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ABSTRACT: Despite the well-established pharmacological properties of aromatic sulfonamides and the interest of introducing ferrocene into drugs, ferrocene sulfonamides have scarcely been studied. General synthetic methods using lithium bases to perform sulfonamide-directed deprotolithiation or 'halogen dance' reaction are here reported for the functionalization of *N*,*N*-dialkylferrocenesulfonamides toward various polysubstituted derivatives. Post-functionalization of the ferrocenyl iodides by cross-coupling and lithium/iodine exchange reactions were also considered. Finally, the ligand behavior of new ferrocene phosphines in palladium-catalyzed coupling reactions was studied, and the reaction outcomes viewed in the light of DFT calculations.

INTRODUCTION

Ferrocenes are three-dimensional compounds wherein iron is located between two cyclopentadienyls. They are generally stable to air, water, heat and light, and able to easily undergo one-electron oxidation; thus, they can be included within a molecule in order to acquire specific physical and chemical properties.[1] Besides, the low toxicity of ferrocene allows its use in medicinal chemistry as a bioisostere of aryl/heteroaryl groups with additional modes of action.[1f,2] Thus, the introduction of ferrocene into biologically active molecules has led to drugs currently under development such as ferrocifens (a family of anticancer drug candidates),[3] ferroquine (in clinical trials in combination with artefenomel used against chloroquine-resistant forms of malaria,[4] as well as a promising candidate for cancer therapeutics).[5]

Furthemore, alongside their well-established use as antibacterials, aromatic sulfonamides exhibit a wide range of pharmacological properties[6] among which anticancer activities.[7] Compounds incorporating both a sulfonamide and a ferrocene moiety have been synthesized and proved to exhibit bioactivities.[8] However, only a few contain a sulfonamide directly linked to ferrocene such as the penicillanic and cephalosporanic secondary sulfonamides depicted in Figure 1, both active toward Gram-positive germs.[9]

Apart from medicinal applications, ferrocene sulfonamides are attractive structures for their ability to act as sensors (hydrogen bonding interactions),[10] or monomers for polymerization.[11] However, despite all these potential applications, polysubstituted ferrocene sulfonamides have barely been studied.[12]

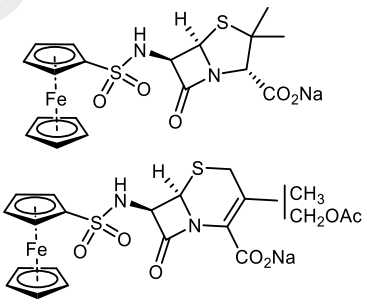


Figure 1. Bioactive ferrocene sulfonamides: penicillanic (top) and cephalosporanic (bottom) derivatives.

Tertiary sulfonamides are powerful groups to direct aromatic deprotometalation[13] at their adjacent position,[14] probably through coordination by the oxygen atom.[15] Therefore, the reaction giving 2-substituted derivatives was rapidly exemplified in the benzene series[16] and beyond.[17] While butyllithium can be used in most cases, recourse to hindered metal dialkylamides also proved possible for sensitive heteroaromatics such as pyridines bearing piperidine-, pyrrolidine- and morpholine-based sulfonamides.[18]

However, although less prone to nucleophilic attack and being better directing groups than the corresponding carboxamides, tertiary sulfonamides have barely been used to direct functionalization in metallocene series. An early example can be found in the work of Sutherland and Unni who 2-lithiated *N*,*N*-dimethylcymanthrenesulfonamide in 1970 by using methyllithium in tetrahydrofuran (THF) at –70 °C.[19] From 2002 to 2005, Ogawa, Sato and co-workers have developed the synthesis of scaffolds containing sulfur-based heterocycles fused to ferrocene. In this

context, they rather used butyllithium to quantitatively deprotometalate *N*,*N*-dimethylferrocenesulfonamide, and intercepted the intermediate ferrocenyllithium with elemental sulfur.[20]

Our goal in the present paper is to generalize the use of *N*,*N*-dialkylsulfonamides as both deprotometalation directing groups and 'halogen dance' stabilizing group in the ferrocene series. The developed methods were used to access a library of previously unknown 2- and 3-substituted, 2,4- and 2,5-disubstituted, 2,3,5-trisubstituted, and even 2,3,4,5-tetrasubstituted *N*,*N*-dialkyl ferrocenesulfonamides.

RESULTS AND DISCUSSION

The pK_a values calculated for *N*,*N*-dimethylferrocenesulfonamide (**1**; see Figure 2) show that *N*,*N*-dimethylsulfonamide is a powerful acidifying group, similar to fluorine, both of them stronger than diisopropylcarboxamide.

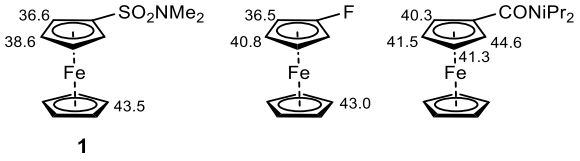


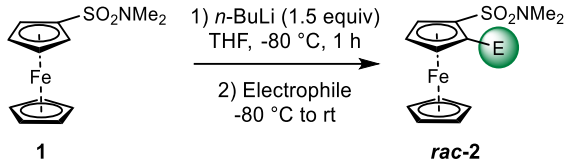
Figure 2. pK_a values of *N*,*N*-dimethylferrocenesulfonamide (**1**), and comparison with fluoroferrocene[21] and *N*,*N*-diisopropylferrocenecarboxamide.[22]

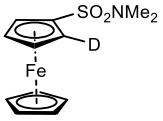
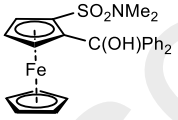
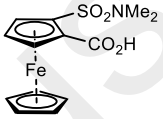
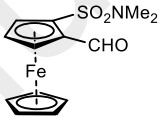
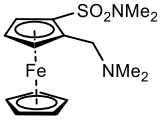
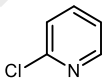
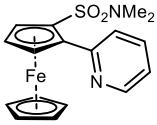
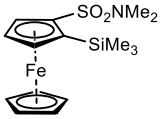
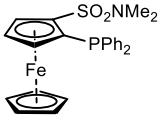
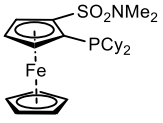
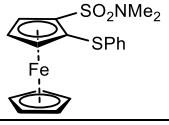
With a view to developing a convenient access to new 2-substituted ferrocenesulfonamides, we initially treated **1** by butyllithium (1.5 equiv) in THF at –80 °C (Table 1). Deprotonation was found complete after 1 h, as determined by subsequent deuteration to produce **2a** (entry 1; quantitative yield).

Next, the sequence of 'deprotolithiation-quenching' successfully led to various 2-substituted derivatives **2** from a range of electrophilic traps. In that respect, reaction of *in situ* formed 2-lithio-*N*,*N*-dimethylferrocenesulfonamide with benzophenone, carbon dioxide and dimethylformamide respectively gave the alcohol **2b** (entry 2; 82% yield), the carboxylic acid **2c** (entry 3; 85% yield) and the aldehyde **2d** (entry 4; 56% yield), whilst with the Eschenmoser's salt (dimethylmethylideneammonium iodide) the amine **2e** was isolated in 66% yield (entry 5).

Deprotolithiation of **1** followed by transmetalation to zinc and palladium-catalyzed Negishi cross-coupling with 2-chloropyridine afforded the derivative **2f** in a moderate yield (entry 6; 68% yield). Finally, the silane **2g** (entry 7; 82% yield) and the phosphines **2h,i** (entries 8 and 9; non-optimized 30-49% yields) were respectively obtained following interception of intermediate 2-lithio-*N*,*N*-dimethylferrocenesulfonamide with chlorotrimethylsilane and chlorophosphines, while reaction with phenyl disulfide yielded the expected phenylthio derivative **2j** in 82% yield (entry 10).

Table 1. Synthesis of 2-substituted *N*,*N*-dimethylferrocenesulfonamides.



Entry	Electrophile[a]	Product **2**, Yield (%)[b]
1	D_2O	 **2a**, 100
2	$Ph_2C{=}O$	 **2b**, 82[c]
3	CO_2	 **2c**, 85
4	Me_2NCHO	 **2d**, 56
5	$CH_2{=}NMe_2I$	 **2e**, 66
6		 **2f**, 68
7	$ClSiMe_3$	 **2g**, 82
8[d]	$ClPPh_2$	 **2h**, 49
9[d]	$ClPCy_2$	 **2i**, 30
10	PhSSPh	 **2j**, 82

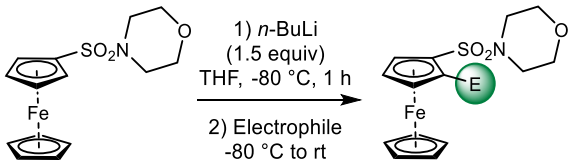
[a] See Experimental Section for more details on the electrophilic trapping and subsequent hydrolysis. [b] Yields are given after purification, as described in Experimental Section. [c] Contaminated by traces of benzhydrol. [d] 1.1 equiv of *n*-BuLi was used instead of 1.5.

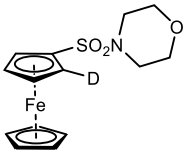
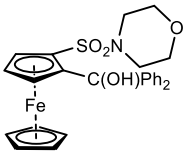
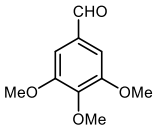
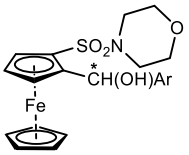
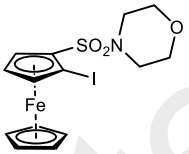
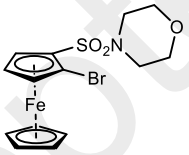
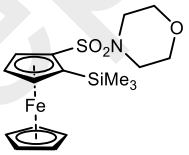
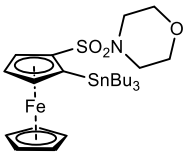
Encouraged by these results, we next turned our attention to (*N*-morpholino)sulfonylferrocene (**3**) which is a pattern of interest in medicinal chemistry.[23] Never used to direct deprotometalation in the benzene series, the (*N*-morpholino)sulfonyl

group has only been employed to this purpose in a few other examples.[18b,c]

Pleasingly, upon treatment by butyllithium (1.5 equiv) in THF at –80 °C for 1 h, deprotometalation of **3** took place efficiently, as evidenced by subsequent trapping with D_2O to afford **4a** in 84% yield (Table 2; entry 1). Reaction of 1-lithio-2-(*N*-morpholino)sulfonylferrocene with benzophenone gave the tertiary alcohol **4b** (entry 2; 95% yield), whilst quenching with 3,4,5-trimethoxybenzaldehyde yielded the secondary alcohols **4c1** and **4c2** without stereoselectivity (entry 3; 40 and 39% yield, respectively). The introduction of halogens next to the (*N*-morpholino)sulfonyl group was also found possible by using iodine (product **4d**, 63% yield; entry 4) and 1,2-dibromoethane (product **4e**, 55% yield; entry 5). Finally, the ferrocenic silane **4f** and stannane **4g** were prepared by trapping the lithio intermediate with chlorotrimethylsilane (entry 6; 82% yield) and chlorotributylstannane (entry 7; 85% yield), respectively.

Table 2. Synthesis of 2-substituted (*N*-morpholino)sulfonylferrocenes.

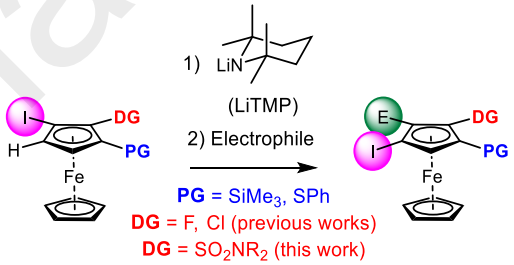


Entry	Electrophile[a]	Product **4**, Yield (%)[b]
1	D_2O	 **4a**, 84
2	$Ph_2C{=}O$	 **4b**, 95
3		 **4c1**, 40 **4c2**, 39
4[c]	I_2	 **4d**, 63
5	$BrCH_2CH_2Br$	 **4e**, 55
6[c]	$ClSiMe_3$	 **4f**, 82
7	PhSSPh	 **4g**, 85

[a] See Experimental Section for more details on the electrophilic trapping and subsequent hydrolysis. [b] Yields are given after purification, as described in Experimental Section. [c] 1.1 equiv of *n*-BuLi was used instead of 1.5.

‘Halogen dance’ is an elegant way to isomerize halogeno-substituted aromatics (I > Br).[24] Usually requiring a hindered lithium dialkylamide (such as lithium 2,2,6,6-tetramethylpiperidide (LiTMP) and lithium diisopropylamide), the reaction is driven by the stability of the generated arylmetal. Evidenced in the ferrocene series from 2010,[25] the reaction has recently been the subject of more detailed studies.[22,21,26] While the use of diisopropylcarboxamide as a stabilizing/directing group (DG) allowed the 2-iodo derivative to be converted into its 3-iodo isomer,[22,27] better results were recorded by combining fluorine (or chlorine) as a stabilizing group and trimethylsilyl (or phenylthio) as a protecting group (PG).[21,26a,b] Our goal is now to evaluate the ability of *N*,*N*-dialkylsulfonamides as stabilizing groups in this reaction (Scheme 1).

Scheme 1. Strategy employed to achieve ferrocene halogen “dance” reactions.



The pK_a values calculated[21-22] for 1-fluoro-4-iodo-2-(trimethylsilyl)ferrocene and 4-iodo-*N*,*N*-dimethyl-2-(trimethylsilyl)ferrocenesulfonamide tend to indicate that dimethylsulfonamide is even a better stabilizing group than fluorine for a 5-lithio compound (Figure 3, left and middle). Thus, we planned to synthesize 2-iodo-*N*,*N*-dimethyl-5-(trimethylsilyl)ferrocenesulfonamide (**5**), which is a suitable substrate to test the ‘halogen dance’ reaction.

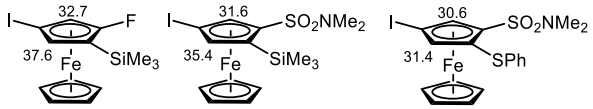


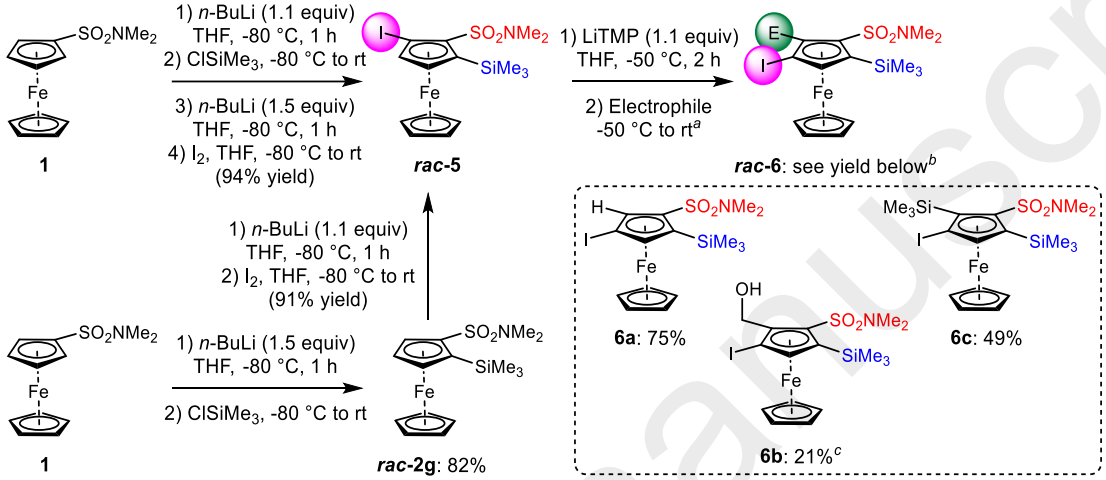
Figure 3. pK_a values of 1-fluoro-4-iodo-2-(trimethylsilyl)ferrocene (left), 4-iodo-*N*,*N*-dimethyl-2-(trimethylsilyl)ferrocenesulfonamide (**6a**; middle) and 4-iodo-*N*,*N*-dimethyl-2-(phenylthio)ferrocenesulfonamide (**10a**; right).

To this end, we first started from **2g** and carried out a second deprotometalation-trapping sequence by using successively butyllithium in THF at –80 °C for 1 h and iodine; by this way, compound **5** was prepared in 91% yield (Scheme 2,

bottom left). Interestingly, iterative deprotometalation-trapping sequences from **1** using two different electrophiles also afforded **5** in a better 94% overall yield for this one-pot reaction (Scheme 2, top left).

The substrate **5** in hand, the 'halogen dance' reaction was next performed, as described previously, by using LiTMP (1.1 equiv) in THF at –50 °C for 2 h.[21] After methanolysis, 4-iodo-*N*,*N*-dimethyl-2-(trimethylsilyl)ferrocenesulfonamide (**6a**) was isolated in 75% yield. Thereafter, reaction of 3-iodo-2-lithio-*N*,*N*-dimethyl-5-(trimethylsilyl)ferrocenesulfonamide with dimethylformamide (DMF) gave, after subsequent reduction (performed in order to facilitate the purification), the alcohol **6b** in 21% overall yield. Finally, quenching the lithiated intermediate by chlorotrimethylsilane yielded the tetrasubstituted ferrocene **6c** in 49% yield (Scheme 2, right).

Scheme 2. Synthesis of 2,5-disubstituted 5, 2,4-disubstituted 6a, and 2,3,5-trisubstituted 6b,c *N*,*N*-dimethylferrocenesulfonamides from 1. [a] See Experimental Section for more details on the electrophilic trapping and subsequent hydrolysis. [b] Yields are given after purification, as described in the Experimental Section. [c] Overall yield after trapping with DMF and reduction of the intermediate aldehyde.

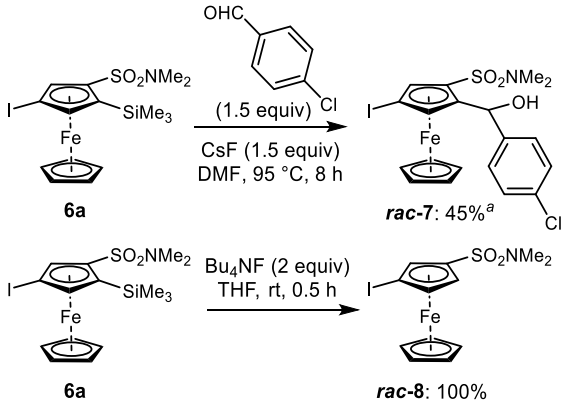


In 1995, Price and Simpkins showed the possible conversion to alcohol of a trimethylsilyl group connected to ferrocene upon reaction with a large excess of benzaldehyde in the presence of cesium fluoride (3 equiv) in DMF at 100 °C for 30 h (55% yield).[28] Inspired by these results, we treated the silane **6a** by 4-chlorobenzaldehyde (1.5 equiv) in the presence of cesium fluoride (1.5 equiv) in DMF at 95 °C for 8 h. Under these conditions, we could only isolate the main diastereoisomer **7**, which was obtained in 45% yield (Scheme 3, top). While the other diastereoisomer was formed in a lower yield (<8%) and could not be purified, the other main product isolated was compound **8** (45% yield), resulting from competitive desilylation. Note that increasing the amounts of both aldehyde and fluoride to 4 equivalents had no positive effect on the course of the reaction.

Our attempts to convert the trimethylsilyl of **6a** into a more valuable chloro group by using *N*-chlorosuccinimide (either in the presence of tetrabutylammonium fluoride (TBAF) in THF at room temperature (rt), or in acetonitrile at reflux as reported previously in the benzene series)[29] were unsuccessful. Similarly, treating **6a** by 4-chlorobenzoyl chloride in the presence of either aluminum chloride in dichloromethane,[30] or cesium fluoride in DMF failed in giving the corresponding ketone. However, these results are not surprising since such reactions are far from common in the ferrocene series.

The competitive desilylation observed previously prompted us to promote this reaction by using TBAF (2 equiv) in THF,[26b] leading to 3-iodo-*N*,*N*-dimethylferrocenesulfonamide (**8**) in a quantitative yield (Scheme 3, bottom). Although potassium *tert*-butoxide (3 equiv) in dimethylsulfoxide (DMSO) at rt for 0.5 h also led to **8**, competitive deiodination was also observed (60:40 ratio between **8** and **1**) under these conditions.

Scheme 3. Desilylation of 6a toward 2,4-disubstituted 7 and 3-substituted 8 *N*,*N*-dimethylferrocenesulfonamides. [a] Yield for the main diastereoisomer isolated.



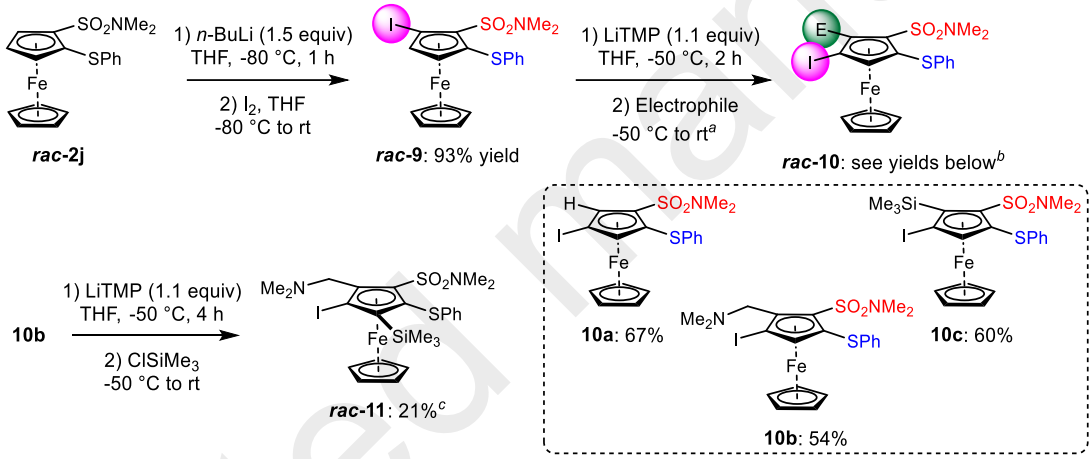
With routes to 2- and 3-substituted (**2**, **8**), 2,4- and 2,5-disubstituted (**6a**, **7**, **5**), and 2,3,5-trisubstituted (**6b**,**c**) *N*,*N*-dimethylferrocenesulfonamides in hand, we next turned our attention to phenylthio-containing ferrocenes. Indeed, whereas this group is more difficult to remove than a trimethylsilyl, it can be easily converted by oxidation to sulfoxide and sulfone which exhibit different electronic, steric and coordinating

properties. In addition, even if both pK_a values at C3 (31.4) and C5 (30.6) for 4-iodo-*N*,*N*-dimethyl-2-(phenylthio)ferrocenesulfonamide (**10a**) are rather close (Figure 3, right), arylthio groups are known to only direct deprotometalation to adjacent sites under specific conditions (*sec*-butyllithium with potassium *tert*-butoxide at –78 °C).[31]

Thus, from our preliminary results in the fluorine series,[26b] we prepared our new 'halogen dance' precursor, 2-iodo-*N*,*N*-dimethyl-5-(phenylthio)ferrocenesulfonamide (**9**). It was obtained in 93% yield from **2j** by a deprotometalation-trapping sequence successively using butyllithium at –80 °C for 1 h and iodine (Scheme 4, top left). We next applied our general 'halogen dance' protocol (LiTMP, THF, –50 °C, 2 h) to **9** by using different electrophiles. Subsequent interception by methanol led to the 2,4-disubstituted *N*,*N*-dimethylferrocenesulfonamide **10a** in 67% yield, whilst the Eschenmoser's salt and chlorotrimethylsilane furnished the amine **10b** and silane **10c** in 54 and 60% yield, respectively (Scheme 4, right). It is worth noting that iodine/lithium exchange at the position next to the sulfonamide is the main competitive reaction, in spite of the use of a lithium amide. Such a side reaction has previously been observed, and could not be discounted.[21-22,26a,b]

We finally considered the introduction of a fifth substituent onto **10b** in order to reach a new hetero-1,2,3,4,5-pentasubstituted ferrocene.[26a] Due to the presence of a heavy halogen in **10b**, we turned to a lithium amide base in order to avoid halogen/metal exchange. Although phenylthio is a bad stabilizing group for deprotometalations mediated by lithium amides,[31] we hoped to benefit from the presence of both short-range acidifying iodine and longer-range acidifying sulfonamide to stabilize a lithiated intermediate. Thus, the successive treatment of **10b** with LiTMP (–50 °C, 4 h) and chlorotrimethylsilane afforded the expected product **11** (Scheme 4, bottom left). Although isolated in a moderate 21% yield due to difficult separation from the remaining starting material, this constitutes the first example of hetero-pentasubstituted ferrocene sulfonamide.

Scheme 4. Synthesis of 2,5-disubstituted 9, 2,4-disubstituted 10a, 2,3,5-trisubstituted 10b,c and 2,3,4,5-tetrasubstituted 11 *N*,*N*-dimethylferrocenesulfonamides from 1. [a] See Experimental Section for more details on the electrophilic trapping and subsequent hydrolysis. [b] Yields are given after purification, as described in the Experimental Section. [c] The rest was mainly recovered **10b** (isolated in 22% yield).



To our knowledge, the use of an arylsulfonyl group to induce deprotometalation onto a ferrocene ring has mainly been attempted by Uemura and co-workers in 1996.[32] By using a butyllithium-diamine chelate in THF to functionalize (4-tolylsulfonyl)ferrocene, the authors also observed products coming from a competitive attack of the base at the *ortho* positions of the tolyl ring. It was thus of interest to attempt the reaction on the phenylsulfonyl-substituted ferrocenesulfonamide **12**, for which the ferrocenyl ring benefits from a stronger activation.

Consequently, compound **12**, prepared by oxidation of **2j**, was involved in the reaction with LiTMP in THF at –50 °C for 2 h before addition of chlorotrimethylsilane in order to intercept the lithio derivative(s). Under these conditions, the products resulting from a deprotonation next to the sulfone (**13a**, isolated in 27% yield) and the sulfonamide (**13b**, isolated in 10% yield) were both formed while starting **12** was recovered in 50% yield (Scheme 5, left and top). This result is in good agreement with the rather close pK_a values at C3 (32.2) and C5 (31.8) calculated (see computational details) for *N*,*N*-dimethyl-2-(phenylsulfonyl)ferrocenesulfonamide (**12**) (Figure 4; the pK_a values were calculated as previously[21-22]). To functionalize the C5 position, one way would be to take advantage of the iodide **14**, which was easily prepared by oxidation of **9** (Scheme 5, bottom right).

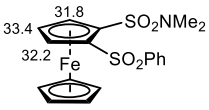


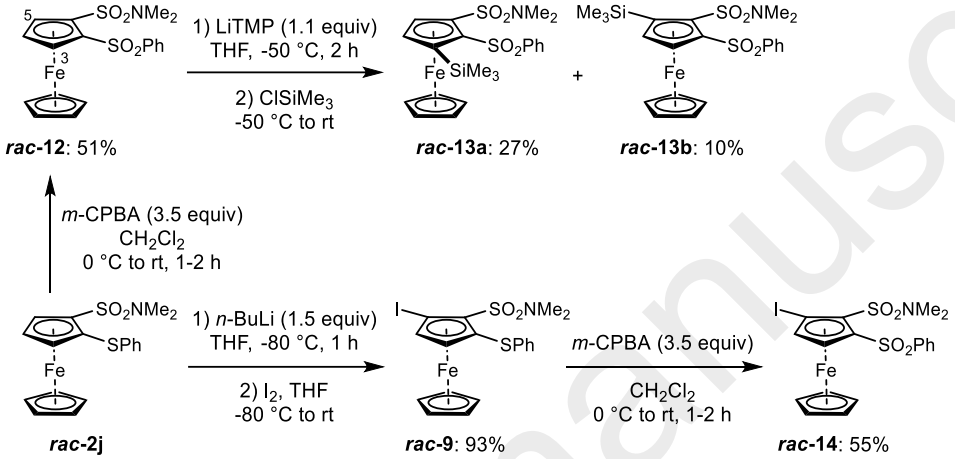
Figure 4. pK_a values of *N*,*N*-dimethyl-2-(phenylsulfonyl)ferrocenesulfonamide (**12**).

In the present study, we employed trimethylsilyl and phenylthio as protecting groups. In the course of their syntheses of ligands based on ferrocene oxazolines, Richards and co-workers have shown from 2017 that deuterium can serve as a

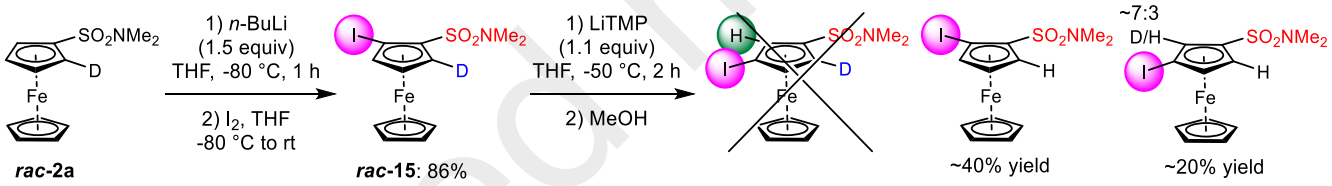
blocking group in deprotonation reactions using alkyllithiums.[33] With lithium diisopropylamide as the base, protection by deuterium has only been observed in very few examples in the pyridine series.[34] Therefore, we wondered if it could be used here to avoid metalation at the site adjacent to the stabilizing group in our 'halogen dance' reactions.

Therefore, in order to test deuterium as a protecting group (PG; see Scheme 1), we synthesized 2-deuterio-5-iodo-*N*,*N*-dimethylferrocenesulfonamide (**15**) from **2a** by deprotometalation-iodolysis using butyllithium in THF at –80 °C (Scheme 6, left). However, when submitted to the 'halogen dance' reaction conditions followed by methanolysis, **15** gave rise to a complex mixture. Unexpectedly, 2-iodo-*N*,*N*-dimethylferrocenesulfonamide (~40% yield) and 2-deuterio-*N*,*N*-dimethylferrocenesulfonamide (**2a**, ~10% yield) were identified in this mixture. In addition, 3-iodo-*N*,*N*-dimethylferrocenesulfonamide was isolated (~20% yield) without the expected deuterium at C5, but partially deuterated at C2 (~7:3 D:H ratio) (Scheme 6, right). These data allowed us imagine a putative reaction sequence given in Supporting information (see Scheme S1).

Scheme 5. Synthesis of phenylsulfonyl-substituted *N*,*N*-dimethylferrocenesulfonamides from 2j.



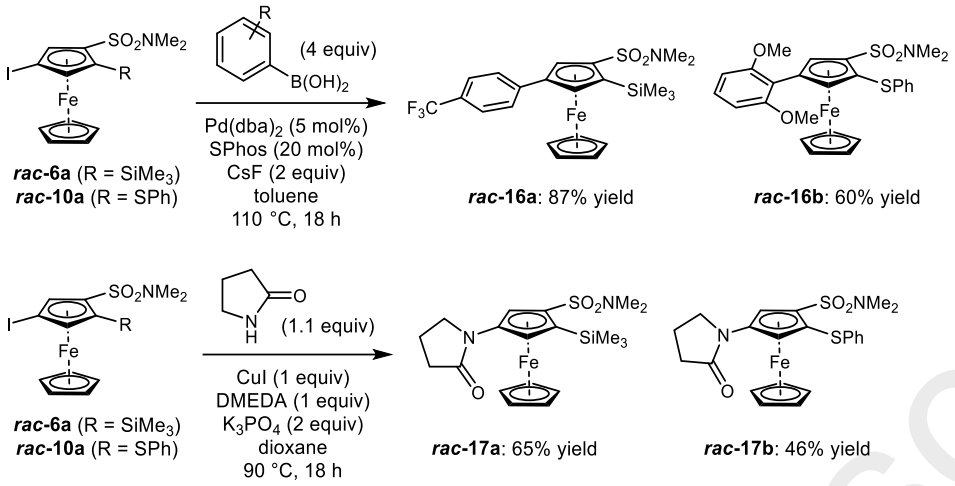
Scheme 6. Unsuccessful attempt to use deuterium as protecting group in 'halogen dance'.



Post-functionalization reactions, taking advantage of the iodine, were next considered from **6a** and **10a**. Both compounds were first engaged into Suzuki-Miyaura coupling reactions, **6a** with 4-(trifluoromethyl)phenylboronic acid, and **10a** with 2,6-dimethoxyphenylboronic acid. Under conditions previously evaluated,[22,27] which consist of the use of $Pd(dba)_2$ (dba = dibenzylideneacetone), 2-dicyclohexylphosphino-2',6'-dimethoxybiphenyl (SPhos) as a suitable ligand for electron-poor[27] or sterically hindered[35] arylboronic acids, and cesium fluoride as the base at toluene reflux overnight, the expected products **16a** and **16b** were obtained in moderate to good yields (Scheme 7, top).

We next considered the involvement of the same iodides **6a** and **10a** in a Goldberg condensation (or copper-catalyzed *N*-arylation of amides). Indeed, we recently reported that the presence of substituents onto an iodoferrocene derivative has a great influence on the reaction efficiency,[36] and we were eager to evaluate the impact of a sulfonamide group on such couplings. Therefore, we selected 2-pyrrolidinone as the coupling partner due to its high reactivity when compared with other lactams and more hindered amides.[37] In the present case, under conditions previously optimized on iodoferrocene (copper(I) iodide, *N*,*N'*-dimethylethylenediamine (DMEDA), and tripotassium phosphate as the base in dioxane at 90 °C overnight),[37] the trimethylsilyl- and phenylthio-substituted derivatives **17a** and **17b** were isolated in 65 and 46% yield, respectively (Scheme 7, bottom). However, when the more hindered iodide **9** was submitted to the same reaction conditions, the expected product was not detected; instead, deiodinated **2j** was isolated at the end together with recovered **9**.

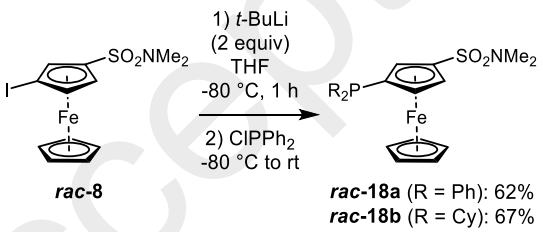
Scheme 7. Cross-coupling reactions from iodo-substituted *N*,*N*-dimethylferrocenesulfonamides 6a and 10a.



Whereas 2-[38] and 3-iodo-*N*,*N*-diisopropylferrocenecarboxamide[27] were recently found to react with carboxylic acids in Ullmann-type cross-coupling reactions (conditions: copper(I) oxide, and acetonitrile at 90 °C), our attempts to repeat these reactions with 2,4-dimethylcarboxylic acid from **6a** completely failed while, from **9**, the product was identified in the crude (moderate yield) but could not be separated.

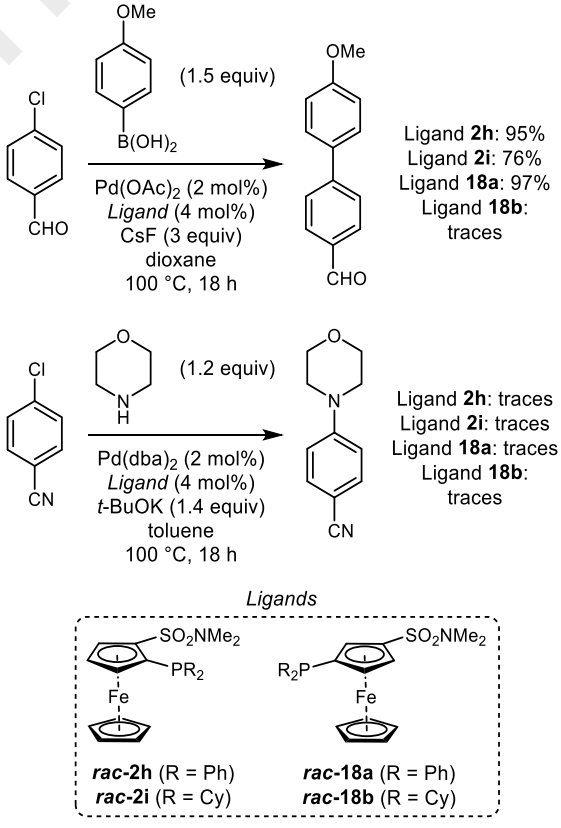
From the 2-substituted *N*,*N*-dimethylferrocenesulfonamides **2** shown in Table 1, **2h** and **2i** are possible candidates for use as ligands in metal-catalyzed reactions.[39] To study the impact of the substitution pattern in catalysis, we also prepared the corresponding 3-phosphino analogs from 3-iodo-*N*,*N*-dimethylferrocenesulfonamide (**8**) by halogen/metal exchange followed by interception with a chlorophosphine. To this end, the iodide **8** was treated by *tert*-butyllithium (2 equiv) in THF at –80 °C for 1 h, as reported previously;[27] subsequent trapping with chlorodiphenylphosphine and chlorodicyclohexylphosphine furnished the 3-phosphino *N*,*N*-dimethylferrocenesulfonamides **18a** and **18b** in 62 and 67% yield, respectively (Scheme 8).

Scheme 8. Synthesis of the phosphine ligands 18 from 8.



In order to evaluate the ability of the phosphines **2h**, **2i**, **18a** and **18b** to act as ligands in palladium-catalyzed cross-couplings, we selected two model reactions. Inspired by the group of Fang who studied the behavior of different ferrocene-based phosphines in Suzuki-Miyaura couplings between aryl chlorides and arylboronic acids,[40] we tested the four phosphines in the reaction between 4-chlorobenzaldehyde and 4-methoxyphenylboronic acid. Under the selected conditions (palladium(II) acetate as the catalyst source, cesium fluoride as the base in dioxane at 100 °C overnight), the coupled product was formed in almost quantitative yields in the presence of the ferrocenyldiphenylphosphines **2h** and **18a**. However, when the dicyclohexylferrocenylphosphines **2i** and **18b** were used, a still good yield was recorded for the former, while only traces of the expected product were detected with the latter (Scheme 9, top).

Scheme 9. Evaluation of the phosphine ligands 2h,i and 18 in palladium-catalyzed reactions.



Encouraged by these results, we turned our attention to the more challenging amination of 4-chlorobenzonitrile with morpholine. Inspired by Hartwig and co-workers who employed a sterically hindered ferrocenyldialkylphosphine in similar reactions,[41] we treated a mixture of the aryl chloride and amine with $Pd(dba)_2$ as the catalyst source, potassium *tert*-butoxide as the base in toluene at 100 °C overnight, in the presence of our phosphines **2h**, **2i**, **18a** and **18b**. However, none of the four ligands allowed the expected product to be formed satisfactorily, with only traces of the coupled product detected (Scheme 9, bottom). However, the results recorded with this second model reaction are not unexpected. Indeed, such amination reactions usually require the presence of bidentate or carbenic ligands, and only very specific monophosphinic ligands can be used.[42]

Finally, we were eager to see if quantum-chemical calculations could give clues to rationalize the results obtained for the Suzuki-Miyaura cross-coupling reactions. Therefore, we calculated atomic charges, electrostatic potential maps (see Supporting information, Table S1 and Figure S1) and molecular orbital energies for the phosphines **2h**, **2i**, **18a** and **18b**. Indeed, it is well known that for dialkylbiarylphosphines the bulky and electron-donating character of these ligands is important for stabilizing the monoligated L_1Pd intermediates, which are believed to be key species in the catalytic cycle.[35b]

At the same time, the analysis of the calculated atomic charges and electrostatic potential maps of the phosphines **2h**, **2i**, **18a** and **18b** did not give a clear understanding of why the phosphine **18b** is a worse supporting ligand in Suzuki-Miyaura coupling than **2i**. It was however shown[35c] that the HOMO energy of a phosphine ligand correlates well with the oxidative addition activation barrier height. The HOMO of the phosphines **2h**, **2i**, **18a** and **18b** is to a significant extent a lone electron pair of phosphorus atom (Figure 5). For the ligands **2h** and **18a**, the calculated HOMO energies are close, which is consistent with the similar yields of Suzuki-Miyaura reaction products in the presence of these ferrocenyldiphenylphosphines (Scheme 9, top). In the phosphine **18b**, the lone electron pair of the phosphorus atom interacts with the π-electrons of the cyclopentadienyl ring, which leads to a noticeable decrease of the HOMO energy of the ligand **18b** in comparison with **2i** (Figure 5). This might be one of the reasons to explain the lower efficiency of the phosphine **18b** in Suzuki-Miyaura cross-coupling when compared with **2i** (Scheme 9, top).

In the frame of this study, we were able to obtain crystals of the compounds **5**, **6a** and **16a**, suitable for X-ray diffraction. At the solid state, the structures of **5** and **6a** present little differences with similar C-I (2.089(5) Å for both **5** and **6a**), C-Si (1.885(6) and 1.887(6) Å for **5** and **6a**, respectively) and C-S (1.755(6) and 1.750(5) Å for **5** and **6a**, respectively) bonds (Figure 6, top). Furthermore, one methyl of the silane moiety is coplanar with the substituted cyclopentadienyl (Cp) ring for both compounds. However, one S=O bond is coplanar with the Cp ring in **5** (1.6(6) ° torsion angle C10-C6-S1-O11) while slightly bended in **6a** (15.2(6) ° torsion angle C9-C10-S1-O1). Compound **16a** features similar geometric parameters with the C-Si (1.885(2) Å) and C-S (1.756(2) Å) bonds and one methyl of the silane group almost coplanar with the Cp ring (-3.2(2) ° torsion angle C8-C7-S1-O12 (Figure 6, bottom).

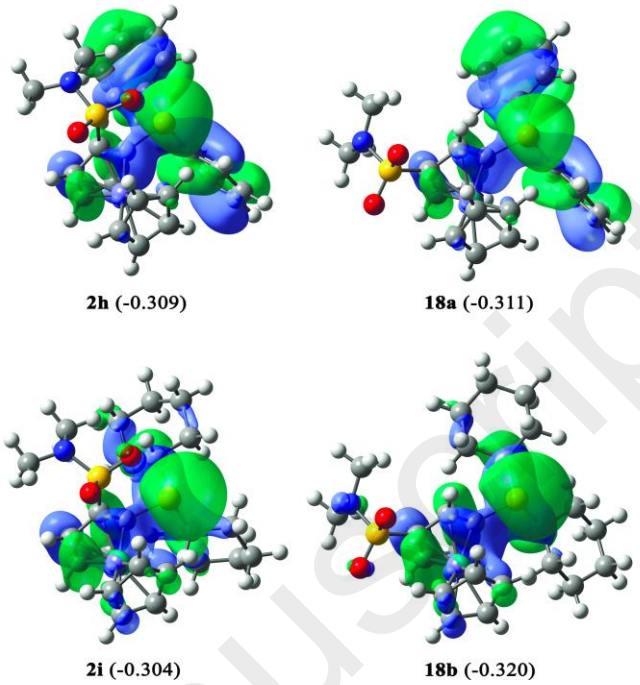


Figure 5. The calculated plots and energies (Hartree) of the HOMO of the ligands **2h**, **2i, 18a** and **18b**.

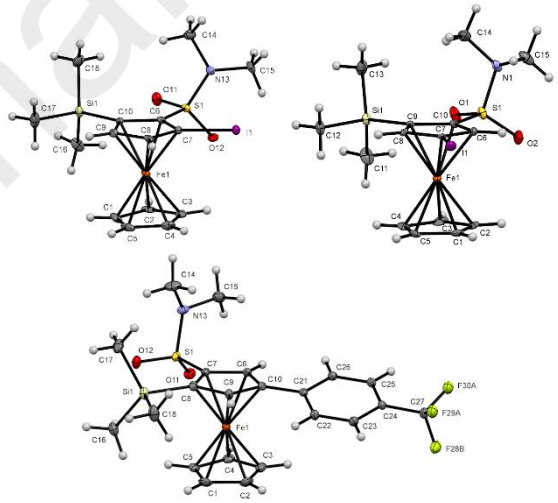


Figure 6. Molecular structures of compounds **5** (top left), **6a** (top right) and **16a** (bottom) (thermal ellipsoids shown at the 30% probability level).

Interestingly, halogen bonds were identified in both structures between the σ-hole of the iodine atom and the lone pair of one oxygen of the sulfonamide, the position of the iodine atom leading to differences in the network. Indeed, a zig-zig chain of halogen bonds is observed in **5** while the remote iodine of **6a** leads to a linear string of bonds. Both bond lengths (I···O 3.174(5) and 3.366(4) Å for **5** and **6a**, respectively) and angles (C-I···O 164.78(19) ° and 157.86(16) ° for **5** and **6a**, respectively) fall within the range of values for halogen bonds.[43] Such interactions could be relevant for the design of iodinated derivatives of ferrocene sulfonamides for applications in medicinal chemistry or catalysis.

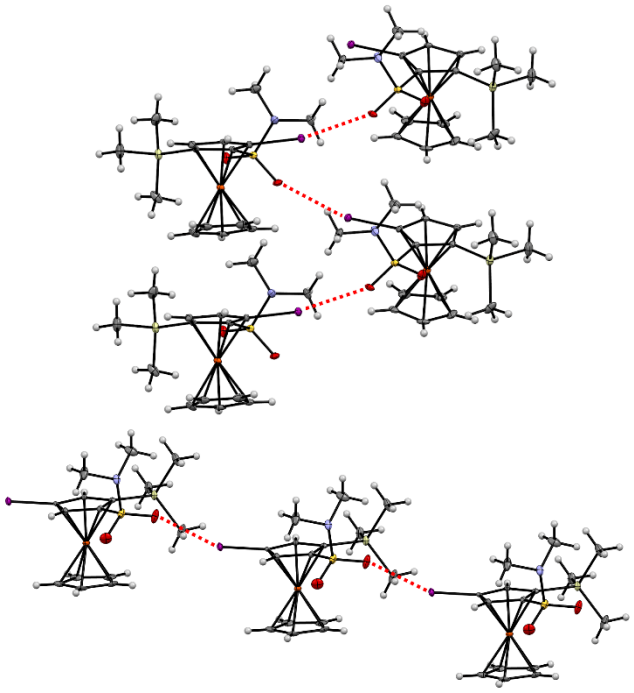


Figure 7. Halogen bond network observed for compounds **5** (top) and **6a** (bottom) (thermal ellipsoids shown at the 30% probability level).

CONCLUSION

In conclusion, from easily accessible *N*,*N*-dialkylferrocenesulfonamides, deprotometalation-trapping sequences allowed various 2-mono- and 2,5-di-substituted derivatives to be obtained efficiently. Recourse to 'halogen dance', for which the dialkylsulfonamide proved to be a powerful stabilizing group, emerged as a key step toward the synthesis of 2,4-di-, 3-mono- and 2,3,5-tri-substituted derivatives. Finally, a hetero-2,3,4,5-tetra-substituted *N*,*N*-dialkylferrocenesulfonamide was also prepared for the first time.

The development of these synthetic methodologies in the ferrocene series considerably expands the available chemical space, and paves the way to a wide range of polysubstituted ferrocenesulfonamides. Looking at the range of applications of sulfonamides, it makes little doubt that these original ferrocene derivatives will, in time, find applications in the fields of catalysis, materials science or medicinal chemistry.

EXPERIMENTAL SECTION

General Details. All the reactions were performed under an argon atmosphere by using anhydrous solvents in dried Schlenk tubes. THF was distilled on sodium-benzophenone prior to use. Dioxane and toluene were distilled on CaH_2. 2,2,6,6-Tetramethylpiperidine was distilled on CaH_2 under vacuum and stored on KOH pellets. Column chromatography separations were achieved on silica gel (40-63 µm). Thin layer chromatographies were performed on aluminum-backed plates pre-coated with silica gel (Merck, silica gel 60 F254). They were visualized by exposure to UV light. Melting points were measured on a Kofler bench. IR spectra were taken on a Perkin-Elmer Spectrum 100 spectrometer. ^{1}H and ^{13}C Nuclear Magnetic Resonance (NMR) spectra were recorded either on a Bruker Avance III spectrometer at 300 MHz and 75.4 MHz, respectively, or on a Bruker Avance III HD spectrometer at 400 MHz and 100 MHz, respectively, or on a Bruker Avance III HD spectrometer at 500 MHz and 126 MHz respectively. ^{1}H chemical shifts (δ) are given in ppm relative to the solvent residual peak and ^{13}C chemical shifts are relative to the central peak of the solvent signal.[44] The numbering used in this Experimental Section is defined in Supporting information. Although elemental analyses of the compounds **2b**, **4b**, **4d** and **10c** are outside the range viewed as establishing analytical purity, they are provided to illustrate the best values obtained to date.

N,*N*-dimethylferrocenesulfonamide (**1**)[45] and (*N*-morpholino)sulfonylferrocene (**3**)[46] were prepared according to reported procedures.

Crystallography. The X-ray diffraction data of **5** and **6a** were collected by using D8 VENTURE Bruker AXS diffractometer equipped with a (CMOS) PHOTON 100 detector. The samples were studied with Mo-Kα radiation (λ = 0.71073 Å, multilayer monochromator) at the temperature given in the product description. The structure was solved by dual-space algorithm using the *SHELXT* program,[47] and then refined with full-matrix least-square methods based on F^2 (*SHELXL*).[48] All non-hydrogen atoms were refined with anisotropic atomic displacement parameters. H atoms were finally included in their calculated positions and treated as riding on their parent atom with constrained thermal parameters. The molecular diagrams were generated by Mercury 4.0.0.

General Procedure A: Deprotolithiation of *N*,*N*-dimethylferrocenesulfonamide (1) followed by Electrophilic Trapping. Unless otherwise specified in the product description, general procedure A is as follows. *n*-BuLi (1.4 M, 1.1 mL, 1.5 mmol, 1.5 equiv) was added dropwise to a solution of *N*,*N*-dimethylferrocenesulfonamide (**1**; 293 mg, 1.0 mmol, 1.0 equiv) in THF (5 mL) at –80 °C. After 1 h at this temperature, the electrophile (1.5 mmol, 1.5 equiv; either pure or in solution, as indicated below) was added, and the reaction mixture was stirred for 15 min at –80 °C before being warmed to rt. Addition of 1 M HCl (5 mL), extraction with AcOEt (3 x 20 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel (eluent given in the product description).

2-Deuterio-*N*,*N*-dimethylferrocenesulfonamide (2a, racemic mixture). Compound **2a** was prepared from compound **1** (2.9 g, 10 mmol, 1.0 equiv) according to the procedure A by using as the electrophile D_2O (1.4 mL, 75 mmol, 7.5 equiv). It was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.52) in a quantitative yield (2.9 g) as an orange solid after column chromatography (eluent: petroleum ether-AcOEt 60:40): mp 160-161 °C; IR (ATR) 709, 824, 949, 1105, 1132, 1156, 1185, 1332, 1461, 2967, 3104 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.59 (s, 6H, NMe_2), 4.38-4.40 (m, 2H, H3 and H4), 4.41 (s, 5H, Cp), 4.59 (t, 1H, *J* = 2.0 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 38.0 ($2CH_3$, NMe_2), 69.1 (t, C, *J* = 27.9, C2, C-D), 69.2 (CH, C5), 70.6 and 70.7 (2CH, C3 and C4), 70.8 (5CH, Cp), 82.3 (C, C1, *C*-SO_2NMe_2). Anal. Calcd for $C_{12}H_{14}DFeNO_2S$ (294.17): C, 49.00; H, 4.80; N, 4.76; S, 10.90. Found: C, 48.95; H, 4.98; N, 4.54; S, 11.03.

2-(1,1-Diphenyl)hydroxymethyl-*N*,*N*-dimethylferrocenesulfonamide (2b, racemic mixture; contaminated by traces of benzhydrol). Compound **2b** was prepared according to the procedure A by using as the electrophile benzophenone (273 mg) in THF (2 mL). It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.43) in 82% yield (388 mg) as an orange solid: mp 198 °C; IR (ATR) 701, 718, 752, 817, 943, 1001, 1019, 1071, 1109, 1133, 1187, 1260, 1319, 1447, 2854, 2959, 3105, 3455 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.13 (s, 6H, NMe_2), 3.67 (dd, 1H, *J* = 2.6 and 1.8 Hz, H3), 4.35 (t, 1H, *J* = 2.6 Hz, H4), 4.52 (s, 5H, Cp), 4.78 (dd, 1H, *J* = 2.5 and 1.8 Hz, H5), 6.23 (s, 1H, OH), 7.18-7.40 (m, 8H, Ph), 7.51 (d, 2H, *J* = 7.4 Hz, Ph); ^{13}C NMR ($CDCl_3$) δ 36.0 ($2CH_3$, NMe_2), 68.1 (CH, C4), 72.1 (5CH, Cp), 73.5 (CH, C5), 75.9 (CH, C3), 77.4 (C, C-OH), 83.1 (C, C1, *C*-SO_2NMe_2), 98.3 (C, C2, *C*-C(OH)Ph_2), 127.1 and 127.6 (2CH, C4' and C4"), 127.2, 127.4, 127.7 and 127.8 (8CH,

C2', C3', C5', C6', C2", C3", C5" and C6"), 145.3 and 148.5 (2C, C1' and C1"). Anal. Calcd for $C_{25}H_{25}FeNO_3S$ (475.38): C, 63.16; H, 5.30; N, 2.95; S, 6.74. Found: C, 66.13; H, 5.35; N, 2.31; S, 5.71. Deviations outside the accepted range are observed, due to benzhydrol still present in the purified product.

2-Carboxy-*N,N*-dimethylferrocenesulfonamide (2c, racemic mixture). Compound **2c** was prepared according to the procedure A by using as the electrophile gaseous carbon dioxide (in excess). It was obtained (eluent: CH_2Cl_2-MeOH 95:5; Rf = 0.43) in 85% yield (285 mg) as an orange solid: mp 184 °C; IR (ATR) 703, 757, 834, 854, 961, 981, 1008, 1041, 1076, 1136, 1449, 1672, 1693, 2875, 2956, 3099 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.69 (s, 6H, NMe_2), 4.53 (s, 5H, Cp), 4.74 (t, 1H, *J* = 2.7 Hz, H4), 4.87 (t, 1H, *J* = 2.2 Hz, H3), 5.23 (t, 1H, *J* = 2.2 Hz, H5), 11.2 (br s, 1H, OH); ^{13}C NMR ($CDCl_3$) δ 37.8 ($2CH_3$, NMe_2), 71.1 (C, C2, *C*-CO_2H), 72.9 (CH, C4), 73.2 (5CH, Cp), 74.9 (CH, C3), 76.4 (CH, C5), 82.4 (C, C1, *C*-SO_2NMe_2), 168.9 (C, CO_2H). Anal. Calcd for $C_{13}H_{15}FeNO_4S$ (337.17): C, 46.31; H, 4.48; N, 4.15; S, 9.51. Found: C, 46.47; H, 4.65; N, 3.82; S, 9.31.

2-Formyl-*N,N*-dimethylferrocenesulfonamide (2d, racemic mixture). Compound **2d** was prepared according to the procedure A by using as the electrophile dimethylformamide (110 mg). It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.12) in 56% yield (180 mg) as a brownish-red solid: mp 130 °C; IR (ATR) 705, 771, 831, 942, 1003, 1033, 1077, 1107, 1140, 1175, 1248, 1335, 1378, 1428, 1461, 1700, 2770, 3113 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.63 (s, 6H, NMe_2), 4.51 (s, 5H, Cp), 4.80 (t, 1H, *J* = 2.7 Hz, H4), 4.94 (dd, 1H, *J* = 2.6 and 1.7 Hz, H5), 5.11 (dd, 1H, *J* = 2.6 and 1.7 Hz, H3), 10.39 (s, 1H, CHO); ^{13}C NMR ($CDCl_3$) δ 37.8 ($2CH_3$, NMe_2), 70.9 (CH, C3), 72.6 (5CH, Cp), 73.6 (CH, C4), 75.3 (CH, C5), 78.3 (C, C2, *C*-CHO), 84.8 (C, C1, *C*-SO_2NMe_2), 193.2 (C, CHO). Anal. Calcd for $C_{13}H_{15}FeNO_3S$ (321.17): C, 48.62; H, 4.71; N, 4.36; S, 9.98. Found: C, 48.53; H, 4.32; N, 4.60; S, 10.06.

2-(Dimethylaminomethyl)-*N,N*-dimethylferrocenesulfonamide (2e, racemic mixture). Compound **2e** was prepared according to the procedure A by using as the electrophile *N,N*-dimethylmethyleneiminium iodide (280 mg), but with the following change. After warming to rt, methanol (0.2 mL) was added before evaporation to dryness. The product was obtained (eluent: AcOEt-Et_3N 98:2; Rf = 0.58) in 66% yield (232 mg) as a brownish-yellow solid: mp 118 °C; IR (ATR) 714, 747, 763, 785, 819, 843, 943, 954, 1002, 1026, 1045, 1106, 1145, 1174, 1257, 1337, 1378, 1419, 1469, 1567, 1630, 2770, 2951, 3098 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.17 (s, 6H, CH_2NMe_2), 2.69 (s, 6H, SO_2NMe_2), 2.96 (d, 1H, *J* = 13.0 Hz, C*H*H), 3.92 (d, 1H, *J* = 13.0 Hz, CH*H*), 4.33 (s, 5H, Cp), 4.32-4.35 (m, 1H, H4), 4.38 (t, 1H, *J* = 1.8 Hz, H3), 4.57 (t, 1H, *J* = 1.7 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 37.9 ($2CH_3$, SO_2NMe_2), 45.4 ($2CH_3$, CH_2NMe_2), 56.9 (CH_2), 68.8 (CH, C4), 71.1 (CH, C5), 71.5 (5CH, Cp), 73.5 (CH, C3), 82.7 (C, C1, *C*-SO_2NMe_2), 85.8 (C, C2, *C*-CH_2NMe_2). Anal. Calcd for $C_{15}H_{22}FeN_2O_2S$ (350.26): C, 51.44; H, 6.33; N, 8.00; S, 9.15. Found: C, 51.15; H, 6.03; N, 7.99; S, 9.46.

***N,N*-dimethyl-2-(2-pyridyl)ferrocenesulfonamide (2f, racemic mixture).** Compound **2f** was prepared according to the procedure A, but with the following changes. After deprotometalation, $ZnCl_2$·TMEDA[49] (303 mg, 1.2 mmol, 1.2 equiv) was added at –80 °C and the reaction mixture was warmed to rt. After addition of 2-chloropyridine (0.11 mL, 1.2 mmol, 1.2 equiv), $PdCl_2$ (14 mg, 80 μmol, 80 mequiv) and 1,1'-bis(diphenylphosphino)ferrocene (44 mg, 80 μmol, 80 mequiv), the reaction mixture was heated at reflux overnight before cooling to rt and addition of water (5 mL). The product was obtained (eluent: petroleum ether-AcOEt 60:40; Rf = 0.23) in 68% yield (251 mg) as an brownish-yellow solid: mp 158 °C; IR (ATR) 716, 746, 785, 820, 843, 943, 955, 995, 1026, 1046, 1106, 1124, 1145, 1175, 1255, 1285, 1337, 1378, 1419, 1470, 1482, 1566, 1591, 1631, 2835, 2952, 3006, 3094 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.42 (s, 6H, NMe_2), 4.40 (s, 5H, Cp), 4.58 (t, 1H, *J* = 2.6 Hz, H4), 4.82 (dd, 1H, *J* = 2.6 and 1.8 Hz, H5), 4.93 (dd, 1H, *J* = 2.6 and 1.8 Hz, H3), 7.18 (ddd, 1H, *J* = 7.5, 4.9 and 1.1 Hz, H5'), 7.70 (td, 1H, *J* = 7.8 and 1.9 Hz, H4'), 8.32 (d, 1H, *J* = 8.0 Hz, H3'), 8.48 (ddd, 1H, *J* = 4.9, 1.7 and 0.9 Hz, H6'); ^{13}C NMR ($CDCl_3$) δ 37.7 ($2CH_3$, NMe_2), 70.1 (CH, C4), 72.2 (5CH, Cp), 73.0 (CH, C5), 73.3 (CH, C3), 83.7 (C, C1, *C*-SO_2NMe_2), 86.9 (C, C2, *C*-2-pyridyl), 122.1 (CH, C5'), 126.6 (CH, C3'), 135.8 (CH, C4'), 148.6 (CH, C6'), 155.9 (C, C2'). Anal. Calcd for $C_{17}H_{18}FeN_2O_2S$ (370.25): C, 55.15; H, 4.90; N, 7.57; S, 8.66. Found: C, 55.19; H, 4.38; N, 7.21; S, 8.87.

***N,N*-dimethyl-2-(trimethylsilyl)ferrocenesulfonamide (2g, racemic mixture).** Compound **2g** was prepared according to the procedure A by using as the electrophile chlorotrimethylsilane (0.19 mL). It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.35) in 82% yield (301 mg) as an orange solid: mp 73 °C; IR (ATR) 664, 702, 758, 816, 829, 948, 1006, 1045, 1071, 1108, 1185, 1241, 1264, 1280, 1333, 1412, 1454, 2901, 2961, 3419 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.35 (s, 9H, $SiMe_3$), 2.64 (s, 6H, NMe_2), 4.30 (dd, 1H, *J* = 2.4 and 1.2 Hz, H3), 4.38 (s, 5H, Cp), 4.53 (t, 1H, *J* = 2.3 Hz, H4), 4.78 (dd, 1H, *J* = 2.4 and 1.2 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 1.1 ($3CH_3$, $SiMe_3$), 37.9 ($2CH_3$, NMe_2), 70.9 (5CH, Cp), 72.5 (CH, C4), 73.0 (CH, C5), 73.7 (C, C2, *C*-$SiMe_3$), 77.6 (CH, C3), 89.2 (C, C1, *C*-SO_2NMe_2). Anal. Calcd for $C_{15}H_{23}FeNO_2SSi$ (365.34): C, 49.31; H, 6.35; N, 3.83; S, 8.78. Found: C, 48.81; H, 6.26; N, 3.69; S, 8.55.

2-(Diphenylphosphino)-*N,N*-dimethylferrocenesulfonamide (2h, racemic mixture). Compound **2h** was prepared according to the procedure A, but with the following changes. *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv) and chlorodiphenylphosphine (0.20 mL, 1.1 mmol, 1.1 equiv) were used. After warming to rt, methanol (0.2 mL) was added before evaporation to dryness. The product was obtained (eluent: petroleum ether-AcOEt 60:40; Rf = 0.82) in 49% yield (234 mg) as a yellow solid: mp 228 °C; IR (ATR) 743, 754, 825, 955, 1002, 1034, 1106, 1134, 1152, 1190, 1329, 1473, 2932 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.30 (s, 6H, NMe_2), 3.93 (s, 1H, H3), 4.32 (s, 5H, Cp), 4.51 (s, 1H, H4), 4.95 (s, 1H, H5), 7.22-7.25 (m, 5H, Ph), 7.38 (br s, 3H, Ph), 7.53-7.56 (m, 2H, Ph); ^{13}C NMR ($CDCl_3$) δ 36.7 ($2CH_3$, NMe_2), 71.2 (CH, C4), 72.0 (5CH, Cp), 75.0 (d, CH, *J* = 1.7 Hz, C5), 75.1 (d, CH, *J* = 4.7 Hz, C3), 77.3 (d, C, *J* not seen due to the presence of the $CDCl_3$ signal, C2, C-P), 90.6 (d, C, *J* = 22.6 Hz, C1, *C*-SO_2NMe_2), 128.3, 128.3, 128.4, 128.4, 128.6 and 129.4 (6CH, C3', C4', C5'), 133.1, 133.3, 135.0 and 135.2 (4CH, C2' and C6'), 137.2 (d, C, *J* = 12.7 Hz, C1'), 139.3 (d, C, *J* = 12.5 Hz, C1'); ^{31}P NMR ($CDCl_3$) δ -24.5. Anal. Calcd for $C_{24}H_{24}FeNO_2PS$ (477.34): C, 60.39; H, 5.07; N, 2.93; S, 6.72. Found: C, 60.13; H, 5.76; N, 3.18; S, 6.64.

2-(Dicyclohexylphosphino)-*N,N*-dimethylferrocenesulfonamide (2i, racemic mixture). Compound **2i** was prepared according to the procedure A, but with the following changes. *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv) and chlorodicyclohexylphosphine (0.24 mL, 1.1 mmol, 1.1 equiv) were used. After warming to rt, methanol (0.2 mL) was added before evaporation to dryness. The product was obtained (eluent: petroleum ether-AcOEt 60:40; Rf = 0.81) in 30% yield (144 mg) as an orange solid: mp 248 °C; IR (ATR) 705, 740, 820, 952, 1001, 1138, 1188, 1337, 1449, 2846, 2925 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.00-1.20 (m, 5H, Cy), 1.25-1.39 (m, 3H, Cy), 1.42-1.54 (m, 3H, Cy), 1.62-1.77 (m, 6H, Cy), 1.85-1.89 (m, 2H, Cy), 2.00-2.10 (m, 2H, Cy), 2.31-2.33 (m, 1H, Cy), 2.75 (s, 6H, NMe_2), 4.34 (s, 1H, H3), 4.41 (s, 5H, Cp), 4.52 (t, 1H, *J* = 2.4 Hz, H4), 4.87 (dt, 1H, *J* = 2.5 and 1.2 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 26.6 (d, CH_2, *J* = 4.6 Hz, Cy), 27.4 (CH_2, Cy), 27.4 (d, CH_2, *J* = 4.6 Hz, Cy), 27.5 (CH_2, Cy), 27.9 (d, CH_2, *J* = 2.1 Hz, Cy), 28.0 (d, CH_2, *J* = 4.7 Hz, Cy), 29.3 (d, CH_2, *J* = 6.2 Hz, Cy), 29.6 (d, CH_2, *J* = 10.6 Hz, Cy), 31.6 (d, CH_2, *J* = 17.0 Hz, Cy), 32.7 (d, CH_2, *J* = 22.1 Hz, Cy), 36.2 (d, CH, *J* = 15.5 Hz, C1'), 36.5 (d, CH, *J* = 14.8 Hz, C1'), 37.4 (d, $2CH_3$, *J* = 3.4 Hz, NMe_2), 70.5 (CH, C4), 72.0 (5CH, Cp), 73.5 (d, CH, *J* = 2.0 Hz, C5), 74.8 (d, CH, *J* = 4.3 Hz, C3), 81.1 (d, C, *J* = 33.5 Hz, C2, C-P), 89.0 (d, C, *J* = 22.8 Hz, C1, *C*-SO_2NMe_2); ^{31}P NMR ($CDCl_3$) δ -13.5. Anal. Calcd for $C_{24}H_{36}FeNO_2PS$ (489.44): C, 58.90; H, 7.41; N, 2.86; S, 6.55. Found: C, 58.95; H, 7.67; N, 2.70; S, 6.13.

***N,N*-dimethyl-2-(phenylthio)ferrocenesulfonamide (2j, racemic mixture).** Compound **2j** was prepared according to the procedure A

by using as the electrophile phenyl disulphide (327 mg) in THF (2 mL). It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.51) in 82% yield (330 mg) as a yellow solid: mp 146 °C; IR (ATR) 715, 745, 818, 829, 854, 947, 958, 1003, 1032, 1052, 1071, 1107, 1142, 1164, 1195, 1264, 1290, 1333, 1361, 1380, 1412, 1456, 1481, 1581, 1671, 2847, 3096 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.50 (s, 6H, NMe_2), 4.49 (s, 5H, Cp), 4.54 (t, 1H, *J* = 2.5 Hz, H4), 4.61 (s, 1H, H3), 4.86 (s, 1H, H5), 7.06-7.11 (m, 3H, H2', H4' and H6'), 7.20 (t, 2H, *J* = 7.6 Hz, H3' and H5'); ^{13}C NMR ($CDCl_3$) δ 37.3 ($2CH_3$, NMe_2), 70.8 (CH, C4), 72.8 (5CH, Cp), 73.2 (CH, C5), 77.6 (C, C2, *C*-SPh), 79.0 (CH, C3), 85.9 (C, C1, *C*-SO_2NMe_2), 125.5 (CH, C4'), 126.6 (2CH, C2' and C6'), 128.9 (2CH, C3' and C5'), 139.7 (C, C1'). Anal. Calcd for $C_{18}H_{19}FeNO_2S_2$ (401.32): C, 53.87; H, 4.77; N, 3.49; S, 15.98. Found: C, 54.06; H, 4.92; N, 3.33; S, 15.49.

General Procedure B: Deprotolithiation of (*N*-morpholino)sulfonylferrocene (3) followed by Electrophilic Trapping. Unless otherwise specified in the product description, general procedure B is as follows. *n*-BuLi (1.4 M, 1.1 mL, 1.5 mmol, 1.5 equiv) was added dropwise to a solution of (*N*-morpholino)sulfonylferrocene (**3**; 335 mg, 1.0 mmol, 1.0 equiv) in THF (5 mL) at –80 °C. After 1 h at this temperature, the electrophile (1.5 mmol, 1.5 equiv; either pure or in solution, as indicated below) was added, and the reaction mixture was stirred for 15 min at –80 °C before being warmed to rt. Addition of 1 M HCl (5 mL), extraction with AcOEt (3 x 20 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel (eluent given in the product description).

1-Deuterio-2-(*N*-morpholino)sulfonylferrocene (4a, racemic mixture). Compound **4a** was prepared according to the procedure B by using as the electrophile D_2O (0.15 mL, 7.5 mmol, 7.5 equiv). It was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.13) in 84% yield (284 mg) as a yellow solid: mp 182 °C; IR (ATR) 725, 767, 780, 818, 942, 1001, 1020, 1072, 1111, 1140, 1176, 1191, 1219, 1260, 1300, 1328, 1341, 1395, 1421, 1449, 1508, 1591, 1670, 2857, 2902, 2960, 3091, 3517 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.91 (t, 4H, *J* = 4.25 Hz, NCH_2), 3.70 (t, 4H, *J* = 4.6 Hz, OCH_2), 4.42 (s, 7H, H4, H5 and Cp), 4.56 (br s, 1H, H3); ^{13}C NMR ($CDCl_3$) δ 46.0 ($2CH_2$, NCH_2), 66.1 ($2CH_2$, OCH_2), 69.1 (td, C, *J* = 27.9 and 3.3 Hz, C1, C-D), 69.2 (d, CH, *J* = 3.5 Hz, C3), 70.9 (5CH, Cp), 70.9-71.0 (m, 2CH, C4 and C5), 82.1 (t, C, *J* = 8.9 Hz, C2, *C*-SO_2-*N*-morpholino). Anal. Calcd for $C_{14}H_{16}DFeNO_3S$ (336.21): C, 50.01; H, 4.80; N, 4.17; S, 9.54. Found: C, 49.62; H, 5.02; N, 3.96; S, 9.65.

1-(1,1-Diphenyl)hydroxymethyl-2-(*N*-morpholino)sulfonylferrocene (4b, racemic mixture). Compound **4b** was prepared according to the procedure B by using as the electrophile benzophenone (255 mg, 1.4 mmol, 1.4 equiv) in THF (2 mL) It was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.24) in 95% yield (492 mg) as a yellow solid: mp 245 °C; IR (ATR) 655, 702, 718, 755, 816, 945, 1002, 1046, 1077, 1110, 1147, 1188, 1220, 1246, 1261, 1300, 1318, 1338, 1411, 1453, 1487, 1730, 2860, 2902, 3094, 3420 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.43 (ddd, 2H, *J* = 12.2, 6.4 and 3.0 Hz, NCH_2), 2.54 (ddd, 2H, *J* = 12.0, 6.3 and 3.0 Hz, NCH_2), 3.28 (ddd, 2H, *J* = 11.5, 6.4 and 3.1 Hz, OCH_2), 3.39 (ddd, 2H, *J* = 11.4, 6.5 and 3.1 Hz, OCH_2), 3.75 (dd, 1H, *J* = 2.6 and 1.7 Hz, H5), 4.38 (t, 1H, *J* = 2.7 Hz, H4), 4.53 (s, 5H, Cp), 4.70 (dd, 1H, *J* = 2.6 and 1.7 Hz, H3), 6.22 (s, 1H, OH), 7.19-7.34 (m, 8H, Ph), 7.55 (d, 2H, *J* = 7.4 Hz, Ph); ^{13}C NMR ($CDCl_3$) δ 44.8 ($2CH_2$, NCH_2), 66.2 ($2CH_2$, OCH_2), 68.6 (CH, C4), 72.3 (5CH, Cp), 72.8 (CH, C3), 75.9 (CH, C5), 77.4 (C, C-OH), 82.1 (C, C2, *C*-SO_2-*N*-morpholino), 99.4 (C, C1, *C*-$C(OH)Ph_2$), 127.2 (2CH, C4' and C4"), 127.5, 127.6, 127.8 and 128.0 (4CH, C2', C3', C5', C6', C2", C3", C5" and C6"), 145.0 and 148.3 (2C, C1' and C1"). Anal. Calcd for $C_{27}H_{27}FeNO_4S$ (517.42): C, 62.67; H, 5.26; N, 2.71; S, 6.20. Found: C, 51.56; H, 5.09; N, 2.54; S, 6.17.

1-(*N*-morpholino)sulfonyl-2-[1-(3,4,5-trimethoxyphenyl)]hydroxymethylferrocene (4c1, major diastereoisomer, racemic mixture). Compound **4c1** was prepared according to the procedure B by using as the electrophile 3,4,5-trimethoxybenzaldehyde (294 mg) in THF (3 mL). It was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.05) in 40% yield (214 mg) as an orange solid: mp 182 °C; IR (ATR) 701, 724, 751, 829, 941, 1001, 1042, 1070, 1084, 1122, 1142, 1174, 1233, 1261, 1326, 1396, 1421, 1453, 1505, 1591, 2859, 3000, 3091, 3511 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.75-2.83 (m, 4H, NCH_2), 3.51-3.60 (m, 5H, OCH_2 and OH), 3.82 (s, 3H, OMe), 3.84 (s, 6H, OMe), 4.32 (t, 1H, *J* = 2.0 Hz, H3), 4.41 (t, 1H, *J* = 2.6 Hz, H4), 4.53 (s, 5H, Cp), 4.59 (dd, 1H, *J* = 2.2 and 1.8 Hz, H5), 5.75 (d, 1H, *J* = 2.1 Hz, C*H*(OH)), 6.64 (s, 2H, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 45.6 ($2CH_2$, NCH_2), 56.3 ($2CH_3$, OMe), 61.0 (CH_3, OMe), 66.1 ($2CH_2$, OCH_2), 69.2 (CH, C4), 70.1 (CH, CH(OH)), 70.9 (CH, C5), 71.7 (5CH, Cp), 71.9 (CH, C3), 81.4 (C, C1, *C*-SO_2-*N*-morpholino), 94.3 (C, C2, *C*-CH(OH)Ar), 104.8 (2CH, C2' and C6'), 137.6 (C, C4', *C*-OMe), 137.9 (C, C1', *C*-CH(OH)Fc), 153.3 (2C, C3' and C5', *C*-OMe). Anal. Calcd for $C_{24}H_{29}FeNO_7S$ (531.40): C, 54.25; H, 5.50; N, 2.64; S, 6.03. Found: C, 54.16; H, 5.61; N, 2.61; S, 5.47.

1-(*N*-morpholino)sulfonyl-2-[1-(3,4,5-trimethoxyphenyl)]hydroxymethylferrocene (4c2, minor diastereoisomer, racemic mixture). Compound **4c2** was similarly prepared and obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.12) in 39% yield (206 mg) as an orange solid: mp 178 °C; IR (ATR) 701, 727, 766, 818, 829, 845, 927, 941, 1000, 1021, 1041, 1069, 1087, 1112, 1130, 1142, 1176, 1243, 1263, 1301, 1327, 1396, 1421, 1451, 1508, 1591, 2860, 2903, 2998, 3090, 3517 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.80-2.84 and 2.87-2.91 (m, 4H, NCH_2), 3.52-3.56 and 3.57-3.62 (m, 4H, OCH_2), 3.84 (s, 3H, OMe), 3.85 (s, 6H, OMe), 3.98 (d, 1H, *J* = 6.7 Hz, OH), 4.33 (t, 1H, *J* = 1.9 Hz, H3), 4.41 (s, 5H, Cp), 4.45 (t, 1H, *J* = 2.6 Hz, H4), 4.64 (t, 1H, *J* = 1.9 Hz, H5), 5.77 (d, 1H, *J* = 6.7 Hz, C*H*(OH)), 6.71 (s, 2H, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 45.6 ($2CH_2$, NCH_2), 56.4 ($2CH_3$, OMe), 61.1 (CH_3, OMe), 66.2 ($2CH_2$, OCH_2), 69.5 (CH, C4), 70.9 (CH, CH(OH)), 71.4 (CH, C5), 72.0 (5CH, Cp), 72.8 (CH, C3), 81.4 (C, C1, *C*-SO_2-*N*-morpholino), 92.5 (C, C2, *C*-CH(OH)Ar), 103.9 (2CH, C2' and C6'), 137.5 (C, C4', *C*-OMe), 138.9 (C, C1', *C*-CH(OH)Fc), 153.1 (2C, C3' and C5', *C*-OMe). Anal. Calcd for $C_{24}H_{29}FeNO_7S$ (531.40): C, 54.25; H, 5.50; N, 2.64; S, 6.03. Found: C, 53.43; H, 5.40; N, 2.50; S, 6.07.

1-Iodo-2-(*N*-morpholino)sulfonylferrocene (4d, racemic mixture). Compound **4d** was prepared according to the procedure B, but with the following changes. *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv) and iodine (279 mg, 1.1 mmol, 1.1 equiv) in THF (3 mL) were used. After warming to rt, a saturated $Na_2S_2O_3$ aqueous solution (5 mL) was added. The product was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.13) in 63% yield (288 mg) as an orange solid: mp 203 °C; IR (ATR) 702, 718, 755, 825, 939, 1000, 1048, 1031, 1070, 1108, 1141, 1163, 1222, 1264, 1319, 1392, 1410, 1447, 1488, 1733, 2864, 2961, 3096, 3419 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.08 (t, 4H, *J* = 4.7 Hz, NCH_2), 3.66-3.74 (m, 4H, OCH_2), 4.43 (s, 5H, Cp), 4.47 (t, 1H, *J* = 2.6 Hz, H4), 4.64 (dd, 1H, *J* = 2.4 and 1.4 Hz, H5), 4.68 (dd, 1H, *J* = 2.4 and 1.5 Hz, H3); ^{13}C NMR ($CDCl_3$) δ 37.2 (C, C1, C-I), 46.4 ($2CH_2$, NCH_2), 66.3 ($2CH_2$, OCH_2), 70.5 (CH, C5), 72.1 (CH, C4), 74.0 (5CH, Cp), 79.8 (CH, C3), 84.8 (C, C2, *C*-SO_2-*N*-morpholino). Anal. Calcd for $C_{14}H_{16}FeINO_3S$ (461.10): C, 36.47; H, 3.50; N, 3.04; S, 6.95. Found: C, 37.23; H, 3.58; N, 3.07; S, 7.33.

1-Bromo-2-(*N*-morpholino)sulfonylferrocene (4e, racemic mixture). Compound **4e** was prepared according to the procedure B by using as the electrophile 1,2-dibromoethane (0.39 g). It was obtained (eluent: petroleum ether-AcOEt 95:5; Rf = 0.60) in 55% yield (228 mg) as a yellow solid: mp 208 °C; IR (ATR) 728, 746, 832, 856, 932, 945, 963, 1003, 1028, 1070, 1108, 1150, 1200, 1259, 1295, 1342, 1396, 1413, 1455, 1477, 1583, 1708, 2867, 2901, 3094 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.07 (t, 4H, *J* = 4.7 Hz, NCH_2), 3.65-3.76 (m, 4H, OCH_2), 4.39 (t, 1H, *J* = 2.6 Hz, H4), 4.47 (s, 5H, Cp), 4.58 (dd, 1H, *J* = 2.6 and 1.4 Hz, H3), 4.66 (dd, 1H, *J* = 2.4 and 1.2 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 46.2 ($2CH_2$, NCH_2), 66.3 ($2CH_2$, OCH_2), 69.3 (CH, C4),

69.8 (CH, C3), 73.6 (5CH, Cp), 74.6 (CH, C5), 76.0 (C, C1, C-Br), 82.4 (C, C2, *C*-SO_2-*N*-morpholino). Anal. Calcd for $C_{14}H_{16}BrFeNO_3S$ (414.10): C, 40.61; H, 3.89; N, 3.38; S, 7.74. Found: C, 40.61; H, 3.86; N, 3.32; S, 7.98.

1-(*N*-morpholino)sulfonyl-2-(trimethylsilyl)ferrocene (4f, racemic mixture). Compound **4f** was prepared according to the procedure B, but with the following changes. *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv) and chlorotrimethylsilane (0.15 mL, 1.1 mmol, 1.1 equiv) were used. The product was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.35) in 82% yield (335 mg) as a yellow solid: mp 124 °C; IR (ATR) 657, 718, 755, 819, 833, 855, 895, 945, 959, 1002, 1018, 1046, 1077, 1113, 1149, 1187, 1218, 1246, 1259, 1301, 1340, 1412, 1452, 1719, 2860, 2902, 2960, 3091 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.35 (s, 9H, $SiMe_3$), 2.99 (dd, 4H, *J* = 5.8 and 3.5 Hz, NCH_2), 3.68 (t, 4H, *J* = 4.7 Hz, OCH_2), 4.32 (s, 1H, H3), 4.39 (s, 5H, Cp), 4.56 (t, 1H, *J* = 2.4 Hz, H4), 4.76 (s, 1H, H5); ^{13}C NMR ($CDCl_3$) δ 1.2 ($3CH_3$, $SiMe_3$), 46.0 ($2CH_2$, NCH_2), 66.3 ($2CH_2$, OCH_2), 71.0 (5CH, Cp), 72.9 (CH, C4), 73.2 (CH, C5), 73.8 (C, C2, *C*-$SiMe_3$), 78.0 (CH, C3), 88.4 (C, C1, *C*-SO_2-*N*-morpholino). Anal. Calcd for $C_{17}H_{25}FeNO_3SSi$ (407.38): C, 50.12; H, 6.19; N, 3.44; S, 7.87. Found: C, 50.18; H, 6.11; N, 3.33; S, 7.93.

1-(*N*-morpholino)sulfonyl-2-(tributylstannyl)ferrocene (4g, racemic mixture). Compound **4g** was prepared according to the procedure B by using as the electrophile chlorotributylstannane (0.41 mL). It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.76) in 85% yield (530 mg) as an orange oil: IR (ATR) 721, 744, 820, 852, 945, 1003, 1033, 1073, 1115, 1143, 1163, 1189, 1260, 1295, 1339, 1377, 1413, 1455, 1518, 1671, 2853, 2919, 2955, 3095 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.92 (t, 9H, *J* = 7.3 Hz, Me), 1.00-1.25 (m, 6H, $SnCH_2$), 1.36 (sext, 6H, *J* = 7.2 Hz, C*H*$_2$Me), 1.49-1.64 (m, 6H, $SnCH_2CH_2$), 2.87-3.00 (m, 4H, NCH_2), 3.62-3.74 (m, 4H, OCH_2), 4.23 (dd, 1H, *J* = 2.3 and 1.1 Hz, H3), 4.34 (s, 5H, Cp), 4.58 (t, 1H, *J* = 2.3 Hz, H4), 4.72 (dd, 1H, *J* = 2.1 and 1.2 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 11.7 ($3CH_2$, $SnCH_2$), 13.9 ($3CH_3$, Me), 27.7 ($3CH_2$, CH_2Me), 29.4 ($3CH_2$, $SnCH_2CH_2$), 45.9 ($2CH_2$, NCH_2), 66.3 ($2CH_2$, OCH_2), 70.7 (5CH, Cp), 71.1 (CH, C5), 72.7 (C, C2, *C*-$SnBu_3$), 73.9 (CH, C4), 77.7 (CH, C3), 88.4 (C, C1, *C*-SO_2-*N*-morpholino). Anal. Calcd for $C_{26}H_{43}FeNO_3SSn$ (624.25): C, 50.03; H, 6.94; N, 2.24; S, 5.14. Found: C, 50.31; H, 7.16; N, 2.41; S, 4.92.

2-Iodo-*N*,*N*-dimethyl-5-(trimethylsilyl)ferrocenesulfonamide (5, racemic mixture). Compound **5** was prepared as follows. *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv) was added dropwise to a solution of *N*,*N*-dimethylferrocenesulfonamide (**1**; 293 mg, 1.0 mmol, 1.0 equiv) in THF (4 mL) at –80 °C. After 1 h at this temperature, chlorotrimethylsilane (0.14 mL, 1.1 mmol, 1.1 equiv) was added, and the reaction mixture was stirred for 15 min at –80 °C and then warmed to rt. After 1 h, the reaction mixture was cooled to –80 °C before addition of *n*-BuLi (1.4 M, 1.1 mL, 1.5 mmol, 1.5 equiv) and, 1 h later, iodine (381 mg) in THF (3 mL). After warming to rt, a saturated $Na_2S_2O_3$ aqueous solution (5 mL) was added. The product was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.94) in 94% yield (462 mg) as an orange solid: mp 125 °C; IR (ATR) 711, 739, 757, 827, 948, 982, 1002, 1024, 1068, 1109, 1144, 1201, 1241, 1256, 1328, 1378, 1413, 1454, 1477, 1482, 2898, 3098 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.34 (s, 9H, $SiMe_3$), 2.76 (s, 6H, NMe_2), 4.37 (d, 1H, *J* = 2.4 Hz, H4), 4.40 (s, 5H, Cp), 4.80 (d, 1H, *J* = 2.4 Hz, H3); ^{13}C NMR ($CDCl_3$) δ 1.1 ($3CH_3$, $SiMe_3$), 37.4 ($2CH_3$, NMe_2), 41.5 (C, C2, C-I), 74.0 (5CH, Cp), 76.6 (C, C5, *C*-$SiMe_3$), 78.4 (CH, C4), 81.8 (CH, C3), 91.8 (C, C1, *C*-SO_2NMe_2). Anal. Calcd for $C_{15}H_{22}FeINO_2SSi$ (491.24): C, 36.68; H, 4.51; N, 2.85; S, 6.53. Found: C, 37.61; H, 4.59; N, 2.76; S, 6.72. **Crystal data for 5**. $C_{15}H_{22}FeINO_2SSi$, *M* = 491.23, *T* = 150 K; monoclinic *P* $2_1/c$ (I.T.#14), *a* = 8.1003(8), *b* = 6.8803(8), *c* = 33.223(4) Å, *β* = 92.927(3) °, *V* = 1849.2(3) Å^3, *Z* = 4, *d* = 1.764 g.cm^{-3}, *μ* = 2.668 mm^{-1}. A final refinement on F^2 with 4141 unique intensities and 204 parameters converged at ω$R(F^2)$ = 0.1210 ($R(F)$ = 0.0482) for 3792 observed reflections with $I > 2\sigma(I)$. CCDC 2055869.

General Procedure C: Halogen Migration from 2-Iodo-*N*,*N*-dimethyl-5-(trimethylsilyl)ferrocenesulfonamide (5) followed by Electrophilic Trapping. Unless otherwise specified in the product description, general procedure C is as follows. To a stirred, cooled (–15 °C) solution of 2,2,6,6-tetramethylpiperidine (0.19 mL, 1.1 mmol, 1.1 equiv) in THF (2 mL) was added *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv). The mixture was stirred for 5 min at 0 °C and then for 2 min at –50 °C before introduction of 2-iodo-*N*,*N*-dimethyl-5-(trimethylsilyl)ferrocenesulfonamide (**5**; 491 mg, 1.0 mmol, 1.0 equiv) in THF (3 mL) at –50 °C. After 2 h at this temperature, the electrophile (1.1 mmol, 1.1 equiv, if not otherwise specified in the product description) was added, and the reaction mixture was warmed to rt before addition of water (20 mL). Extraction with AcOEt (3 x 20 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel (eluent given in the product description).

4-Iodo-*N*,*N*-dimethyl-2-(trimethylsilyl)ferrocenesulfonamide (6a, racemic mixture). Compound **6a** was prepared according to the procedure C by using as the electrophile methanol in excess (0.5 mL). It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.83) in 75% yield (368 mg) as an orange solid: mp 128 °C; IR (ATR) 712, 730, 759, 827, 885, 904, 944, 1003, 1072, 1145, 1216, 1244, 1311, 1325, 1414, 1448, 2952 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.34 (s, 9H, $SiMe_3$), 2.67 (s, 6H, NMe_2), 4.40 (s, 5H, Cp), 4.50 (d, 1H, *J* = 1.3 Hz, H3), 5.00 (d, 1H, *J* = 1.3 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 1.0 ($3CH_3$, $SiMe_3$), 37.8 ($2CH_3$, NMe_2), 40.8 (C, C4, C-I), 73.9 (5CH, Cp), 75.6 (C, C2, *C*-$SiMe_3$), 78.4 (CH, C5), 83.8 (CH, C3), 90.1 (C, C1, *C*-SO_2NMe_2). Anal. Calcd for $C_{15}H_{22}FeINO_2SSi$ (491.24): C, 36.68; H, 4.51; N, 2.85; S, 6.53. Found: C, 36.85; H, 4.46; N, 2.77; S, 6.71. **Crystal data for 6a**. $C_{15}H_{22}FeINO_2SSi$, *M* = 491.23, *T* = 150 K; triclinic *P* 1 (I.T.#1), *a* = 7.0450(7), *b* = 8.6273(9), *c* = 8.8026(8) Å, *α* = 108.595(3), *β* = 112.215(3), *γ* = 94.589(4) °, *V* = 457.02(8) Å^3, *Z* = 1, *d* = 1.785 g.cm^{-3}, *μ* = 2.699 mm^{-1}. A final refinement on F^2 with 3755 unique intensities and 204 parameters converged at ω$R(F^2)$ = 0.0535 ($R(F)$ = 0.0223) for 3620 observed reflections with $I > 2\sigma(I)$. CCDC 2055870.

2-Hydroxymethyl-3-iodo-*N*,*N*-dimethyl-5-(trimethylsilyl)ferrocenesulfonamide (6b, racemic mixture). Compound **6b** was prepared as follows. First, procedure C was applied by using as the electrophile dimethylformamide (85 μL) to afford 117 mg of an inseparable mixture of expected **6b** (eluent: petroleum ether-AcOEt 80:20; Rf = 0.64) and **2g**. This mixture was dissolved in methanol (2 mL) and treated by $NaBH_4$ (17 mg, 0.45 mmol) for 30 min at 0 °C. The expected alcohol **6b** was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.29) in 21% overall yield (106 mg) as a yellow solid: mp 132 °C; IR (ATR) 708, 733, 755, 827, 839, 906, 926, 960, 976, 996 1055, 1108, 1125, 1244, 1260, 1332, 1379, 1411, 1453, 2947, 3354 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.34 (s, 9H, $SiMe_3$), 2.69 (s, 6H, NMe_2), 2.89 (dd, 1H, *J* = 7.5 and 6.4 Hz, OH), 4.38 (s, 5H, Cp), 4.55 (dd, 1H, *J* = 12.8 and 7.6 Hz, C*H*H), 4.62 (s, 1H, H4) 4.89 (dd, 1H, *J* = 12.8 and 6.3 Hz, C*H*H); ^{13}C NMR ($CDCl_3$) δ 0.9 ($3CH_3$, $SiMe_3$), 37.1 ($2CH_3$, NMe_2), 48.9 (C, C3, C-I), 59.7 (CH_2), 74.2 (5CH, Cp), 78.2 (C, C5, C-$SiMe_3$), 83.0 (CH, C4), 88.0 (C, C1, *C*-SO_2NMe_2), 90.8 (C, C2, *C*-CH_2OH). Anal. Calcd for $C_{16}H_{24}FeINO_3SSi$ (521.27): C, 36.87; H, 4.64; N, 2.69; S, 6.15. Found: C, 36.69; H, 4.33; N, 2.92; S, 6.51.

3-Iodo-*N*,*N*-dimethyl-2,5-bis(trimethylsilyl)ferrocenesulfonamide (6c, racemic mixture). Compound **6c** was prepared according to the procedure C by using as the electrophile chlorotrimethylsilane (0.14 mL). It was obtained (eluent: petroleum ether-AcOEt 90:10; Rf = 0.94) in 49% yield (279 mg) as a yellow solid: mp 136 °C; IR (ATR) 710, 740, 756, 822, 945, 958, 1003, 1069, 1109, 1139, 1202, 1241, 1304, 1378, 1413, 1454, 1582, 2899, 2951 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.35 (s, 9H, C5-$SiMe_3$), 0.50 (s, 9H, C2-$SiMe_3$), 2.56 (s, 6H, NMe_2), 4.41 (s, 5H, Cp), 4.75 (s, 1H, H4); ^{13}C NMR ($CDCl_3$) δ 1.4 ($3CH_3$, C5-Si*Me*$_3$), 2.7 ($3CH_3$, C2-Si*Me*$_3$), 36.9 ($2CH_3$, NMe_2), 52.4 (C, C3, C-I), 73.6 (5CH, Cp), 75.9

(C, C2, *C*2-SiMe$_3$), 82.5 (C, C5, *C*5-SiMe$_3$), 89.1 (CH, C4), 94.4 (C, C1, *C*-SO$_2$NMe$_2$). Anal. Calcd for $C_{18}H_{30}FeINO_2SSi_2$ (563.42): C, 38.37; H, 5.37; N, 2.49; S, 5.69. Found: C, 38.30; H, 5.44; N, 2.85; S, 5.29.

2-[1-(4-Chlorophenyl)hydroxylmethyl]-4-iodo-*N*,*N*-dimethylferrocenesulfonamide (7, main diastereoisomer, racemic mixture). Compound **7** was prepared as follows. To a solution of 4-iodo-*N*,*N*-dimethyl-2-(trimethylsilyl)ferrocenesulfonamide (**6a**; 123 mg, 0.25 mmol, 1.0 equiv) and 4-chlorobenzaldehyde (53 mg, 0.375 mmol, 1.5 equiv) in dimethylformamide (2 mL) was added CsF (57 mg, 0.375 mmol, 1.5 equiv). The reaction mixture was heated at 95 °C for 8 h. After cooling, addition of AcOEt (20 mL) and filtration, the organic phase was washed with brine (10 mL), dried over Na_2SO_4, and the solvent was removed under reduced pressure. The product was obtained (eluent: petroleum ether-AcOEt 95:5; Rf = 0.48) in 45% yield (50 mg) as a yellow solid: mp 150 °C; IR (ATR) 705, 777, 824, 840, 878, 953, 1010, 1053, 1089, 1107, 1152, 1242, 1269, 1333, 1371, 1410, 1489, 1597, 2923, 3552 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.53 (s, 6H, NMe$_2$), 3.91 (d, 1H, *J* = 6.7 Hz, OH), 4.39 (s, 5H, Cp), 4.46 (d, 1H, *J* = 1.5 Hz, H3), 4.92 (d, 1H, *J* = 1.5 Hz, H5), 5.75 (d, 1H, *J* = 6.7 Hz, C*H*(OH)), 7.34-7.37 (m, 2H, H3' and H5'), 7.41 (d, 2H, *J* = 8.5 Hz, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 37.4 (2CH$_3$, NMe$_2$), 37.7 (C, C4, C-I), 70.0 (CH, CH(OH)), 74.9 (5CH, Cp), 77.1 (CH, C5), 78.6 (CH, C3), 83.3 (C, C1, *C*-SO$_2$NMe$_2$), 92.9 (C, C2, *C*-CH(OH)C$_6$H$_4$-4Cl), 128.0 (2CH, C2' and C6'), 128.5 (2CH, C3' and C5'), 133.6 (C, C4', C-Cl), 141.3 (C, C1', *C*-CH(OH)Fc). Anal. Calcd for $C_{19}H_{19}ClFeINO_3S$ (559.92): C, 40.78; H, 3.42; N, 2.50; S, 5.73. Found: C, 40.22; H, 3.23; N, 2.65; S, 5.62.

3-Iodo-*N*,*N*-dimethylferrocenesulfonamide (8, racemic mixture). Compound **8** was prepared as follows. To a solution of 4-iodo-*N*,*N*-dimethyl-2-(trimethylsilyl)ferrocenesulfonamide (**6a**; 491 mg, 1.0 mmol, 1.0 equiv) in THF (3 mL) was added a 1.0 M solution of tetrabutylammonium fluoride in THF (2.0 mL, 2.0 mmol, 2.0 equiv). The reaction mixture was stirred at rt for 30 min before addition of water (20 mL). Extraction with AcOEt (3 x 20 mL), washing the combined organic phases with brine (10 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel (eluent: petroleum ether-AcOEt 80:20). The product was obtained (Rf = 0.71) in 100% yield (434 mg) as a yellow solid: mp 105 °C; IR (ATR) 711, 759, 822, 882, 903, 949, 1002, 1040, 1072, 1108, 1145, 1200, 1245, 1326, 1413, 1449, 1723, 2919, 3096 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.62 (s, 6H, NMe$_2$), 4.43 (s, 5H, Cp), 4.59 (dd, 1H, *J* = 2.4 and 1.2 Hz, H5), 4.64 (dd, 1H, *J* = 2.4 and 1.3 Hz, H4), 4.85 (t, 1H, *J* = 1.2 Hz, H2); ^{13}C NMR ($CDCl_3$) δ 38.0 (2CH$_3$, NMe$_2$), 38.8 (C, C3, C-I), 70.1 (CH, C5), 73.8 (5CH, Cp), 74.9 (CH, C2), 77.2 (CH, C4), 83.4 (C, C1, *C*-SO$_2$NMe$_2$). Anal. Calcd for $C_{12}H_{14}FeINO_2S$ (419.06): C, 34.39; H, 3.37; N, 3.34; S, 7.65. Found: C, 34.63; H, 3.34; N, 3.29; S, 7.51.

2-Iodo-*N*,*N*-dimethyl-5-(phenylthio)ferrocenesulfonamide (9, racemic mixture). Compound **9** was prepared as follows. *n*-BuLi (1.4 M, 1.1 mL, 1.5 mmol, 1.5 equiv) was added dropwise to a solution of *N*,*N*-dimethyl-2-(phenylthio)ferrocenesulfonamide (**2j**; 401 mg, 1.0 mmol, 1.0 equiv) in THF (4 mL) at –80 °C. After 1 h at this temperature, iodine (381 mg, 1.5 mmol, 1.5 equiv) in THF (3 mL) was introduced at –80 °C. After warming to rt, a saturated $Na_2S_2O_3$ aqueous solution (5 mL) was added. The product was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.50) in 93% yield (489 mg) as a yellow solid: mp 150 °C; IR (ATR) 710, 740, 827, 865, 880, 961, 1003, 1027, 1058, 1109, 1153, 1203, 1260, 1294, 1341, 1373, 1412, 1438, 1477, 1455, 1583, 2904, 3077 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.70 (s, 6H, NMe$_2$), 4.48 (s, 5H, Cp), 4.58 (d, 1H, *J* = 2.4 Hz, H4), 4.80 (d, 1H, *J* = 2.4 Hz, H3), 7.13-7.17 (m, 3H, H2', H4' and H6'), 7.26 (t, 2H, *J* = 7.4 Hz, H3' and H5'); ^{13}C NMR ($CDCl_3$) δ 37.6 (2CH$_3$, NMe$_2$), 40.6 (C, C2, C-I), 75.9 (5CH, Cp), 78.8 (CH, C4), 79.7 (CH, C3), 81.4 (C, C5, *C*-SPh), 85.9 (C, C1, *C*-SO$_2$NMe$_2$), 126.3 (CH, C4'), 128.2 (2CH, C2' and C6'), 129.1 (2CH, C3' and C5'), 138.4 (C, C1'). Anal. Calcd for $C_{18}H_{18}FeINO_2S_2$ (527.22): C, 41.01; H, 3.44; N, 2.66; S, 12.16. Found: C, 41.05; H, 3.70; N, 2.48; S, 12.19.

General Procedure D: Halogen Migration from 2-Iodo-*N*,*N*-dimethyl-5-(phenylthio)ferrocenesulfonamide (9) followed by Electrophilic Trapping. Unless otherwise specified in the product description, general procedure D is as follows. To a stirred, cooled (–15 °C) solution of 2,2,6,6-tetramethylpiperidine (0.19 mL, 1.1 mmol, 1.1 equiv) in THF (2 mL) was added *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv). The mixture was stirred for 5 min at 0 °C and then for 2 min at –50 °C before introduction of 2-iodo-*N*,*N*-dimethyl-5-(phenylthio)ferrocenesulfonamide (**9**; 527 mg, 1.0 mmol, 1.0 equiv) in THF (3 mL) at –50 °C. After 2 h at this temperature, the electrophile (1.1 mmol, 1.1 equiv, if not specified in the product description) was added, and the reaction mixture was warmed to rt before addition of water (20 mL). Extraction with AcOEt (3 x 20 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel (eluent given in the product description).

4-Iodo-*N*,*N*-dimethyl-2-(phenylthio)ferrocenesulfonamide (10a, racemic mixture). Compound **10a** was prepared according to the procedure D by using as the electrophile methanol in excess (0.5 mL). It was obtained (eluent: petroleum ether-AcOEt 95:5; Rf = 0.60) in 67% yield (355 mg) as a yellow solid: mp 120 °C; IR (ATR) 712, 730, 746, 835, 871, 932, 945, 963, 1004, 1032, 1070, 1108, 1150, 1200, 1259, 1295, 1343, 1396, 1413, 1455, 1477, 1582, 1709, 2867, 2901, 3040 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.55 (s, 6H, NMe$_2$), 4.50 (s, 5H, Cp), 4.80 (d, 1H, *J* = 1.4 Hz, H5), 5.10 (d, 1H, *J* = 1.4 Hz, H3), 7.12 (d, 2H, *J* = 7.4 Hz, H2' and H6'), 7.15 (t, 1H, *J* = 7.3 Hz, H4'), 7.25 (t, 2H, *J* = 7.5 Hz, H3' and H5'); ^{13}C NMR ($CDCl_3$) δ 37.3 (2CH$_3$, NMe$_2$), 37.8 (C, C4, C-I), 75.6 (5CH, Cp), 78.7 (CH, C3), 79.8 (C, C1, *C*-SO$_2$NMe$_2$), 84.0 (CH, C5), 86.7 (C, C2, *C*-SPh), 126.2 (CH, C4'), 127.5 (2CH, C2' and C6'), 129.2 (2CH, C3' and C5'), 138.4 (C, C1'). Anal. Calcd for $C_{18}H_{18}FeINO_2S_2$ (527.22): C, 41.01; H, 3.44; N, 2.66; S, 12.16. Found: C, 40.94; H, 3.42; N, 2.45; S, 12.43.

2-(Dimethylaminomethyl)-3-iodo-*N*,*N*-dimethyl-5-(phenylsulfonyl)ferrocenesulfonamide (10b, racemic mixture). Compound **10b** was prepared according to the procedure D by using as the electrophile *N*,*N*-dimethylmethyleneiminium iodide (280 mg, 1.5 mmol, 1.5 equiv), but with the following change. After warming to rt, methanol (0.2 mL) was added before evaporation to dryness. The product was obtained (eluent: petroleum ether-AcOEt 40:60; Rf = 0.16) in 54% yield (316 mg) as an orange solid: mp 164 °C; IR (ATR) 710, 738, 759, 826, 915, 958, 1003, 1070, 1108, 1144, 1241, 1336, 1376, 1439, 1477, 1581, 2898, 3076 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.26 (s, 6H, CH$_2$N*Me*$_2$), 2.73 (s, 6H, SO$_2$NMe$_2$), 3.05 (d, 1H, *J* = 12.6 Hz, C*H*H), 4.24 (d, 1H, *J* = 12.6 Hz, CH*H*), 4.37 (s, 5H, Cp), 4.79 (s, 1H, H4), 7.11 (d, 2H, *J* = 8.5 Hz, H2' and H6'), 7.16 (t, 1H, *J* = 7.4 Hz, H4'), 7.26 (t, 2H, *J* = 7.6 Hz, H3' and H5'); ^{13}C NMR ($CDCl_3$) δ 37.1 (2CH$_3$, SO$_2$NMe$_2$), 45.1 (2CH$_3$, CH$_2$N*Me*$_2$), 47.6 (C, C3, C-I), 56.2 (CH$_2$), 76.3 (5CH, Cp), 82.5 (CH, C4), 82.9 (C, C5, *C*-SPh), 85.5 (C, C1, *C*-SO$_2$NMe$_2$), 88.5 (C, C2, *C*-CH$_2$NMe$_2$), 126.2 (CH, C4'), 127.9 (2CH, C2' and C6'), 129.2 (2CH, C3' and C5'), 138.4 (C, C1'). Anal. Calcd for $C_{21}H_{25}FeIN_2O_2S_2$ (584.31): C, 43.17; H, 4.31; N, 4.79; S, 10.97. Found: C, 43.10; H, 4.19; N, 4.65; S, 10.89.

3-Iodo-*N*,*N*-dimethyl-5-(phenylthio)-2-(trimethylsilyl)ferrocenesulfonamide (10c, racemic mixture). Compound **10c** was prepared according to the procedure D by using as the electrophile chlorotrimethylsilane (0.14 mL). It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.92) in 60% yield (357 mg) as a yellow solid: mp 152 °C; IR (ATR) 729, 739, 757, 827, 915, 981, 1002, 1024, 1069, 1109, 1145, 1200, 1257, 1330, 1413, 1455, 1477, 1582, 2900, 3099 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.56 (s, 9H, SiMe$_3$), 2.55 (s, 6H, NMe$_2$), 4.47 (s, 5H, Cp), 4.92 (s, 1H, H4), 7.17-7.21 (m, 3H, H2', H4' and H6'), 7.28 (t, 2H, *J* = 7.6 Hz, H3' and H5'); ^{13}C NMR ($CDCl_3$) δ 4.0 (3CH$_3$, SiMe$_3$), 36.9 (2CH$_3$, NMe$_2$), 47.5 (C, C3, C-I), 75.7 (5CH, Cp), 77.2 (C, C2, *C*-SiMe$_3$), 84.9 (C, C1, *C*-SO$_2$NMe$_2$), 88.6 (CH, C4), 93.5 (C, C5, *C*-SPh), 126.4 (CH, C4'), 128.3 (2CH, C2' and C6'), 129.1 (2CH, C3' and C5'), 137.6 (C, C1').

Anal. Calcd for $C_{21}H_{26}FeINO_2S_2Si$ (599.40): C, 42.08; H, 4.37; N, 2.34; S, 10.70. Found: C, 42.92; H, 4.47; N, 2.19; S, 10.83.

2-(Dimethylaminomethyl)-3-iodo-*N*,*N*-dimethyl-5-(phenylsulfonyl)-4-(trimethylsilyl)ferrocenesulfonamide (11, racemic mixture). Compound **11** was prepared as follows. To a stirred, cooled (0 °C) solution of 2,2,6,6-tetramethylpiperidine (0.21 mL, 1.2 mmol, 1.2 equiv) in THF (2 mL) was added *n*-BuLi (1.4 M, 0.86 mL, 1.2 mmol, 1.2 equiv). The mixture was stirred for 5 min at 0 °C and then for 2 min at –50 °C before introduction of 2-(dimethylaminomethyl)-3-iodo-*N*,*N*-dimethyl-5-(phenylsulfonyl)ferrocenesulfonamide (**10b**; 584 mg, 1.0 mmol, 1.0 equiv) in THF (3 mL) at –50 °C. After 4 h at this temperature, chlorotrimethylsilane (0.15 mL, 1.2 mmol, 1.2 equiv) was added, and the reaction mixture was warmed to rt before addition of 1 M HCl (10 mL). Extraction with AcOEt (3 x 20 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over neutral silica gel. The product was obtained (eluent: petroleum ether-AcOEt 95:5; Rf = 0.71) in 21% yield (137 mg) as an orange oil: IR (ATR) 714, 736, 759, 836, 964, 1016, 1040, 1070, 1116, 1151, 1175, 1227, 1247, 1289, 1334, 1413, 1439, 1455, 1478, 1582, 2770, 2817, 2854, 2940 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.36 (s, 9H, $SiMe_3$), 2.33 (s, 6H, CH_2NMe_2), 2.60 (s, 6H, SO_2NMe_2), 3.30 (d, 1H, *J* = 12.1 Hz, C*H*H), 4.29 (d, 1H, *J* = 12.4 Hz, CH*H*), 4.40 (s, 5H, Cp), 7.11 (d, 2H, *J* = 7.0 Hz, H2' and H6'), 7.01 (t, 1H, *J* = 6.6 Hz, H4'), 7.15 (t, 2H, *J* = 6.6 Hz, H3' and H5'); ^{13}C NMR ($CDCl_3$) δ 2.5 ($3CH_3$, $SiMe_3$), 36.4 ($2CH_3$, SO_2NMe_2), 45.1 ($2CH_3$, CH_2NMe_2), 56.5 (CH_2), 58.0 (C, C3, C-I), 75.8 (5CH, Cp), 82.6 (C, C4, *C*-$SiMe_3$), 83.2 (C, C5, *C*-SPh), 91.4 (C, C1, *C*-SO_2NMe_2), 92.9 (C, C2, *C*-CH_2NMe_2), 124.4 (2CH, C2' and C6'), 124.5 (CH, C4'), 128.8 (2CH, C3' and C5'), 142.0 (C, C1'). Anal. Calcd for $C_{24}H_{33}FeIN_2O_2S_2Si$ (656.49): C, 43.91; H, 5.07; N, 4.27; S, 9.77. Found: C, 43.77; H, 4.64; N, 4.37; S, 9.95.

***N*,*N*-dimethyl-2-(phenylsulfonyl)ferrocenesulfonamide (12, racemic mixture).** Compound **12** was prepared as follows. To a solution of *N*,*N*-dimethyl-2-(phenylthio)ferrocenesulfonamide (**2j**; 401 mg, 1.0 mmol, 1.0 equiv) in CH_2Cl_2 (5 mL) was added portionwise, at 0 °C, 3-chloroperbenzoic acid (70%; 862 mg, 3.5 mmol, 3.5 equiv). The reaction mixture was stirred at rt for 1-2 h before addition of AcOEt (10 mL). The organic phase was washed three times with a 10% NaOH aqueous solution (3 x 10 mL). Drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel. The product was obtained (eluent: petroleum ether-AcOEt 60:40; Rf = 0.29) in 51% yield (220 mg) as a reddish-brown solid: mp 166 °C; IR (ATR) 713, 765, 816, 830, 889, 1015, 1002, 1031, 1065, 1109, 1140, 1200, 1370, 1413, 1444, 1698, 3112 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.41 (s, 6H, NMe_2), 4.60 (s, 5H, Cp), 4.64 (t, 1H, *J* = 2.7 Hz, H4), 4.87 (dd, 1H, *J* = 2.6 and 1.8 Hz, H5), 5.09 (dd, 1H, *J* = 2.7 and 1.8 Hz, H3), 7.47-7.52 (m, 2H, H3' and H5'), 7.53-7.58 (m, 1H, H4'), 7.98-8.01 (m, 2H, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 37.1 ($2CH_3$, NMe_2), 70.6 (CH, C4), 73.7 (5CH, Cp), 75.2 (CH, C5), 75.8 (CH, C3), 86.2 (C, C1, *C*-SO_2NMe_2), 90.5 (C, C2, *C*-SO_2Ph), 128.2 (2CH, C2' and C6'), 128.8 (2CH, C3' and C5'), 133.2 (CH, C4'), 142.4 (C, C1'). Anal. Calcd for $C_{18}H_{19}FeNO_4S_2$ (433.32): C, 49.89; H, 4.42; N, 3.23; S, 14.80. Found: C, 50.01; H, 4.33; N, 3.29; S, 14.27.

***N*,*N*-dimethyl-2-(phenylsulfonyl)-3-(trimethylsilyl)ferrocenesulfonamide (13a, racemic mixture).** Compound **13a** was prepared as follows. To a stirred, cooled (0 °C) solution of 2,2,6,6-tetramethylpiperidine (0.19 mL, 1.1 mmol, 1.1 equiv) in THF (2 mL) was added *n*-BuLi (1.4 M, 0.79 mL, 1.1 mmol, 1.1 equiv). The mixture was stirred for 5 min at 0 °C and then for 2 min at –50 °C before introduction of *N*,*N*-dimethyl-2-(phenylsulfonyl)ferrocenesulfonamide (**12**; 435 mg, 1.0 mmol, 1.0 equiv) at –50 °C. After 2 h at this temperature, chlorotrimethylsilane (0.15 mL, 1.2 mmol, 1.2 equiv) was added, and the reaction mixture was warmed to rt before addition of 1 M HCl (10 mL). Extraction with AcOEt (3 x 20 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel. The product was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.55) in 27% yield (96 mg) as a yellow solid: mp 236 °C; IR (ATR) 707, 724, 761, 825, 889, 854, 1003, 1094, 1145, 1210, 1243, 1314, 1353, 1446, 2996 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.43 (s, 9H, $SiMe_3$), 2.36 (s, 6H, NMe_2), 4.55 (s, 5H, Cp), 4.64 (d, 1H, *J* = 2.0 Hz, H4), 5.03 (d, 1H, *J* = 2.0 Hz, H5), 7.48 (t, 2H, *J* = 7.3 Hz, H3' and H5'), 7.53 (t, 1H, *J* = 7.1 Hz, H4'), 7.97 (d, 2H, *J* = 7.8 Hz, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 1.7 ($3CH_3$, $SiMe_3$), 37.0 ($2CH_3$, NMe_2), 73.8 (5CH, Cp), 77.9 (CH, C4 or C5), 78.0 (CH, C4 or C5), 82.3 (C, C3, *C*-$SiMe_3$), 89.6 (C, C1, *C*-SO_2NMe_2), 93.3 (C, C2, *C*-SO_2Ph), 127.9 (2CH, C2' and C6'), 128.5 (2CH, C3' and C5'), 132.8 (CH, C4'), 143.4 (C, C1'). Anal. Calcd for $C_{21}H_{27}FeNO_4S_2Si$ (505.50): C, 49.90; H, 5.38; N, 2.77; S, 12.68. Found: C, 50.54; H, 5.75; N, 2.07; S, 12.20.

***N*,*N*-dimethyl-2-(phenylsulfonyl)-5-(trimethylsilyl)ferrocenesulfonamide (13b, racemic mixture).** Compound **13b** was similarly prepared and obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.67) in 10% yield (35 mg) as a yellow solid: mp 168 °C; IR (ATR) 713, 730, 759, 827, 885, 904, 911, 984, 1003, 1087, 1127, 1145, 1245, 1307, 1325, 1415, 1448, 2950 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.33 (s, 9H, $SiMe_3$), 2.17 (s, 6H, NMe_2), 4.62 (s, 1H, H4), 4.75 (s, 5H, Cp), 5.24 (s, 1H, H3), 7.47-7.53 (m, 3H, H3', H4' and H5'), 7.82 (d, 2H, *J* = 6.9 Hz, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 1.0 ($3CH_3$, $SiMe_3$), 36.1 ($2CH_3$, NMe_2), 73.8 (5CH, Cp), 77.5 (CH, C4), 78.4 (CH, C3), 84.1 (C, C5, *C*-$SiMe_3$), 90.6 (C, C1 or C2), 91.7 (C, C1 or C2), 127.0 (2CH, C2' and C6'), 128.7 (2CH, C3' and C5'), 132.6 (CH, C4'), 142.7 (C, C1'). Anal. Calcd for $C_{21}H_{27}FeNO_4S_2Si$ (505.50): C, 49.90; H, 5.38; N, 2.77; S, 12.68. Found: C, 50.21; H, 5.66; N, 2.72; S, 12.48.

2-Iodo-*N*,*N*-dimethyl-5-(phenylsulfonyl)ferrocenesulfonamide (14, racemic mixture). Compound **14** was prepared as follows. To a solution of 2-iodo-*N*,*N*-dimethyl-5-(phenylthio)ferrocenesulfonamide (**9**; 527 mg, 1.0 mmol, 1.0 equiv) in CH_2Cl_2 (5 mL) was added portionwise, at 0 °C, 3-chloroperbenzoic acid (70%; 862 mg, 3.5 mmol, 3.5 equiv). The reaction mixture was stirred at rt for 1-2 h before addition of AcOEt (10 mL). The organic phase was washed three times with a 10% NaOH aqueous solution (3 x 10 mL). Drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel. The product was obtained (eluent: petroleum ether-AcOEt 95:5; Rf = 0.60) in 55% yield (311 mg) as a brown solid: mp 160 °C; IR (ATR) 712, 728, 757, 832, 945, 932, 964, 1002, 1032, 1069, 1107, 1148, 1200, 1258, 1295, 1342, 1396, 1413, 1455, 1582, 1707, 2866, 2901, 3099 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.47 (s, 6H, NMe_2), 4.62 (s, 5H, Cp), 4.94 (s, 1H, H3), 5.26 (s, 1H, H4), 7.49 (t, 2H, *J* = 6.7 Hz, H3' and H5'), 7.56 (t, 1H, *J* = 7.0 Hz, H4'), 7.99 (d, 2H, *J* = 7.2 Hz, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 37.2 ($2CH_3$, NMe_2), 41.5 (C, C2, C-I), 76.6 (5CH, Cp), 77.1 (CH, C4), 80.0 (CH, C3), 88.2 (C, C1, *C*-SO_2NMe_2), 92.4 (C, C5, *C*-SO_2Ph), 128.7 (4CH, C2', C3', C5' and C6'), 133.3 (CH, C4'), 141.7 (C, C1'). Anal. Calcd for $C_{18}H_{18}FeINO_4S_2$ (559.21): C, 38.66; H, 3.24; N, 2.50; S, 11.47. Found: C, 39.18; H, 3.04; N, 2.20; S, 11.37.

2-Deuterio-5-iodo-*N*,*N*-dimethylferrocenesulfonamide (15, racemic mixture). Compound **15** was prepared as follows. *n*-BuLi (1.4 M, 2.4 mL, 3.3 mmol, 1.5 equiv) was added dropwise to a solution of 2-deuterio-*N*,*N*-dimethylferrocenesulfonamide (**2a**; 647 mg, 2.2 mmol, 1.0 equiv) in THF (18 mL) at –80 °C. After 1 h at this temperature, iodine (847 mg, 3.3 mmol, 1.5 equiv) in THF (10 mL) was introduced at –80 °C. After warming to rt, a saturated $Na_2S_2O_3$ aqueous solution (10 mL) was added. The product was obtained after column chromatography (eluent: petroleum ether-AcOEt 80:20) in 86% yield (794 mg) as an orange solid(eluent: petroleum ether-AcOEt 70:30; Rf = 0.50): mp 114-116 °C; IR (ATR) 706, 820, 841, 918, 949, 1002, 1046, 1109, 1140, 1184, 1334, 1471, 2921, 3096 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.73 (s, 6H, NMe_2), 4.41 (s, 5H, Cp), 4.45 (d, 1H, *J* = 2.5 Hz, H3), 4.65 (d, 1H, *J* = 2.6 Hz, H4); ^{13}C NMR ($CDCl_3$) δ 37.2 (C,

C5, C-I), 38.3 ($2CH_3$, NMe_2), 70.3 (t, C, *J* = 28.2, C2, C-D), 71.8 (CH, C3), 73.9 (5CH, Cp), 79.5 (CH, C4), 85.1 (C, C1, *C*-SO_2NMe_2). Anal. Calcd for $C_{12}H_{13}DFeINO_2S$ (420.06): C, 34.31; H, 3.12; N, 3.33; S, 7.63. Found: C, 34.83; H, 3.36; N, 3.31; S, 8.04.

General Procedure E: Suzuki-Miyaura Cross-coupling from Iodides 6a and 10a. The iodide (0.25 mmol, 1.0 equiv), boronic acid (1.0 mmol, 4.0 equiv), palladium bis(dibenzylideneacetone) (7.2 mg, 12.5 µmol, 50 mequiv), 2-dicyclohexylphosphino-2',6'-dimethoxybiphenyl (SPhos; 20.5 mg, 50 µmol, 0.20 equiv) and CsF (76 mg, 0.50 mmol, 2.0 equiv) were charged in a dried Schlenk tube. After 3 cycles of vacuum/argon, toluene (2 mL) was introduced, and the stirred mixture was heated overnight at 110 °C in a pre-heated oil bath. The reaction mixture was cooled before addition of water (5 mL). Extraction with AcOEt (3 x 10 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel (eluent given in the product description).

***N,N*-dimethyl-4-(4-(trifluoromethyl)phenyl)-2-(trimethylsilyl)ferrocenesulfonamide (16a, racemic mixture).** Compound **16a** was prepared from **6a** (123 mg) and 4-(trifluoromethyl)phenylboronic acid (190 mg) according to the procedure E. It was obtained (eluent: petroleum ether-AcOEt 95:5; Rf = 0.18) in 87% yield (111 mg) as an orange solid: mp 189-190 °C; IR (ATR) 693, 712, 755, 824, 836, 857, 952, 986, 1050, 1067, 1107, 1134, 1149, 1160, 1244, 1324, 1419, 1457, 1616, 2962 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.41 (s, 9H, $SiMe_3$), 2.72 (s, 6H, NMe_2), 4.27 (s, 5H, Cp), 4.77 (d, 1H, *J* = 1.5 Hz, H3), 5.29 (d, 1H, *J* = 1.5 Hz, H5), 7.58 (d, 2H, *J* = 8.6 Hz, H3' and H5'), 7.61 (d, 2H, *J* = 8.6 Hz, H2' and H6'); ^{13}C NMR ($CDCl_3$) δ 1.1 ($3CH_3$, $SiMe_3$), 37.9 ($2CH_3$, NMe_2), 71.4 (CH, C5), 72.7 (5CH, Cp), 75.5 (C, C2, *C*-$SiMe_3$), 75.7 (CH, C3), 87.6 (C, C4), 90.6 (C, C1, *C*-SO_2NMe_2), 124.3 (q, C, *J* = 271.8 Hz, CF_3), 125.8 (q, 2CH, *J* = 3.5 Hz, C3' and C5'), 126.4 (2CH, C2' and C6'), 129.1 (q, C, *J* = 32.7 Hz, C4'), 141.1 (C, C1'); ^{19}F NMR ($CDCl_3$) δ -62.5. Anal. Calcd for $C_{22}H_{26}F_3FeNO_2SSi$ (509.44): C, 51.87; H, 5.14; N, 2.75; S, 6.29. Found: C, 51.48; H, 5.04; N, 2.54; S, 6.29. **Crystal data for 16a**. $C_{22}H_{26}F_3FeNO_2SSi$, *M* = 509.4, *T* = 150 K; orthorhombic *P b c a* (I.T.#61), *a* = 12.5703(6), *b* = 13.6179(7), *c* = 26.5598(12) Å, *V* = 4546.5(4) $Å^3$, *Z* = 8, *d* = 1.488 $g.cm^{-3}$, *µ* = 0.852 mm^{-1}. A final refinement on F^2 with 5208 unique intensities and 289 parameters converged at $\omega R(F^2)$ = 0.0954 (*R*(*F*) = 0.0412) for 4698 observed reflections with $I > 2\sigma(I)$. CCDC 2056120.

4-(2,6-Dimethoxyphenyl)-*N,N*-dimethyl-2-(phenylthio)ferrocenesulfonamide (16b, racemic mixture). Compound **16b** was prepared from **10a** (123 mg) and 2,6-dimethoxyphenylboronic acid (182 mg) according to the procedure E. It was obtained (eluent: petroleum ether-AcOEt 70:30; Rf = 0.61) in 60% yield (80 mg) as a yellow solid: mp 178 °C; IR (ATR) 709, 733, 743, 781, 818, 853, 899, 954, 992, 1024, 1036, 105, 1143, 1158, 1241, 1283, 1334, 1434, 1472, 1580, 1595, 2834, 2936 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.53 (s, 6H, NMe_2), 3.88 (s, 6H, OMe), 4.38 (s, 5H, Cp), 5.32 (d, 1H, *J* = 1.7 Hz, H3), 5.48 (d, 1H, *J* = 1.7 Hz, H5), 6.62 (d, 2H, *J* = 8.4 Hz, H3" and H5"), 7.08 (tt, 1H, *J* = 7.0 and 1.4 Hz, H4'), 7.16-7.22 (m, 4H, H2', H3', H5' and H6'), 7.26 (t, 1H, *J* = 8.4 Hz, H4"); ^{13}C NMR ($CDCl_3$) δ 37.4 ($2CH_3$, NMe_2), 55.8 ($2CH_3$, OMe), 73.8 (5CH, Cp), 75.4 (CH, C5), 76.0 (C, C2, *C*-SPh), 81.7 (C, C4), 82.4 (CH, C3), 84.1 (C, C1, *C*-SO_2NMe_2), 104.3 (2CH, C3" and C5"), 111.7 (C, C1"), 125.2 (CH, C4'), 126.3 (2CH, C2' and C6'), 128.7 (CH, C4"), 128.8 (2CH, C3' and C5'), 140.5 (C, C1'), 158.4 (2C, C2" and C6", C-OMe). Anal. Calcd for $C_{26}H_{27}FeNO_4S_2$ (537.47): C, 58.10; H, 5.06; N, 2.61; S, 11.93. Found: C, 58.55; H, 5.41; N, 2.45; S, 11.85.

General Procedure F: Goldberg Reaction with 2-pyrrolidinone from Iodides 6a and 10a. The iodide (0.25 mmol, 1.0 equiv), 2-pyrrolidinone (21 µL, 0.275 mmol, 1.1 equiv), CuI (47.5 mg, 0.25 mmol, 1.0 equiv), K_3PO_4 (106 mg, 0.50 mmol, 2.0 equiv) and *N,N*-dimethylethylenediamine (DMEDA; 27 µL, 0.25 mmol, 1.0 equiv) were charged in a dried Schlenk tube. After 3 cycles of vacuum/argon, dioxane (1 mL) was introduced, and the stirred mixture was heated overnight at 90 °C in a pre-heated oil bath. The reaction mixture was cooled before addition of water (5 mL). Extraction with AcOEt (3 x 10 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel (eluent given in the product description).

***N,N*-dimethyl-4-(2-oxo-*N*-pyrrolidyl)-2-(trimethylsilyl)ferrocenesulfonamide (17a, racemic mixture).** Compound **17a** was prepared from **6a** (123 mg) according to the procedure F. It was obtained after column chromatography (eluent: petroleum ether-AcOEt 50:50 to 30:70) in 65% yield (73 mg) as an orange sticky oil (eluent: petroleum ether-AcOEt 70:30; Rf = 0.13): IR (ATR) 707, 728, 757, 820, 837, 916, 953, 983, 1088, 1139, 1159, 1244, 1313, 1334, 1405, 1461, 1496, 1693, 2896, 2956 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.35 (s, 9H, $SiMe_3$), 2.17 (quint, 2H, *J* = 7.9 Hz, NCH_2CH_2), 2.49 (t, 2H, *J* = 7.9 Hz, $NC(O)CH_2$), 2.66 (s, 6H, NMe_2), 3.64-3.72 (m, 2H, NCH_2), 4.37 (s, 5H, Cp), 4.81 (s, 1H, H3), 5.37 (s, 1H, H5); ^{13}C NMR ($CDCl_3$) δ 1.1 ($3CH_3$, $SiMe_3$), 18.3 (CH_2, NCH_2CH_2), 32.2 (CH_2, $NC(O)CH_2$), 37.9 ($2CH_3$, NMe_2), 48.4 (CH_2, NCH_2), 64.0 (CH, C5), 68.4 (CH, C3), 70.2 (C, C2, *C*-$SiMe_3$), 71.6 (5CH, Cp), 86.1 (C, C1, *C*-SO_2NMe_2), 99.8 (C, C4, C-N), 174.1 (C, C=O). Anal. Calcd for $C_{19}H_{28}FeN_2O_3SSi$ (448.43): C, 50.89; H, 6.29; N, 6.25; S, 7.15. Found: C, 50.44; H, 6.88; N, 6.48; S, 7.05.

***N,N*-dimethyl-4-(2-oxo-*N*-pyrrolidyl)-2-(phenylthio)ferrocenesulfonamide (17b, racemic mixture).** Compound **17b** was prepared from **10a** (123 mg) according to the procedure F. It was obtained (eluent: petroleum ether-AcOEt 40:60; Rf = 0.30) in 46% yield (56 mg) as a yellow solid: mp 108 °C; IR (ATR) 706, 742, 800, 823, 952, 987, 1008, 1058, 1071, 1107, 1140, 1241, 1289, 1332, 1346, 1403, 1480, 1581, 1691, 1774, 2952, 3097 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.18 (quint, 2H, *J* = 7.6 Hz, NCH_2CH_2), 2.50 (t, 2H, *J* = 8.0 Hz, $NC(O)CH_2$), 2.50 (s, 6H, NMe_2), 3.63-3.67 (m, 2H, NCH_2), 4.47 (s, 5H, Cp), 5.31 (d, 1H, *J* = 1.8 Hz, H3), 5.32 (d, 1H, *J* = 1.8 Hz, H5), 7.07-7.10 (m, 3H, H2', H4' and H6'), 7.20 (t, 2H, *J* = 7.7 Hz, H3' and H5'); ^{13}C NMR ($CDCl_3$) δ 18.3 (CH_2, NCH_2CH_2), 32.1 (CH_2, $NC(O)CH_2$), 37.3 ($2CH_3$, NMe_2), 48.1 (CH_2, NCH_2), 63.8 (CH, C5), 70.5 (CH, C3), 73.5 (5CH, Cp), 74.7 (C, C2, *C*-SPh), 83.0 (C, C1, *C*-SO_2NMe_2), 97.6 (C, C4, C-N), 125.6 (CH, C4'), 126.6 (2CH, C2' and C6'), 129.0 (2CH, C3' and C5'), 139.6 (C, C1'), 174.2 (C, C=O). Anal. Calcd for $C_{22}H_{24}FeN_2O_3S_2$ (484.41): C, 54.55; H, 4.99; N, 5.78; S, 13.24. Found: C, 54.98; H, 5.37; N, 5.34; S, 13.10.

General Procedure G: Iodine/lithium Exchange of 3-iodo-*N,N*-dimethylferrocenesulfonamide (8) followed by Electrophilic Trapping with Chlorophosphines. *t*-BuLi (1.6 M, 1.3 mL, 2.0 mmol, 2.0 equiv) was added dropwise to a solution of 3-iodo-*N,N*-dimethylferrocenesulfonamide (**8**; 419 mg, 1.0 mmol, 1.0 equiv) in THF (4 mL) at –80 °C. After 1 h at this temperature, the chlorophosphine (1.2 mmol, 1.2 equiv) was added, and the reaction mixture was stirred for 15 min at –80 °C before being warmed to rt. Methanol (0.2 mL) was added before evaporation to dryness. The product was purified by chromatography over silica gel (eluent given in the product description).

3-(Diphenylphosphino)-*N,N*-dimethylferrocenesulfonamide (18a, racemic mixture). Compound **18a** was prepared by using chlorodiphenylphosphine (0.21 mL) according to the procedure G. It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.80) in 62% yield (246 mg) as a yellow oil: IR (ATR) 709, 743, 825, 955, 1003, 1055, 1136, 1192, 1329, 1434, 2923 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.58 (s, 6H, NMe_2), 4.31-4.33 (m, 6H, Cp and H4), 4.52 (t, 1H, *J* = 1.3 Hz, H2), 4.76 (t, 1H, *J* = 1. 2 Hz, H5), 7.27-7.31 (m, 10H, Ph); ^{13}C NMR ($CDCl_3$) δ 38.2 ($2CH_3$, NMe_2), 71.4 (d, CH, *J* = 3.8 Hz, C5), 72.0 (5CH, Cp), 73.3 (d, CH, *J* = 13.8 Hz, C2), 75.4 (d, CH, *J* = 15.7 Hz, C4), 80.3 (d, C, *J* = 12.7 Hz, C3, C-P), 84.6 (d, C, *J* = 3.0 Hz, C1, *C*-SO_2NMe_2), 128.5, 128.5, 128.6, 128.7, 129.0 and 129.2 (6CH, C3', C4', C5'), 133.3, 133.4, 133.5 and 133.6 (4CH, C2' and C6'), 138.0 (d, C, *J* = 9.6 Hz, C1'), 138.3 (d, C, *J* = 9.9 Hz, C1'); ^{31}P NMR

($CDCl_3$) δ -17.8. Anal. Calcd for $C_{24}H_{24}FeNO_2PS$ (477.34): C, 60.39; H, 5.07; N, 2.93; S, 6.72. Found: C, 60.43; H, 4.59; N, 2.92; S, 6.97.

3-(Dicyclohexylphosphino)-*N*,*N*-dimethylferrocenesulfonamide (18b, racemic mixture). Compound **18b** was prepared by using chlorodicyclohexylphosphine (0.27 mL) according to the procedure G. It was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.46) in 67% yield (327 mg) as a yellow solid: mp 173 °C; IR (ATR) 710, 744, 820, 849, 945, 1002, 1058, 1108, 1144, 13436, 1434, 2932 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.96-1.06 (m, 2H, Cy), 1.08-1.16 (m, 2H, Cy), 1.18-1.34 (m, 7H, Cy), 1.67-1.70 (m, 2H, Cy), 1.73-1.80 (m, 7H, Cy), 1.87-1.93 (m, 2H, Cy), 2.60 (s, 6H, NMe_2), 4.37 (br s, 1H, H4), 4.39 (s, 5H, Cp), 4.57 (s, 1H, H2), 4.69 (dd, 1H, *J* = 1.7 and 1.2 Hz, H5); ^{13}C NMR ($CDCl_3$) δ 26.5 (CH_2, Cy), 26.6 (CH_2, Cy), 27.2 (d, CH_2, *J* = 5.3 Hz, Cy), 27.3 (d, CH_2, *J* = 5.7 Hz, Cy), 27.3 (d, CH_2, *J* = 4.0 Hz, Cy), 27.4 (d, CH_2, *J* = 3.5 Hz, Cy), 30.1 (d, CH_2, *J* = 6.5 Hz, Cy), 30.1 (d, CH_2, *J* = 5.0 Hz, Cy), 30.2 (d, CH_2, *J* = 12.4 Hz, Cy), 30.4 (d, CH_2, *J* = 14.5 Hz, Cy), 33.3 (d, CH, *J* = 12.0 Hz, C1'), 33.4 (d, CH, *J* = 12.0 Hz, C1'), 38.2 ($2CH_3$, NMe_2), 70.0 (d, CH, *J* = 2.3 Hz, C5), 71.9 (d, CH, *J* = 10.5 Hz, C2), 72.0 (5CH, Cp), 73.7 (d, CH, *J* = 11.2 Hz, C4), 80.6 (d, C, *J* = 23.7 Hz, C3, C-P), 83.3 (d, C, *J* = 1.7 Hz, C1, *C*-SO_2NMe_2); ^{31}P NMR ($CDCl_3$) δ -8.1. Anal. Calcd for $C_{24}H_{36}FeNO_2PS$ (489.44): C, 58.90; H, 7.41; N, 2.86; S, 6.55. Found: C, 59.10; H, 7.84; N, 2.55; S, 6.39.

General Procedure H: Evaluation of 2h, 2i, 18a and 18b as ligands in Suzuki-Miyaura Cross-coupling. 4-Chlorobenzaldehyde (77 mg, 0.50 mmol, 1.0 equiv), 4-methoxyphenylboronic acid (114 mg, 0.75 mmol, 1.5 equiv), palladium(II) acetate (2.2 mg, 10 µmol, 20 mequiv), the phosphine ligand (20 µmol, 40 mequiv) and CsF (228 mg, 1.5 mmol, 3.0 equiv) were charged in a dried Schlenk tube. After 3 cycles of vacuum/argon, dioxane (2.5 mL) was introduced, and the stirred mixture was heated overnight at 100 °C in a pre-heated oil bath. The reaction mixture was cooled before addition of water (5 mL). Extraction with AcOEt (3 x 10 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, which was purified by chromatography over silica gel. The product was obtained (eluent: petroleum ether-AcOEt 80:20; Rf = 0.44) as a white solid (yields are given in Scheme 9): mp 156-158 °C (lit.[50] 155-156 °C); IR (ATR) 814, 957, 998, 1010, 1031, 1184, 1197, 1252, 1269, 1291, 1359, 1400, 1495, 1527, 1578, 1597, 1673, 2841, 2958 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.63 (s, 3H, MeC=O), 3.87 (s, 3H, OMe), 7.00 (d, 2H, *J* = 8.7 Hz), 7.58 (d, 2H, *J* = 8.7 Hz), 7.65 (d, 2H, *J* = 8.4 Hz), 8.01 (d, 2H, *J* = 8.4 Hz); ^{13}C NMR ($CDCl_3$) δ 26.8 (CH_3, *Me*C=O), 55.5 (CH_3, OMe), 114.6 (2CH, Ar), 126.8 (2CH, Ar), 128.6 (2CH, Ar), 129.1 (2CH, Ar), 132.4 (C, Ar), 135.5 (C, Ar), 145.5 (C, Ar), 160.1 (C, Ar), 197.8 (C, C=O). The ^1H NMR data are similar to those reported previously.[50]

General Procedure I: Evaluation of 2h, 2i, 18a and 18b as Ligands in Buchwald-Hartwig Cross-coupling. 4-Chlorobenzonitrile (69 mg, 0.50 mmol, 1.0 equiv), morpholine (52.5 µL, 0.60 mmol, 1.2 equiv), palladium bis(dibenzylideneacetone) (5.75 mg, 10 µmol, 20 mequiv), the phosphine ligand (20 µmol, 40 mequiv) and *t*-BuOK (78.5 mg, 0.70 mmol, 1.4 equiv) were charged in a dried Schlenk tube. After 3 cycles of vacuum/argon, toluene (1 mL) was introduced, and the stirred mixture was heated overnight at 100 °C in a pre-heated oil bath. The reaction mixture was cooled before addition of water (5 mL). Extraction with AcOEt (3 x 10 mL), drying over $MgSO_4$ and removal of the solvents under reduced pressure led to the crude product, in which the expected compound was only detected as traces.

Computational Details. All electronic structure calculations were conducted using Gaussian 09 suite.[51] Full geometry optimizations of the considered species were performed using the B3LYP hybrid functional.[52] Before optimizing the geometry, a conformational search has been done, using structures from the X-ray diffraction analysis as starting guess if available. Vibrational frequencies were calculated to prove the nature of the stationary points. The LANL2DZ basis set[53] with the effective core potential was used to describe Fe and I, while the 6-31G(d) basis set[54] was used to treat the rest of the atoms. NPA charges and electrostatic potential maps were obtained using the B3LYP functional, and the Hartree-Fock approximation was used to calculate molecular orbital energies.

The CH acidity constants were calculated using an approach derived earlier,[55] which was applied in the ferrocene series.[22,27] The pK_a values were obtained from the Gibbs energy of the homodesmic reaction between the studied (RH) and a reference compound (HetH):

$$R–H(solv) + Het^–(solv) \rightarrow R^–(solv) + Het–H(solv),$$

where furan with pK_a(THF) = 35.6[56] was used as the reference compound. Single point energies were obtained using the CAM-B3LYP hybrid functional.[57] The solvent effects for p*K*a calculations were treated using polarizable continuum model (IEF-PCM)[58] with the default parameters for THF.

ASSOCIATED CONTENT

Supporting Information

Putative reaction sequence to rationalize the unsuccessful attempt to use deuterium as protecting group in the 'halogen dance' reaction; Selected calculated NPA charges of potential donor centers; Molecular electrostatic potential mapped on an SCF density; Calculated values of the Gibbs energies $\Delta_{acid}G$ for the deprotonation at the corresponding positions of the investigated compounds (gas-phase acidities); NMR spectra and NOESY correlations; Cartesian coordinates of DFT optimized structures (PDF)
Crystallographic data (CIF)

Accession Codes

CCDC 2055869, 2055870 and 2056120 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

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Notes

The authors declare no competing financial interest.

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Dedicated to Professor Victor Snieckus in recognition of his stimulating work on *ortho*-deprotometalation and ferrocene functionalization.

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