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Assignment of ^{1}H NMR Chemical Shifts in 1,2- and 1,1'-Disubstituted Ferrocenes

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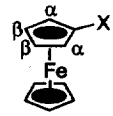
Abstract: The effect of 29 commonly encountered substituents on the chemical shifts of α, β and C_5H_5 positions in monosubstituted ferrocenes are tabulated and employed for determining ^{1}H NMR assignments in 1,2- and 1,1'-disubstituted ferrocene derivatives.
Keywords: ferrocenes, models, NMR, regiochemistry.

Introduction

There has recently been a resurgence of interest in the chemistry of ferrocene derivatives due to their increasing application in asymmetric catalysis and materials science.[1] In particular, several methods have been published on the asymmetric synthesis of 1,2-disubstituted ferrocene derivatives displaying planar chirality,[2,3] and also on the synthesis of unsymmetrical 1,1'-disubstituted derivatives.[4] A feature of our own and other groups contributions to this area is the lack of detailed ^{1}H NMR assignments for the substituted cyclopentadienyl rings, assignments that would significantly aid product verification. In our own case this deficiency is due to the absence of a comprehensive table of chemical shifts for ferrocene derivatives. Although the older literature contains a number of studies and tables detailing such substituent effects,[5] these do not include many of the functional groups now frequently employed, nor has it been shown that these can be used in the same manner as tables are applied to determining assignments in multiply substituted benzenes.[6] In this Letter we collate the effect of 29 commonly encountered groups on the chemical shifts of α, β and C_5H_5 positions in monosubstituted ferrocenes, and show that these can be applied to determining assignments in 1,2- and 1,1'-disubstituted derivatives.



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Results and Discussion

The 400 MHz ^{1}H NMR spectra of 29 substituted derivatives[7] were all recorded in $CDCl_3$, and shifts in the α, β and C_5H_5 positions relative to ferrocene itself (4.19 ppm) are given in Table 1. Although most of these spectra have been previously reported, they were re-recorded to ensure uniformity of solvent and concentration, and consistency of reference to an internal standard of either residual $CHCl_3$ (7.27 ppm),

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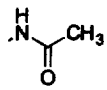
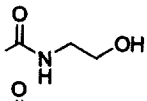
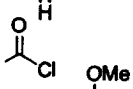
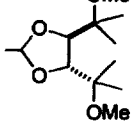
Table 1. Changes in chemical shift (S) for α,β and C_5H_5 positions relative to ferrocene (4.19 ppm).[a]

		α[b]	β[b]	C_5H_5			α[b]	β[b]	C_5H_5
1	$-CH_3$	-0.11	-0.15	-0.08	15		+0.56	+0.15	+0.01
2	$-CH_2OH$	0.00	+0.03	0.00	16	$-NO_2$	+1.06	+0.33	+0.15
3	$-CH_2NMe_2$	-0.04	-0.10	-0.10	17	$-NH_2$	-0.17	-0.32	-0.07
4		+0.03	+0.17	-0.08	18		+0.38	-0.19	-0.02
5	-Ph	+0.46	+0.13	-0.13	19[c]	-OH	-0.20	-0.43	-0.05
6		+0.28	+0.02	+0.04	20	-SPh	+0.22	+0.15	+0.08
7		+0.48	+0.21	+0.16	21[d]	-SOPh	+0.32	+0.18	+0.20
8		+0.55	+0.36	+0.02	22	$-SO_2Ph$	+0.50	+0.22	+0.31
9		+0.59	+0.32	+0.02	23	-F	+0.13	-0.39	+0.09
10		+0.68	+0.28	+0.07	24	-Cl	+0.21	-0.13	+0.06
11		+0.61	+0.20	+0.01	25	-Br	+0.23	-0.08	+0.05
12		+0.50	+0.18	+0.04	26	-I	+0.23	-0.03	+0.01
13		+0.74	+0.39	+0.16	27	-TMS	-0.06	+0.17	-0.03
14[e]		-0.04	+0.17	+0.02	28	$-SnBu_3$	-0.12	+0.19	-0.04
					29	$-PPh_2$	-0.12	+0.14	-0.15

a) All spectra were recorded at room temperature in $CDCl_3$ at a concentration of ~0.04 mmol/ml. b) Where resolved, peaks observed as triplets with J = 1.45 - 2.14 Hz. c) Values obtained from 2-(2-hydroxyferrocenyl)-4,4-dimethyloxazoline[8] after subtraction of the oxazoline contribution. d) α value an average of +0.42 and +0.22 for the two diastereotopic positions, β value an average of +0.19 and +0.16.

ferrocene, or both. The assignment of α and β positions in **1**, **4**, **6**, **8** and **9** have previously been achieved by comparison of their spectra to those of the corresponding 2,5-dideuterated derivatives.[5b,c] By analogy with the two latter examples, the α positions of compounds containing other electron-accepting substituents are assigned the larger of the two positive chemical shifts (**7**, **10-13**, **15**, **16**, **21**, **22**). Also in this category ($\delta_\alpha > \delta_\beta > 0$) is **5**, assigned by the NOE between the *ortho*-hydrogens of the phenyl group and the α positions (3% enhancement). The uniformity of the sulfide-sulfoxide-sulfone series (**20-22**) is matched by that of the halogens (**23-26**) in which α,β assignments ($\delta_\alpha > 0$, $\delta_\beta < 0$) have been established by deuterium labeling,[5c] and on this basis the β positions of **18** are also assigned to the upfield signal. Similarly, the amino and hydroxy substituents of **17** and **19** both result in an upfield shift, with the effect on the β positions being greatest ($\delta_\beta < \delta_\alpha < 0$).[5d] Due to their electropositive character, three of the substituents (**14**, **28**, **29**) fell into a final category to which **27** has previously been assigned ($\delta_\alpha < 0$, $\delta_\beta > 0$).[5c]

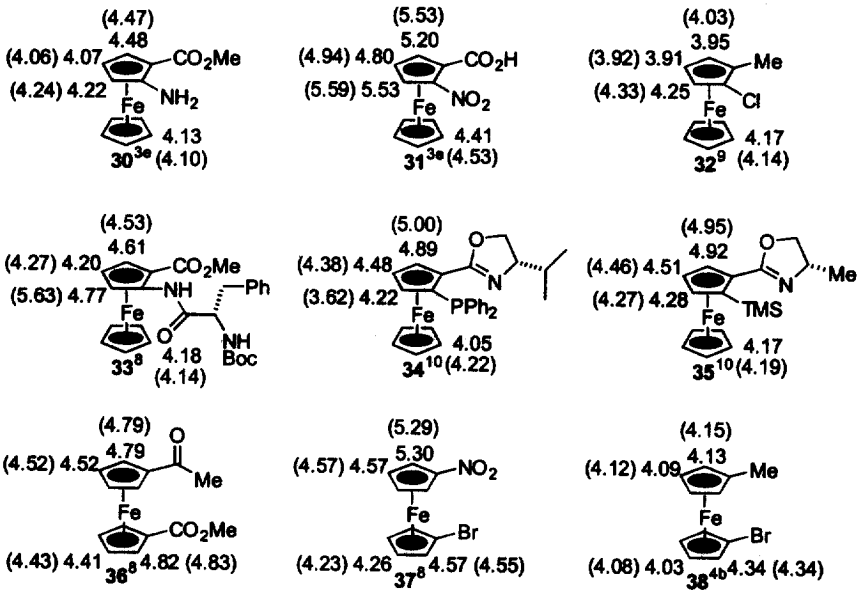


Figure 1. Calculated ($\delta = 4.19 + \sum S_i$) and observed (in parenthesis) chemical shifts for **30-38**.

The use of Table 1 for determining assignments in 1,2-disubstituted ferrocenes was tested with derivatives **30-35**, these containing a representative mixture of the four categories mentioned above. The agreement between calculated and observed values is generally good permitting assignment of each cyclopentadienyl position as shown in Figure 1. The only exceptions arose in **33** and **34** for positions adjacent to substituents that display a pronounced anisotropic effect, the conformation of which is affected by the

second substituent. Application of these tables to a variety of 1,2-disubstituted derivatives containing acetal[11] and sulfoxide[3b,3c] groups also gave good agreement between calculated and reported values. Finally, the excellent agreement in values for the three 1,1'-derivatives **36-38** indicates the validity of incorporating the C_5H_5 contribution into these calculations.

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