,16-tetraoxa-1-acetyl-10-diazacyclooctadecyl))benzene)]iron Hexafluorophosphate (8a). Crude complex **2d** (750 mg, 1.0 mmol) was dissolved in 10 mL of CH_2Cl_2, the flask was cooled with ice, Ac_2O (1 mL, 10 equiv) and Et_3N (2 mL, 14 equiv) were added, then the mixture was warmed to room temperature and stirred overnight. The reaction mixture was rotary evaporated and the residue was washed with ether. Without further purification, the crude product was used for preparing **9a**. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.11 (2H, d, J = 9.2), 6.57 (2H, d, J = 9.2), 5.38 (5H, s). HRMS-FAB: calcd for $C_{25}H_{35}O_5ClN_2Fe$ (M − H) 535.1662, found M − H 535.1643.

[(η^5-Cyclopentadienyl)(η^6-(1-piperazino-4-(4,7,13,16-tetraoxa-1-acetyl-10-diazacyclooctadecyl))benzene)]-iron hexafluorophosphate (9a). The above crude **8a** (1 mmol) was dissolved in 15 mL of CH_3CN, piperazine (5 equiv) was added, and the mixture was heated to reflux for 6 h, then cooled and filtered through Celite. The filtrate was dried by rotary evaporation, and the residue was washed with ether (30 mL). Without further purification, the dark-red residue was submitted directly to demetalation. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 5.75 (4H, q, J = 5.7), 4.98 (5H, s). HRMS-FAB: calcd for $C_{32}H_{45}O_5N_4Fe$ 585.2739, found 585.2719.

1-Piperazino-4-(4,7,13,16-tetraoxa-1-acetyl-10-diazacyclooctadecyl)benzene (10a). The above crude **9a** was dissolved in 30 mL of CH_3CN and irradiated with a 100-W Q-beam halogen lamp for 45 min. The mixture was filtered through Celite, and the solvent was removed by rotary evaporation. The residue was purified by flash chromatography (silica gel, CH_2Cl_2/Et_3N/CH_3OH 30/1/1, R_f 0.2) to afford **10a** as an orange oil (226 mg, 53% yield from **1**). ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.87 (2H, d, J = 9.0), 6.65 (2H, d, J = 9.0), 3.63 (24H, s), 3.0 (8H, s), 2.51 (1H, br), 2.09 (3H, s). ^{13}C NMR (50 MHz, $CDCl_3$): δ 169.8, 144.5, 143.3, 119.4, 114.1, 71.4, 71.2, 71.1, 71.1, 70.8, 70.4, 70.1, 69.8, 52.7, 52.5, 50.0, 47.4, 46.8, 21.6. HRMS-FAB: calcd for $C_{24}H_{40}O_5N_4$ 464.2999, found 464.3005.

[(η^5-Cyclopentadienyl)(η^6-(1-chloro-4-(4,7,13,16-tetraoxa-1-benzoyl-10-diazacyclooctadecyl))benzene)]iron Hexafluorophosphate (8b). One portion of crude **2d** (300 mg, 0.22 mmol) was dissolved in 2 mL of CH_3CN, the flask was cooled with ice, then benzoyl chloride (70 μL, 0.6 mmol) and pyridine (0.1 mL) were added. The mixture was warmed to room temperature and stirred for 5 h, then refluxed for 1 h. The reaction mixture was cooled and filtered through Celite, and the solvent was removed by rotary evaporation. The dark red residue was washed with benzene and ether. Without further purification, the residue was used for preparing **9b**. ^{1}H NMR (200 MHz, CD_3CN): δ 7.41(5H, s), 6.48 (2H, d, J = 6.9), 6.01 (2H, d, J = 6.9), 5.1 (5H, s). HRMS-FAB: calcd for $C_{30}H_{38}O_5ClN_2Fe$ 597.1820, found 597.1820.

1-Piperazino-4-(4,7,13,16-tetraoxa-1-benzoyl-10-diazacyclooctadecyl)benzene (10b). Similar to **10a**. ^{1}H NMR (300 MHz, CD_3COCD_3): δ 7.44 (5H, s), 6.88 (2H, d, J = 9.1), 6.70 (2H, d, J = 9.1), 3.58 (25H), 3.02 (8H, s). ^{13}C NMR (75 MHz, CD_3COCD_3): δ 171.9, 144.1, 143.7, 138.5, 129.7, 129.1, 127.5, 119.3, 113.9, 71.5, 70.0, 52.4, 52.0, 46.4. HRMS-FAB: calcd for $C_{29}H_{43}O_5N_4$ (MH^+) 527.3233, found MH^+ 527.3233.

[(η^5-Cyclopentadienyl)(η^6-(1-chloro-4-(4,7,13,16-tetraoxa-1-benzyl-10-diazacyclooctadecyl))benzene)]iron Hexafluorophosphate (8c). One portion of **2d** (190 mg, 0.22 mmol) and Na_2CO_3 (64 mg, 0.6 mmol) were dissolved in 2 mL of CH_3CN, the flask was cooled with ice, and $PhCH_2Br$ (70 μL, 0.58 mmol) was added. The mixture was warmed to room temperature and stirred for 5 h, then heated to reflux for 1 h. The reaction mixture was cooled to room temperature, and filtered through Celite. The solvent was removed by rotary evaporation, and the yellow residue was washed with benzene and ether. Without further purification, the crude product was used directly for preparing **9c**. ^{1}H NMR (200 MHz, CD_3CN): δ 7.6 (m), 6.37 (2H, d, J = 6.9), 5.84 (2H, d, J = 6.9), 4.98 (5H, s). HRMS-FAB: calcd for $C_{30}H_{40}O_4ClN_2Fe$ 583.2026, found 583.2007.

1-Piperazino-4-(4,7,13,16-tetraoxa-1-benzyl-10-diazacyclooctadecyl)benzene (10c). Similar to **10a**. ^{1}H NMR (200 MHz, CD_3COCD_3): δ 7.30 (5H), 6.84 (2H, d, J = 9.2), 6.68 (2H, d, J = 9.2), 3.5−3.7 (22H), 2.92 (8H, s), 2.82 (1H, br), 2.80 (4H, t, J = 4.9). ^{13}C NMR (75 MHz, CD_3COCD_3): δ 144.1, 143.1, 141.2, 129.5, 128.9, 127.4, 119.2, 114.0, 71.6, 71.3, 70.8, 69.9, 60.5, 54.7, 52.7, 52.4, 47.0. HRMS-FAB: calcd for $C_{29}H_{45}O_4N_4$ (MH^+) 513.3441, found MH^+ 513.3432.

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Supporting Information Available: Detailed experimental procedure for **2b**−**d**, **3b**−**f**, **4b**−**f**, **5b**, **9b**,**c,** and **10b**,**c**;^{1}H and ^{13}C NMR spectra of **4a**−**f**, **5a**,**b**, **6**, **7**, and **10a**−**c**. This material is available free of charge via the Internet at http://pubs.acs.org.

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