Synthesis of $[5_2]$(1,2)Ferrocenophane

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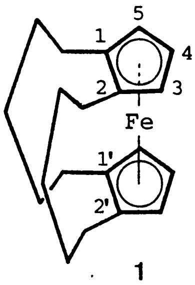
Synopsis. The title compound **1** has been synthesized via bridge enlargement of compound **2** which was formed by cyclization of [5]ferrocenophane-2-propionic acid. By this study the structure of **2**, which was discrepantly described by two groups, has been established as [5]-α-oxo[3](1,2)ferrocenophane.

In the previous papers,[1,2] we reported on the synthesis of $[5_2]$(1,3)-, $[5_3]$(1,2,4)-, and $[5_4]$(1,2,3,4)ferrocenophanes[3,4] multi-bridged with pentamethylene chains. However, $[5_2]$(1,2)ferrocenophane (**1**) bridged with two chains at the neighboring positions each other has not yet been synthesized. The compound **1** might be derived from [5]-α-oxo[3](1,2)ferrocenophane (**2**) by application of a general method that we developed for insertion of two methylene units into the trimethylene bridge of ferrocenophanes.[1,2]

Brown and Winstead[5] described that the compound **A** (77%, mp 156—158 °C) given in the cyclization of [5]ferrocenophane-2-propionic acid was phane **2**, but Struchkov et al.[6] claimed for the structure of the compound **A** to be revised. They obtained a dibridged compound **B** (2.5%, mp 149—151 °C) as a by-product in the reaction of [5]ferrocenophane with acryloyl chloride and $AlCl_3$, and assigned the compound **B** to [5](1,1′)-α-oxo[3](3,2′)ferrocenophane (**3**), a slantwise dibridged ferrocenophane. They mentioned that Brown's compound **A** was phane **3**, because **B** was almost identical with **A** in melting point and spectral data. Both groups described the chemical shift values of the cyclopentadienyl (Cp) ring proton signals in ^{1}H NMR spectra but not the multiplicities and coupling constants of the signals. Accordingly, the proper structure of **A** or **B** cannot be judged only by their descriptions.

In the first place, we reinvestigated the reaction reported by Brown and Winstead in order to solve the discrepancy between the descriptions of the two groups. [5]Ferrocenophane-2-propionic acid was treated with trifluoroacetic anhydride in dichloromethane to give two products **2** (75%, mp 163—163.5 °C) and **3** (6.3%, mp 75—78 °C) which both showed the molecular ion peak at m/z 308 in the mass spectra. The melting point of **2** is close to those of compounds **A** and **B**, and the chemical shift values of **2** are also almost similar to the data of **A** and **B**. Accordingly, the phane **2** definitely corresponds to **A** and **B**. In the ^{1}H NMR spectra, the two triplet signals of the Cp ring protons of **2** at δ 4.24 and 4.38 are split by 2.4 and 2.6 Hz, respectively, whereas two triplets of **3** at δ 4.08 and 4.78 have the coupling constants of 2.4 and 1.4 Hz. The usual ortho and meta coupling constants in multibridged ferrocenophanes are 2.0—3.1 and 1.0—1.6 Hz, respectively.[1,2,7,8] Therefore, the three protons appearing as triplet with a larger coupling constant have hydrogens at two ortho positions in the Cp rings, and only one proton of **3** has hydrogens at two meta positions. The spectra indicate that compound **2** have a symmetrically bridged structure at 1,2-positions and **3** is a slantwise bridged ferrocenophane.

Bridge enlargement of **2** with diazomethane and BF_3 etherate according to the method used in the synthesis of multibridged $[5_n]$ferrocenophanes[1,2] afforded two enlarged ketones **4** and **5**. The mass spectra of **4** and **5** indicated that they were produced by insertion of one and two units of methylene group, respectively. Reduction of **5** with $LiAlH_4$ and $AlCl_3$ afforded compound **1**. The C_{2v} symmetric structure of **1** was deter-



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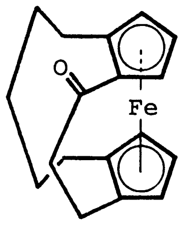

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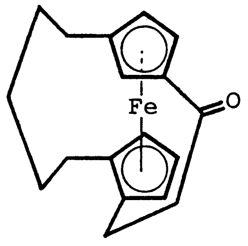

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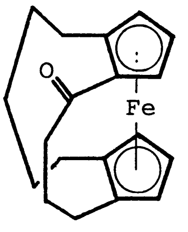

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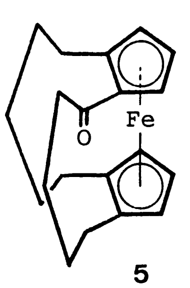

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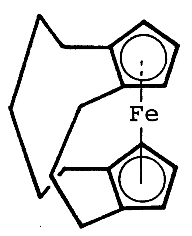

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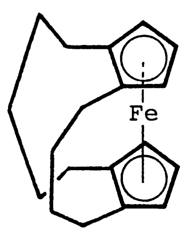

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mined by NMR spectrometry. The Cp ring protons of **1** appear as only two signals at δ 3.93(d) and 4.18(t). The ^{13}C NMR spectrum of **1** shows a simple pattern which consists of only three methylene carbon and three ring carbon signals.

The NMR spectra of **6** and **7** obtained by reduction of **2** and **4**, respectively, indicate their C_s symmetric structure. The melting point (153—153.5 °C) and the chemical shift values of the Cp ring protons of **6** are almost similar to those of reduction product (mp 153—154 °C[5]) of compound **A**. Therefore, it has been confirmed that the description by Brown and Winstead was correct.

Experimental

All melting points were uncorrected. Spectra were measured on the same instruments as those used in the synthesis of [5$_4$]ferrocenophane.[2] All reactions were carried out according to the procedures described in the previous reports.[1,2]

Bridging Reaction of [5]Ferrocenophane-2-propionic Acid (8). The starting material **8** was prepared by condensation of 2-formyl[5]ferrocenophane[1] with malonic acid and piperidine in pyridine followed by hydrogenation with H_2/Pd-C in acetone. The acid **8** (260 mg) was treated with trifluoroacetic anhydride (550 mg) in dichloromethane (20 ml). The crude product was column-chromatographed over silica gel with benzene. The first band yielded [5]-α-oxo[3](1,2)ferrocenophane (**2**) (177 mg, 75%), which was recrystallized from ethyl acetate to give orange rodlike crystals; mp 163—163.5 °C (lit, mp 156—158 °C,[5] 149—151 °C[6]). IR (KBr) 1665 (C=O) cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.30—3.50 (14H, m, -CH$_2$-), 3.70 (1H, dd, J=1.4 and 2.4 Hz, 3′- or 5′-H), 4.04 (1H, dd, J=1.4 and 2.6 Hz, 3- or 5-H), 4.24 (1H, t, J=2.4 Hz, 4′-H), 4.38 (1H, t, J=2.6 Hz, 4-H), 4.54 (1H, dd, J=1.4 and 2.4 Hz, 3′- or 5′-H), 4.78 (1H, dd, J=1.4 and 2.6 Hz, 3- or 5-H); MS m/z (rel intensity) 308 (100, M$^+$).

The second band yielded [5](1,1′)-α-oxo[3](3,2′)ferrocenophane (**3**) (15 mg, 6.3%), which was recrystallized from ethyl acetate to give orange prisms; mp 75—78 °C. IR(KBr) 1650 (C=O) cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.50—3.80 (14H, m, -CH$_2$-), 3.94 (1H, dd, J=1.5 and 2.4 Hz, 3′- or 5′-H), 4.08 (1H, t, J=2.4 Hz, 4′-H), 4.16 (1H, dd, J=1.4 and 2.4 Hz, 5-H), 4.30 (1H, dd, J=1.5 and 2.4 Hz, 3′- or 5′-H), 4.47 (1H, dd, J=1.4 and 2.4 Hz, 4-H), 4.78 (1H, t, J=1.4 Hz, 2-H); MS m/z (rel intensity) 308 (100, M$^+$).

Found: m/z 308.0847. Calcd for $C_{18}H_{20}OFe$: M, 308.0862.

Bridge Enlargement of Ketone 2. Ketone **2** (900 mg) in benzene (150 ml) was allowed to react with alcohol-free diazomethane (50 ml of an ether solution) in the presence of BF$_3$ etherate (1.0 ml). The crude product was column-chromatographed over silica gel with benzene-ethyl acetate (50:1). The first band yielded [5]-β-oxo[4](1,2)ferrocenophane (yellow crystals, 161 mg, 17%). IR(KBr) 1695 (C=O) cm^{-1}. The β-ketone was contaminated with further enlarged products, and could not be purified.

The second band yielded [5]-α-oxo[5](1,2)ferrocenophane (**5**) (333 mg, 35%), which was recrystallized from ethyl acetate to give red plates; mp 134—135 °C. IR(KBr) 1648 (C=O) cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.30—3.20 (18H, m, -CH$_2$-), 3.85 (1H, t, J=2.0 Hz, 4′-H), 4.15 (2H, m, Cp-H), 4.27 (1H, t, J=2.0 Hz, 4-H), 4.57 (2H, m, Cp-H); MS m/z (rel intensity) 336 (100, M$^+$), 308 (6), 322 (2).

Found: C, 71.51; H, 7.12; m/z 336.1191. Calcd for $C_{20}H_{24}OFe$: C, 71.44; H, 7.19; M, 336.1175.

The starting material **2** (98 mg, 11%) was yielded from the third band. The fourth band yielded [5]-α-oxo[4](1,2)ferrocenophane (**4**) (216 mg, 23%), which was recrystallized from ethyl acetate to give orange needles; mp 157—158 °C. IR (KBr) 1645 (C=O) cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.20—3.00 (16H, m, -CH$_2$-), 3.95 (2H, m, Cp-H), 4.15 (1H, t, J=2.5 Hz, 4′-H), 4.27 (1H, t, J=2.0 Hz, 4-H), 4.51 (2H, m, Cp-H); MS m/z (rel intensity) 322 (100, M$^+$), 298 (5).

Found: C, 70.80; H, 6.81; m/z 322.1019. Calcd for $C_{19}H_{22}OFe$: C, 70.82; H, 6.88; M, 322.1018.

[5][3](1,2)Ferrocenophane (6). Ketone **2** (40 mg) was reduced with LiAlH$_4$ (20 mg) and AlCl$_3$ (70 mg) in ether (10 ml). Phane **6** (35 mg, 92%), isolated from the crude product by column chromatography over silica gel with benzene, was recrystallized from hexane to give yellow needles; mp 153—153.5 °C (lit, mp 153—154 °C[5]). ^{1}H NMR (CDCl$_3$) δ=1.20—3.20 (16H, m, -CH$_2$-), 3.78 (4H, d, J=2.4 Hz, 3,3′,5,5′-H), 4.14 (2H, t, J=2.4 Hz, 4,4′-H); ^{13}C NMR (CDCl$_3$) δ=21.10, 21.44, 22.27, 26.46, and 34.65 (methylene-C), 66.58, 68.09, and 69.35 (unsubstd. Cp-C), 83.20 and 85.78 (substd. Cp-C); MS m/z (rel intensity) 294 (100, M$^+$); λ_{max} (THF) 442 nm (ε=221).

[5][4](1,2)Ferrocenophane (7). Ketone **4** (40 mg) was reduced with LiAlH$_4$ (20 mg) and AlCl$_3$ (70 mg) in ether (10 ml). Phane **7** (38 mg, quant.) was isolated by column chromatography over alumina with benzene and recrystallized from ethyl acetate to give yellow needles; 137—138 °C. ^{1}H NMR (CDCl$_3$) δ=1.30—3.00 (18H, m, -CH$_2$-), 3.82 (2H, dd, J=1.4 and 3.2 Hz, 3,3′-H), 3.97 (2H, dd, J=1.4 and 3.2 Hz, 5,5′-H), 4.04 (2H, t, J=3.2 Hz, 4,4′-H); ^{13}C NMR (CDCl$_3$) δ=22.27, 22.86, 25.39, 26.37, and 26.71 (methylene-C), 65.65, 67.06, and 68.77 (unsubstd. Cp-C), 85.88 and 86.12 (substd. Cp-C); MS m/z (rel intensity) 308 (100, M$^+$); λ_{max} (THF) 444 nm (ε=110).

Found: C, 74.12; H, 7.82; m/z 308.1213. Calcd for $C_{19}H_{24}Fe$: C, 74.40; H, 7.85; M, 308.1225.

[5$_2$](1,2)Ferrocenophane (1). Ketone **5** (39 mg) was reduced with LiAlH$_4$ (18 mg) and AlCl$_3$ (62 mg) in ether (10 ml). Phane **1** (35 mg, 95%) was isolated by column chromatography over alumina with benzene and recrystallized from ethyl acetate to give orange plates; mp 130—132 °C. ^{1}H NMR (CDCl$_3$) δ=1.20—3.00 (20H, m, -CH$_2$-), 3.93 (4H, d, J=2.4 Hz, 3,3′,5,5′-H), 4.18 (2H, t, J=2.4 Hz, 4,4′-H); ^{13}C NMR (CDCl$_3$) δ=22.42, 22.81, and 25.78 (methylene-C), 66.72 and 67.55 (unsubstd. Cp-C), 85.14 (substd. Cp-C); MS m/z (rel intensity) 322 (100, M$^+$); λ_{max} (THF) 446 nm (λ=109).

Found: C, 74.14; H, 8.00; m/z 322.1379. Calcd for $C_{20}H_{26}Fe$: C, 74.54; H, 8.13; M, 322.1382.

References

1) M. Hisatome and M. Hillman, *J. Organomet. Chem.*, **212**, 217 (1981).

2) M. Hisatome, J. Watanabe, R. Yamashita, and K. Yamakawa, 18th Symposium on Structural Organic Chemistry, Toyama, Oct. 1985, Abstr. No. B2-08; M. Hisatome, R. Yamashita, J. Watanabe, K. Yamakawa, and Y. Iitaka, *Bull. Chem. Soc. Jpn.*, in press.

3) The nomenclature of ferrocenophanes[2] in the present work is a modification of that presented by Vögtle and Neumann.[4]

4) F. Vögtle and P. Neumann, *Tetrahedron*, **26**, 5847 (1970).

5) A. D. Brown, Jr. and J. A. Winstead, *J. Org. Chem.*, **36**, 2832 (1971).

6) Y. T. Struchkov, G. G. Aleksandrov, A. Z. Kreindlin, and M. I. Rybinskaya, *J. Organomet. Chem.*, **210**, 237 (1981).

7) M. Hisatome, T. Sakamoto, and K. Yamakawa, *J. Organomet. Chem.*, **107**, 87 (1976).

8) M. Hisatome, N. Watanabe, T. Sakamoto, and K. Yamakawa, *J. Organomet. Chem.*, **125**, 79 (1977).