($PhCH_2$), 13.0 ($CH_3$). Correlations observed in a long-range (10 Hz-optimized) HETCOR NMR experiment were *H*2/*C*4, *H*2/*C*5, Ph*H*/Ph-quaternary *C*, Ph*H*/Ph*C*, Ph*H*/Ph*C*$H_2$, *C*$H_2$N/*C*2, *C*$H_2$N/*C*5, *C*$H_2$N/Ph*C*$H_2$, Ph*C*$H_2$/Ph-quaternary *C*, Ph*C*$H_2$/Ph*C*, Ph*C*$H_2$/*C*$H_2$N, *C*$H_3$/*C*4, *C*$H_3$/*C*5. High-resolution CI($CH_4$)-mass spectrum: 231.1152 ($C_{13}H_{15}N_2O_2$ requires 231.1133).

**1-[(Benzyloxy)methyl]-4-(methoxycarbonyl)imidazole-5-carboxaldehyde (13).** A solution of 1 (566 mg, 1 mmol) in 20 mL of anhyd THF under argon was cooled to −78 °C and was treated dropwise with BuLi (0.7 mL of a 1.43 M solution in hexanes, 1.0 mmol). The reaction mixture was stirred for 20 min at −78 °C and then was treated dropwise with $(CH_3)_3SiCl$ (0.13 mL, 1.0 mmol). The reaction mixture was allowed to warm slowly to room temperature and stirred for 4 h. After the mixture was cooled to −78 °C, BuLi (0.7 mL of a 1.43 M solution in hexanes, 1.0 mmol) was added dropwise and the reaction mixture was stirred for 0.5 h at −78 °C, followed by addition of $(CH_3)_2NN(CH_3)CHO$[14] (110 μL, 1.0 mmol). The reaction mixture was allowed to warm slowly to room temperature over 20 min and then was cooled to −78 °C immediately. BuLi (0.7 mL of a 1.43 M solution in hexanes, 1.0 mmol) was then added dropwise, and the reaction was stirred for 0.5 h at −78 °C, followed by addition of $(CH_3OCO)_2O$ (110 μL, 1.0 mmol). The reaction mixture was allowed to warm slowly to −35 °C (dry ice/anisole bath) and was kept at this temperature for 4 h. The mixture was then allowed to rise to room temperature and was quenched by the addition of 20 mL of saturated aqueous $NH_4Cl$. The product was isolated by extraction (EtOAc) and was purified by radial chromatography (1:1 EtOAc/hexanes) to afford 68 mg (25%) of 13 as a pale yellow oil: $^1H$ NMR ($CDCl_3$) δ 10.52 (s, 1, CHO), 7.82 (s, 1, H2), 7.33–7.27 (m, 5, PhH), 5.80 (s, 2, $CH_2N$), 4.60 (s, 2, $PhCH_2$), 4.00 (s, 3, $CH_3$); $^{13}C$ NMR ($CDCl_3$) δ 182.8 (CHO), 162.1 ($CO_2$), 141.6 (C2), 135.9 (Ph-quaternary C), 128.6–127.8 (each Ph-C), 75.9 ($CH_2N$), 71.6 ($PhCH_2$), 52.5 ($OCH_3$). Prolonged storage in $CDCl_3$ solution apparently promoted a D-for-H exchange (presumably at C2) of the sample of 13 ultimately submitted for HRMS: high-resolution EI-mass spectrum 275.1041 ($C_{14}H_{13}DO_4N_2$ requires 275.1015).

**1-[(Benzyloxy)methyl]imidazo[4,5-*d*]pyridazin-4(5*H*)-one (14).** A mixture of 13 (50 mg, 0.18 mmol) and 97% $NH_2NH_2$ (150 μL, 4.8 mmol) in 10 mL of abs EtOH was heated at reflux for 12 h. The reaction mixture was allowed to cool to room temperature and was rotary evaporated in vacuo. An aqueous solution of the residue obtained was acidified to pH 4 by the addition of 0.1 M HCl. The product was isolated by extraction (EtOAc) and was purified by radial chromatography (10% $CH_3OH/CH_2Cl_2$) to afford 54 mg (80%) of 11 as a pale yellow oil: $^1H$ NMR ($CDCl_3$) δ 8.26 (s, 1, H7), 8.00 (s, 1, H2), 7.35–7.23 (m, 5, PhH), 5.61 (s, 2, $CH_2N$), 4.52 (s, 2, $PhCH_2$); high-resolution CI($CH_4$)-mass spectrum 256.0959 ($C_{13}H_{12}O_2N_4$ requires 256.0960).

**8 from 14.** A solution of 14 (45 mg, 0.18 mmol) in 4 mL of 1:1 3 M HCl/$Me_2CO$ was stirred at room temperature for 0.5 h. The $Me_2CO$ was then rotary evaporated and the resulting aqueous solution was neutralized to pH 7 by the dropwise addition of 3 M NaOH. The precipitate which formed was collected by filtration and was recrystallized from EtOH to afford 24 mg (98%) of 8 as a white solid: $^1H$ NMR spectrum identical to that of 8 obtained by the route outlined in Scheme I.

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# Structural Features of 1,1′-Bis(azaaryl)-Substituted Ferrocenes

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The Friedländer condensation of acetyl- and propionylferrocene with various aromatic *o*-amino aldehydes results in the formation of azaaryl-substituted ferrocenes. The same reaction carried out on the 1,1′-diacetyl- and 1,1′-dipropionyl analogs provides the corresponding 1,1′-bis(azaaryl)-substituted derivatives. In solution, $^1H$ NMR shielding effects indicate π-stacking of the azaaryl rings with the pyrido moieties overlapped and pointing in opposite directions. These observations are supported by a single-crystal X-ray analysis.

There is considerable current interest in the design of molecular systems possessing two or more sites capable of interacting in a productive fashion.[1] Such systems might bring together a catalyst and a substrate and often are modeled after naturally occurring prototypes. We have designed several polyaza cavity shaped molecules where conformational effects controlled by polymethylene bridging have been used to mediate the interaction of various species bound in the cavity.[2] In a similar fashion, two "active sites" can be oriented in parallel planes by using appropriate spacer groups.[3] The relative orientation of the sites in these two parallel planes could be varied if the spacer group demonstrated the appropriate axial conformational mobility.

As a spacer group ferrocene shows excellent mobility about the organometallic bond, possessing a low rotational barrier which interconverts syn and anti isomers of a 1,1′-disubstituted derivative.[4] In the event that substituents A and B are planar aromatic species, rotation about the A/B–Cp bond also becomes important. Kasahara and co-workers have reported a variety of 1,1′-diaryl-substituted ferrocenes (aryl = phenyl, 1′-naphthyl, or 4-bi-

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0022-3263/92/1957-3780$03.00/0 

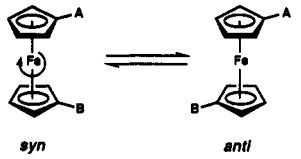
Table I. $^1$H NMR Chemical Shift Data for Azaaryl-Substituted Ferrocenes[a]

| | azaaryl protons | | | | | | ferrocene protons[b] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| compd | $H_3$ | $H_4$ | $H_5$ | $H_6$ | $H_7$ | $H_8$ | $H_\alpha$ | $H_\beta$ | $H_\gamma$ | $CH_3$ |
| **3a** | 7.56 | 8.03 | 7.74 | 7.45 | 7.66 | 8.04 | 5.07 | 4.47 | 4.06 | |
| **5a** | 6.98 | 7.19 | 7.40 | 7.38 | 7.58 | 7.86 | 5.05 | 4.43 | | |
| | (0.58) | (0.84) | (0.34) | (0.07) | (0.08) | (0.18) | (0.02) | (0.04) | | |
| **3b** | 7.62 | 8.06 | 8.12 | 7.42 | 9.05 | | 5.22 | 4.54 | 4.06 | |
| **5b** | 7.06 | 7.12 | 7.59 | 7.29 | 8.97 | | 5.26 | 4.51 | | |
| | (0.56) | (0.94) | (0.53) | (0.13) | (0.08) | | (−0.04) | (0.03) | | |
| **3c** | 7.63 | 8.02 | 7.33 | 7.38 | 7.03 | | 5.07 | 4.45 | 4.06 | 4.08 |
| **5c** | 7.11 | 7.23 | 7.04 | 7.34 | 6.98 | | 5.05 | 4.38 | | 4.06 |
| | (0.52) | (0.79) | (0.29) | (0.04) | (0.05) | | (0.02) | (0.07) | | (0.02) |
| **3d** | | 7.86 | 7.71 | 7.46 | 7.62 | 8.05 | 5.15 | 4.49 | 4.12 | 2.79 |
| **5d** | | 6.47 | 7.30 | 7.41 | 7.58 | 7.90 | 5.29 | 4.46 | | 2.30 |
| | | (1.39) | (0.41) | (0.05) | (0.04) | (0.15) | (−0.14) | (0.03) | | (0.49) |
| **3e** | | 7.89 | 8.06 | 7.37 | 9.02 | | 5.29 | 4.53 | 4.12 | 2.81 |
| **5e** | | 6.59 | 7.64 | 7.33 | 8.99 | | 5.47 | 4.52 | | 2.39 |
| | | (1.30) | (0.38) | (0.04) | (0.03) | | (−0.18) | (0.01) | | (0.42) |
| **3f** | | 7.82 | 7.27 | 7.36 | 6.95 | | 5.08 | 4.43 | 4.11 | 2.79 4.06 |
| **5f** | | 6.60 | 6.95 | 7.33 | 6.95 | | 5.31 | 4.41 | | 2.33 4.08 |
| | | (1.22) | (0.32) | (0.03) | (0) | | (−0.23) | (0.02) | | (0.46) (−0.02) |

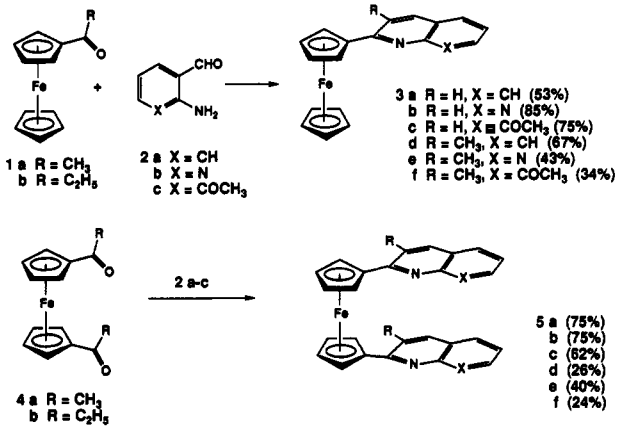
[a] Recorded at 300 MHz in $CDCl_3$ and reported in ppm downfield from internal TMS. Differences between analogous mono- and disubstituted ferrocenes are given in parentheses. [b] $H_\alpha$ and $H_\beta$ refer to protons on the substituted Cp ring.

phenylyl) in which the aryl groups are linked by an ethano or etheno bridge.[5] They observed an expected upfield shift for the aryl proton NMR resonances since these systems are constrained to a syn geometry.

We have employed mono- and diacylferrocenes in Friedländer condensations to prepare a series of azaaromatic ferrocenes in which rotation about the organometallic bond should be comparatively facile. The conformational properties of these species will be presented and discussed.




Treatment of acetylferrocene (**1a**) or propionylferrocene (**1b**) with 1 equiv of the *o*-amino aldehydes **2a–c** results in a Friedländer condensation to provide the azaaryl-substituted ferrocenes **3a–f**. Similar treatment of the




diacyl analogues **4a,b** with 2 equiv of **2a–c** provides the disubstituted ferrocenes **5a–f**.

The $^1$H NMR spectra of these ferrocenes in $CDCl_3$ have been carefully analyzed and the data are collected in Table I. We find that the azaaryl protons of the disubstituted

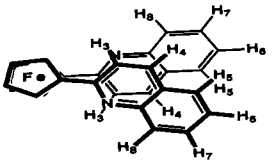



**Figure 1.** Conformational picture of **5a** derived from $^1$H NMR data.

ferrocenes **5** are always shielded and hence shifted upfield as compared with the analogous resonances of the monosubstituted ferrocenes **3**. The same shielding effect is observed in benzene-$d_6$ which implies that $\pi$-stacking between the azaaryl rings is not solvent dependent. The shielding is strongest for $H_4$ and moderate for $H_3$ and $H_5$, indicating that this portion of the quinoline ring experiences the greatest overlap. The shielding of $H_6$–$H_8$ is considerably less. The picture which develops from this NMR data would therefore have the two quinolines coplanar with their adjacent Cp ring, pointing in opposite directions, with their pyridine moieties partially overlapped (Figure 1).

Closer examination of the NMR data reveals that the 3-methyl derivatives **5d–f** show the largest upfield shift of $H_4$, implying that the most favorable conformation for these systems would have this proton lying most nearly over the opposing quinoline. The 3-methyl group should cause an increase in the dihedral angle between the Cp and quinoline rings and thus have a sort of locking effect on the molecule. This effect would consequently inhibit rotation about the organometallic bond, allowing an increased preference for the $\pi$-stacked conformation. Musso and co-workers have shown that when the Cp–aryl dihedral angle approaches 90° $\pi$-stacking does not occur and the diarylferrocene adopts an anti conformation.[6]

Further support for our NMR-based predictions was obtained through a single-crystal X-ray analysis of **5c** which demonstrates that the solid-state structure is in excellent agreement with what is observed in solution.[7] Figure 2 presents a top and side view of **5c** which shows that the quinoline rings are held in a parallel arrangement with almost perfect overlap between the pyrido portions

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(7) Crystal data: $C_{30}H_{24}N_2O_2Fe{\cdot}2CHCl_3$, FW = 739.1, space group $P2_{1/c}$ with $a$ = 19.494 (4) Å, $b$ = 9.213 (2) Å, $c$ = 18.333 (4) Å, $\beta$ = 90.22 (2)°, $V$ = 3293 Å$^3$, $\rho$ = 1.49 g·cm$^{-3}$ for $Z$ = 4.

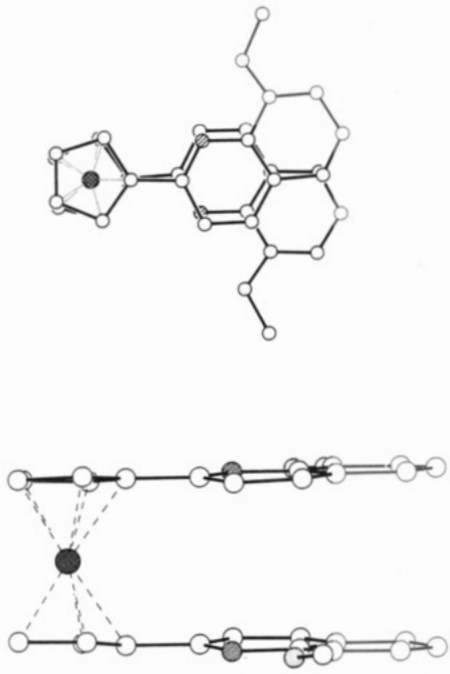

**Figure 2.** Top and side views from the ORTEP plot of **5c**.

of the two quinolines. The distance between the mean planes of the two quinolines is 3.42 Å and these rings are oriented in opposite directions to reduce dipolar repulsions.

Although there is a tendency for the azaaryl rings to $\pi$-stack and a 3-methyl group locking effect enhances this stacking, we observe only one resonance for the ortho proton ($H_\alpha$) on the Cp ring of **5**. At room temperature rotation about the Cp–azaaryl bond is still fast on the NMR time scale. We examined the NMR spectra of **5c–e** in $CDCl_3$ at lower temperatures but were unable to decoalesce $H_\alpha$ upon cooling to −50 °C. However we did observe the even further (0.25 ppm) upfield shift of $H_4$ for **5c**, consistent with increased $\pi$-stacking.

Future studies will involve the incorporation of more elaborate azaaryl host moieties on the Cp rings of molecules similar to **5** and use of the "variable hinge" properties of the ferrocene nucleus to control interactions with an appropriate guest.

## Experimental Section

Nuclear magnetic resonance spectra were recorded on General Electric QE-300 and NT-300 spectrometers at 300 MHz for $^1H$ NMR and 75 MHz for $^{13}C$ NMR, and chemical shifts are reported in parts per million downfield from $Me_4Si$. Infrared spectra were obtained on a Perkin Elmer 1330 spectrometer. All solvents were freshly distilled reagent grade and all melting points are uncorrected. The 2-aminobenzaldehyde (**2a**) was prepared by the method of Opie;[8] 2-aminonicotinaldehyde (**2b**)[9] and 3-methoxy-2-aminobenzaldehyde (**2c**)[10] were prepared following literature procedures. Elemental analyses were performed by Canadian Microanalytical Service, Ltd., Delta, B.C. Several analytical samples were found to retain water even after careful drying.

**2-Ferrocenylquinoline (3a).** A mixture of 0.23 g (1 mmol) of acetylferrocene[11] (**1a**) and 0.145 g (1.2 mmol) of 2-aminobenzaldehyde (**2a**) in 15 mL of absolute EtOH with five drops of saturated methanolic KOH was refluxed under argon for 18 h. After cooling, the solvent was removed and the crude product was chromatographed on 50 g of alumina eluting with 9:1 hexane/EtOAc to provide 0.165 g (53%) of **3a**: mp 130–133 °C (lit.[12] mp 139–141 °C); $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 8.04 (d, $H_8$, $J_{7,8}$ = 8.3 Hz), 8.03 (d, $H_4$, $J_{3,4}$ = 8.6 Hz), 7.74 (d, $H_5$, $J_{5,6}$ = 8.1 Hz), 7.66 (dd, $H_7$, $J_{6,7}$ = 8.2 Hz), 7.56 (d, $H_3$), 7.45 (dd, $H_6$), 5.07 (t, 2 H, $H_\alpha$), 4.47 (t, 2 H, $H_\beta$), 4.06 (s, 5 H, Fc-H); $^{13}C$ NMR (75 MHz, $CDCl_3$) 159.5, 148.2, 135.5, 129.4, 128.9, 127.5, 126.7, 125.4, 119.5, 83.8, 70.5, 69.7, 68.0 ppm; IR (KBr) 1667, 1669, 1614, 1523, 1472, 1443, 1395, 1298, 1122, 838, 835, 776 $cm^{-1}$.

**2-Ferrocenyl-1,8-naphthyridine (3b).** The procedure described above for **3a** was followed using 0.23 g (1 mmol) of acetylferrocene (**1a**) and 0.16 g (1.3 mmol) of 2-aminonicotinaldehyde (**2b**). The crude product was chromatographed on 35 g of alumina eluting with 1:1 hexane/EtOAc to provide 0.250 g (85%) of **3b**: mp 222–225 °C; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 9.05 (d, $H_7$, $J_{6,7}$ = 4.2 Hz), 8.12 (d, $H_5$, $J_{5,6}$ = 7.9 Hz), 8.06 (d, $H_4$, $J_{3,4}$ = 8.5 Hz), 7.62 (dd, $H_6$), 7.42 (d, $H_3$), 5.22 (t, 2 H, $H_\alpha$), 4.54 (t, 2 H, $H_\beta$), 4.06 (s, 5 H, Fc-H), 1.68 (s, $H_2O$); $^{13}C$ NMR (75 MHz, DMSO-$d_6$) 162.7, 155.6, 153.1, 137.1, 136.9, 121.1, 120.9, 120.4, 82.8, 70.8, 69.5, 68.1 ppm; IR (KBr) 3058, 2236, 1600, 1539, 1503, 1445, 1386, 1103, 830, 812, 790, 725 $cm^{-1}$. Anal. Calcd for $C_{18}H_{14}FeN_2 \cdot {}^1/_4H_2O$: C, 67.84; H, 4.59; N, 8.79. Found: C, 67.91; H, 4.48; N, 8.82.

**2-Ferrocenyl-8-methoxyquinoline (3c).** The procedure described above for **3a** was followed using 0.228 g (1.0 mmol) of acetylferrocene (**1a**) and 0.17 g (1.13 mmol) of 3-methoxy-2-aminobenzaldehyde (**2c**) to give 0.26 g (75%) of **3c**: mp 130–132 °C; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 8.02 (d, $H_4$, $J_{3,4}$ = 8.6 Hz), 7.63 (d, $H_3$), 7.38 (dd, $H_6$, $J_{5,6}$ = 7.7 Hz, $J_{6,7}$ = 7.2 Hz), 7.33 (d, $H_5$), 7.03 (d, $H_7$), 5.07 (t, 2 H, $H_\alpha$), 4.45 (t, 2 H, $H_\beta$), 4.08 (s, 3 H, $OCH_3$), 4.06 (s, 5 H, Fc-H); $^{13}C$ NMR (75 MHz, $CDCl_3$) 158.4, 155.0, 140.0, 135.3, 127.7, 125.4, 120.2, 119.5, 108.3, 84.4, 70.2, 69.6, 68.2, 56.2 ($OCH_3$) ppm; IR (KBr) 1693, 1631, 1507, 1486, 1465, 1360, 1287, 1253, 1140, 1130, 869, 768 $cm^{-1}$. Anal. Calcd for $C_{20}H_{17}FeNO \cdot {}^1/_8H_2O$: C, 69.53; H, 5.00; N, 4.06. Found: C, 69.47; H, 4.86; N, 4.08.

**2-Ferrocenyl-3-methylquinoline (3d).** The procedure described above for **3a** was followed using 0.242 g (1 mmol) of propionylferrocene[13] (**1b**) and 0.145 g (1.2 mmol) of 2-aminobenzaldehyde (**2a**) to give 0.22 g (67%) of **3d** after chromatography on alumina eluting with 9:1 hexane/EtOAc: mp 123–125 °C; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 8.05 (d, $H_8$, $J_{7,8}$ = 8 Hz), 7.86 (s, $H_4$), 7.71 (d, $H_5$, $J_{5,6}$ = 8 Hz), 7.62 (dd, $H_7$), 7.46 (dd, $H_6$), 5.15 (t, 2 H, $H_\alpha$), 4.49 (t, 2 H, $H_\beta$), 4.12 (s, 5 H, Fc-H), 2.79 (s, 3 H, $CH_3$); $^{13}C$ NMR (75 MHz, $CDCl_3$) 158.5, 146.7, 136.6, 129.2, 128.9, 128.4, 126.9, 126.5, 125.5, 85.4, 70.0, 69.8, 69.5, 21.4 ppm; IR ($CH_2Cl_2$) 1595, 1490, 1405, 1325, 1120, 1105, 1070, 1000, 820 $cm^{-1}$. Anal. Calcd for $C_{20}H_{17}FeN \cdot {}^1/_2H_2O$: C, 71.45; H, 5.40; N, 4.17. Found: C, 71.84; H, 5.57; N, 3.80.

**2-Ferrocenyl-3-methyl-1,8-naphthyridine (3e).** Following the procedure described above for **3a**, the reaction of 0.121 g (0.5 mmol) of propionylferrocene[13] (**1b**) and 0.073 g (0.6 mmol) of 2-aminonicotinaldehyde (**2b**) gave 0.070 g (43%) of **3e** after chromatography on 40 g of alumina eluting with 1:1 hexane/EtOAc: mp 142–145 °C; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 9.02 (d, $H_7$, $J_{6,7}$ = 4.1 Hz), 8.06 (d, $H_5$, $J_{5,6}$ = 8.0 Hz), 7.89 (s, $H_4$), 7.37 (dd, $H_6$), 5.29 (t, 2 H, $H_\alpha$), 4.53 (t, 2 H, $H_\beta$), 4.12 (s, 5 H, Fc-H), 2.81 (s, 3 H, $CH_3$); $^{13}C$ NMR (75 MHz, $CDCl_3$) 162.8, 154.9, 152.7, 137.4, 135.7, 130.5, 120.9 (2 peaks), 84.0, 70.7, 70.5, 69.7, 21.4 ppm; IR (KBr) 2960, 1608, 1600, 1545, 1490, 1445, 1410, 1380, 1305, 1260, 1105, 818, 786 $cm^{-1}$. Anal. Calcd for $C_{19}H_{16}FeN_2$: C, 69.53; H, 4.91; N, 8.54. Found: C, 69.26; H, 5.11; N, 8.28.

**2-Ferrocenyl-8-methoxy-3-methylquinoline (3f).** The procedure described above for **3a** was followed using 0.110 g (0.45 mmol) of propionylferrocene[13] (**3b**) and 0.070 g (0.46 mmol) of 2-amino-3-methoxybenzaldehyde (**2c**). The crude product was chromatographed on alumina eluting with 9:1 hexane/$CHCl_3$ to provide 0.055 g (34%) of **3f**: mp 117–118 °C; $^1H$ NMR (300 MHz, $CDCl_3$) $\delta$ 7.82 (s, $H_4$), 7.36 (dd, $H_6$, $J_{5,6}$ = 8.9 Hz, $J_{6,7}$ = 7.5 Hz), 7.27 (d, $H_5$), 6.95 (d, $H_7$), 5.08 (t, 2 H, $H_\alpha$), 4.43 (t, 2 H, $H_\beta$), 4.11 (s, 5 H, Fc-H), 4.06 (s, 3 H, $OCH_3$), 2.79 (s, 3 H, $CH_3$); $^{13}C$ NMR (75 MHz, $CDCl_3$)[14] 136.6, 125.7, 118.6, 107.3, 70.0, 69.7, 69.4, 56.2, 21.2 ppm; IR ($CH_2Cl_2$) 1600, 1560, 1490, 1460, 1355, 1195, 1115, 1075, 1010, 820 $cm^{-1}$. Anal. Calcd for $C_{21}H_{19}FeON$: C, 70.61; H, 5.36; N, 3.92. Found: C, 70.23; H, 5.50; N, 3.92.

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**1,1′-Bis(2-quinolyl)ferrocene (5a).** The procedure described above for **3a** was followed using 0.27 g (1 mmol) of 1,1′-diacetylferrocene[15] (**4a**) and 0.29 g (2.4 mmol) of 2-aminobenzaldehyde (**2a**) to give 0.335 g (75%) of **5a** after chromatography on alumina (50 g) eluting with 1:1 hexane/EtOAc: mp 209–210 °C (lit.[12] mp 209–211 °C); $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.86 (d, $H_8$, 2 H, $J_{7,8}$ = 78.5 Hz), 7.58 (m, $H_6$, 2 H), 7.40 (d, $H_5$, 2 H, $J_{5,6}$ = 4.0 Hz), 7.38 ($H_6$, 2 H), 7.19 (d, $H_4$, 2 H, $J_{3,4}$ = 8.6 Hz), 6.98 (d, $H_3$, 2 H), 5.05 (t, $H_\alpha$, 4 H), 4.43 (t, $H_\beta$, 4 H), 1.68 (s, $H_2O$); $^{13}$C NMR (75 MHz, $CDCl_3$) 157.2, 148.0, 134.9, 129.0, 128.6, 127.4, 126.3, 125.0, 119.1, 85.6, 71.2, 69.0 ppm; IR (KBr) 3106, 1618, 1530, 1452, 1331, 1119, 935, 841, 792 cm$^{-1}$.

**1,1′-Bis[2-(1,8-naphthyridyl)]ferrocene (5b).** The procedure described above for **3a** was followed using 0.32 g (1.2 mmol) of 1,1′-diacetylferrocene[15] (**4a**) and 0.32 g (2.6 mmol) of 2-aminonicotinaldehyde (**2b**) to give 0.4 g (75%) of **5b** after chromatography on alumina (35 g) eluting with 1:19 MeOH/$CH_2Cl_2$: mp >300 °C; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 8.97 (dd, 2 H, $H_7$, $J_{6,7}$ = 4.2 Hz), 7.60 (dd, 2 H, $H_5$, $J_{5,6}$ = 8.0 Hz), 7.29 (dd, 2 H, $H_6$), 7.12 (d, 2 H, $H_4$, $J_{3,4}$ = 8.5 Hz), 7.06 (d, 2 H, $H_3$), 5.26 (t, 4 H, $H_\alpha$), 4.51 (t, 4 H, $H_\beta$), 1.64 (s, $H_2O$); $^{13}$C NMR[14] (75 MHz, $CDCl_3$), 152.8, 136.5, 135.4, 120.3 (2 carbons), 84.5, 71.9, 69.4 ppm; IR (KBr) 1606, 1552, 1513, 1448, 1301, 1157, 1108, 845, 816, 778 cm$^{-1}$. Anal. Calcd for $C_{26}H_{18}FeN_4 \cdot {}^1/_3H_2O$: C, 69.66; H, 4.16; N, 12.50. Found: C, 69.28; H, 3.76; N, 12.25.

**1,1′-Bis[2-(8-methoxyquinolyl)]ferrocene (5c).** A solution of 0.216 g (0.8 mmol) of 1,1′-diacetylferrocene[15] (**4a**) and 0.30 g (2 mmol) of 3-methoxy-2-aminobenzaldehyde (**2c**) in 15 mL of absolute EtOH was refluxed for 15 min. Then, 6 drops of 15% methanolic KOH was added and the solution was refluxed for 24 h. The solvent was evaporated and the crude product was recrystallized from a mixture of 1:1 hexane/$CHCl_3$ to provide 0.22 g (62%) of **5c**: mp 200–201 °C; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.34 (dd, 2 H, $H_6$, $J_{5,6}$ = 8.0, $J_{6,7}$ = 7.5 Hz), 7.23 (d, 2 H, $H_4$, $J_{3,4}$ = 8.5 Hz), 7.11 (d, 2 H, $H_3$), 7.04 (d, 2 H, $H_5$), 6.98 (d, 2 H, $H_7$), 5.05 (t, 4 H, $H_\alpha$), 4.38 (t, 4 H, $H_\beta$), 4.06 (s, 6 H, $OCH_3$), 1.74 (s, $H_2O$); $^{13}$C NMR (75 MHz, $CDCl_3$) 156.6, 155.0, 140.0, 134.9, 127.6, 125.1, 119.8, 119.6, 108.3, 86.0, 71.1, 69.3, 56.3 ($OCH_3$) ppm; IR (KBr) 1612, 1568, 1524, 1494, 1467, 1435, 1340, 1269, 1120, 1109, 842, 768 cm$^{-1}$. Anal. Calcd for $C_{30}H_{24}FeN_2O_2 \cdot {}^1/_4H_2O$: C, 71.37; H, 4.86; N, 5.55. Found: C, 71.40; H, 4.82; N, 5.60.

**1,1′-Bis[2-(3-methylquinolyl)]ferrocene (5d).** The procedure described above for **3a** was followed using 0.26 g (0.9 mmol) of 1,1′-dipropionylferrocene[15] (**4b**) and 0.24 g (2 mmol) of 2-aminobenzaldehyde (**2a**) to give, after evaporation of the solvent, 0.110 g (26%) of **5d**: mp 263–264 °C; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.90 (d, $H_8$, $J_{7,8}$ = 8.4 Hz), 7.58 (dd, $H_7$, $J_{6,7}$ = 7.2 Hz), 7.41 (dd, $H_6$, $J_{5,6}$ = 8.0 Hz), 7.30 (d, $H_5$), 6.47 (s, $H_4$), 5.29 (t, 4 H, $H_\alpha$), 4.46 (t, 4 H, $H_\beta$), 2.30 (6 H, $CH_3$), 1.67 (s, $H_2O$); $^{13}$C NMR (75 MHz, $CDCl_3$) 156.3, 146.3, 136.0, 128.6, 128.4, 128.0, 126.4, 125.0, 86.4, 71.0, 70.5, 21.4 ppm; IR (KBr) 1660, 1605, 1590, 1485, 1405, 1270, 895, 745 cm$^{-1}$. Anal. Calcd for $C_{30}H_{24}FeN_2 \cdot {}^1/_2H_2O$: C, 75.48; H, 5.28; N, 5.87. Found: C, 75.83; H, 5.24; N, 5.86.

**1,1′-Bis[2-(3-methyl-1,8-naphthyridyl)]ferrocene (5e).** The procedure described above for **3a** was followed using 150 mg (0.5 mmol) of 1,1′-dipropionylferrocene[15] (**4b**) and 183 mg (1.5 mmol) of 2-aminonicotinaldehyde (**2b**) to give 95 mg (40%) of **5e** after chromatography on alumina eluting with 1% MeOH/EtOAc: mp 220–223 °C; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 8.99 (d, $H_7$, $J_{6,7}$ = 4.2 Hz) 7.64 (d, $H_5$, $J_{5,6}$ = 8.0 Hz), 7.33 (dd, $H_6$), 6.59 (s, $H_4$), 5.47 (s, 4 H, $H_\alpha$), 4.42 (s, 4 H, $H_\beta$), 2.39 (s, 6 H, $CH_3$), 1.61 (s, $H_2O$); IR (KBr) 1608, 1600, 1555, 1490, 1445, 1100, 903 cm$^{-1}$. The $^{13}$C NMR of **5e** was not reported because of its poor solubility in common NMR solvents. Anal. Calcd for $C_{28}H_{22}FeN_4 \cdot {}^1/_4H_2O$: C, 70.83; H, 4.74; N, 11.80. Found: C, 70.71; H, 4.80; N, 11.69.

**1,1′-Bis[2-(8-methoxy-3-methylquinolyl)]ferrocene (5f).** A solution of 0.125 g (0.42 mmol) of 1,1′-dipropionylferrocene[15] (**4b**) and 0.150 g (1 mmol) of 3-methoxy-2-aminobenzaldehyde (**2c**) in 15 mL of absolute EtOH was refluxed for 15 min. Then, 6 drops of 15% methanolic KOH was added and the solution was refluxed for 48 h. The solution was cooled and the precipitate formed was filtered and chromatographed on alumina eluting with 2:1 hexane/$CHCl_3$ to provide 0.052 g (24%) of **5f**: mp 218–220 °C; $^1$H NMR (300 MHz, $CDCl_3$) $\delta$ 7.33 (dd, $H_6$, $J_{5,6}$ or $J_{6,7}$ = 8.1 Hz, $J_{5,6}$ or $J_{6,7}$ = 7.5 Hz), 6.95 (d, $H_5$ or $H_7$), 6.95 (d, $H_5$ or $H_7$), 6.60 (s, $H_4$), 5.31 (t, 4 H, $H_\alpha$), 4.41 (t, 4 H, $H_\beta$), 4.08 (s, 6 H, $OCH_3$), 2.33 (s, 6 H, $CH_3$), 1.63 (s, $H_2O$); $^{13}$C NMR (75 MHz, $CDCl_3$) 155.5, 155.2, 138.5, 136.0, 129.4, 127.8, 125.1, 118.8, 107.2, 86.9, 71.1, 70.6, 56.2, 21.2 ppm; IR ($CH_2Cl_2$) 3680, 3050, 2970, 2290, 1600, 1555, 1420, 1270, 1250, 1110, 890, 760 cm$^{-1}$. Anal. Calcd for $C_{32}H_{28}FeN_2O_2$: C, 72.74; H, 5.34; N, 5.30. Found: C, 72.50; H, 5.32; N, 5.30.

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**Supplementary Material Available:** Experimental details for the X-ray determination including data collection and processing parameters, atomic coordinates, bond lengths and angles, and proton and carbon NMR spectra of compounds **3a–f** and **5a–f** (18 pages). Ordering information is given on any current masthead page.

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# Synthesis of Macrocyclic Dilactones by Cyclization of Sulfonium Salts

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An efficient method for the formation of macrocyclic dilactones via cyclization of (ω-carboxyalkyl)diphenylsulfonium salts **3** containing an ester linkage under mild conditions is described. These sulfonium salts **3** were cyclized in the presence of cesium carbonate under high-dilution conditions to give 11- to 16-membered dilactones **4** in good yields. The cyclization of sulfonium salt **22** was successfully carried out for the synthesis of 11-membered dilactonic pyrrolizidine alkaloid, 13,13-dimethyl-1,2-didehydrocrotalanine **23**.

Much attention has been focused in recent years on the synthesis of macrolides, particularly dilactones, from the viewpoint of their bioactivities, ability to complex with metal cations, and usefulness as perfumes.[1] The growing

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