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A New, Facile, and General Synthesis of Functional and Heterodifunctional Ferrocenes†

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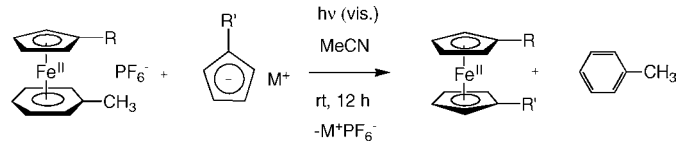
ABSTRACT



A new, very simple, and general method for the synthesis of functional and heterodifunctional 1,1′-ferrocenes is reported using the visible-light photolysis of a simple 100-W desk lamp with the easily available complexes [(η^5-C_5H_4R)Fe(η^6-toluene)][PF_6] (R = Me, Cl, COMe, CO_2H, CO_2Me, CO_2CH_2CCH, $CONHCH_2Ph$) and a substituted cyclopentadienyl salt MC_5H_4R' (M = Li, Na, R′ = H, COMe, CO_2Me, $SiMe_2CH_2Cl$, PPh_2) under ambient conditions. All the reactions give high yields except when the side chain contains a strong ligand competing with the Cp anion complexation.

Ferrocene derivatives[1] are useful in many areas including anticancer drugs[2] and other biomedical applications,[3] electrochemistry,[4] redox biosensors,[5] reagents and standards,[6] mediators of enzyme reactions,[7] resins, fuel additives, paints,[8] ligand scaffold,[9] catalysis,[9] liquid crystals,[10] nonlinear optical materials,[11] self-assembled monolayers,[12] magnetic materials,[13] polymers,[14] and dendrimers.[15] The major synthetic routes that have been extensively reported and used for ferrocene derivatives are (i) direct synthesis of 1,1′-disubstituted ferrocenes from substituted cyclopentadienyls, (ii) electrophilic Friedel−Crafts-type reactions, and (iii) metalation with *n*-butyllithium followed by electrophilic reactions.[16] Although the free cyclopentadienyl ring is less

† Dedicated to Prof. René Dabard.

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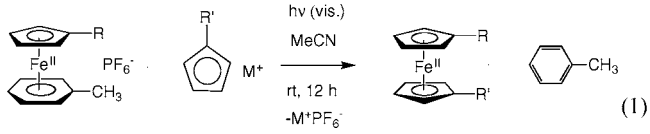
reactive than those of ferrocene itself after a first electrophilic or metalation reaction, the formation of 1,1′-disubstituted derivatives is rarely avoided and further requires chromatographic separation of the mono- and disubstituted compounds, which is energy-, money-, and time-consuming (although of pedagogical value!).



(1)

The direct synthesis from substituted cyclopentadienyl rings and iron chloride has sometimes been used, for instance for the synthesis of decasubstituted derivatives such as decamethylferrocene and related compounds.[17] However, an alternative synthesis of monosubstituted ferrocenes by successive introduction of the CpR ring (CpR = η^5-C_5H_4R) onto Fe^{II} followed by, in a second step, introduction of the other differently substituted ring CpR′ has, to our knowledge, never been reported.

This latter "stepwise" strategy has been used with the pentamethylcyclopentadienyl ligand (Cp*) that stabilizes half-sandwich Fe^{II} complexes such as [Cp*Fe$(NCMe)_3$]-[PF_6][18] and [Cp*Fe(acac)] (acac = acetylacetonate).[19] These compounds have been reported to be stable at room temperature under inert atmosphere and react with substituted salts CpR′M (M = Na or Li) to yield complexes [Cp*FeCpR′].[20] Such a strategy has also been used in exceptional cases with the dimers [η^5-$C_5R_5Fe(CO)_2]_2$ (R = H or Me) with specific ligands related to Cp such as phospholes[21] or a C_{60} derivative.[22] These methods cannot be generalized to the syntheses of many functional or bifunctional ferrocenes, however, because the parent complex [(η^5-C_5H_5)Fe$(NCMe)_3$][PF_6][23] is not stable above −40 °C, and the parent complex [(η^5-C_5H_5)Fe(acac)] is unknown. Their functional equivalents with CpR cannot be reached, and the analogs [(CpR)Fe$(CO)_2]_2$ are unknown or may not always be synthesized or withstand synthetic conditions. Therefore, we have investigated the photolytic synthesis of functional and heterodifunctional ferrocenes from the easily accessible complexes [(CpR)Fe(η^6-toluene)] [PF_6][24] and MCpR′, M = Li or Na, using visible light in acetonitrile or dichloromethane. A large family of robust complexes [(CpR)-Fe(η^6-arene)] [PF_6] have been known for a long time with various R groups (R = H, chloro, amino, alkyl, acyl, carboxylic acid, esters, amides, etc.). They are available mostly by ligand substitution of a cyclopentadienyl ring from ferrocene derivatives with arenes in the presence of aluminum chloride or by further functionalization.[24] The toluene complexes are probably among the easiest to make in high yields, and they are photolyzed under ambient conditions in a few hours with the visible light of an ordinary desk lamp. Such visible-light photolysis has already been used to introduce other arene ligands in dichloromethane[25] or phosphine and acetonitrile ligands, leading to piano stool Fe^{II} complexes in acetonitrile.[26]

The new syntheses are performed by irradiating mixtures of the complexes [CpRFe(η^6-toluene)][PF_6] and CpR′M (M = Li or Na) in MeCN or CH_2Cl_2 using a 100-W desk lamp under ambient conditions overnight to provide the mono- or heterodifunctional ferrocenes according to eq 1. High yields are obtained for a large array of R and R′ groups (eq 1, Tables 1 and 2).

Table 1. Yields of Monofunctional Ferrocenes Obtained under Ambient Conditions upon Photolysis with a 100-W Desk Lamp According to Eq 1 from [(η^5-C_5H_5)Fe(η^6-toluene)][PF_6] and CpR′M, M = Li or Na) after Flash Chromatography[a]

C_5H_5Fe(CpR′)	R′	yield (%)
1	CO_2Me	98
2	PPh_2	51
3	$SiMe_2CH_2Cl$	80

[a] Reactions were carried out in MeCN or **1** and **2** and in CH_2Cl_2 for **3**.

Limitations involving reduced yields are only encountered when the R or R′ group contains a strongly coordinating anionic ligand such as carboxylate or, to a lesser extent, phosphine. The advantage of the reaction is that it is extremely facile to carry out and only subsequently requires quick flash chromatography on a short silica gel column to purify the ferrocene derivative obtained. All attempted trials

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Table 2. Yields of Heterobifunctional Ferrocenes Obtained under Ambient Conditions upon Photolysis with a 100-W Desk Lamp According to Eq 1 from [(CpR)Fe(η^6-toluene)][PF_6] and CpR′M, M = Li or Na) after Flash Chromatography[a]

Fe(CpR)(CpR′)	R	R′	yield (%)
4	COMe	CO_2Me	95
4	CO_2Me	COMe	88
5	COMe	$SiMe_2CH_2Cl$	75
6	CO_2H	COMe	15
7	$CO_2CH_2C{\equiv}CH$	CO_2Me	85
8	$CONHCO_2Ph$	CO_2Me	70
9	Cl	CO_2Me	90
10	Me	CO_2Me	98

[a] The reactions were carried out in MeCN, except for **5** in CH_2Cl_2.

are reported in Table 1 with unoptimized yields; no failure was observed, and the reaction could potentially be extended to a large variety of other compounds of the type CpR′M (M = Li or Na) and other complexes of the family [(CpR)Fe([η^6-arene)] [PF_6].

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Supporting Information Available: Spectroscopic and analytical data and spectra of new ferrocenyl derivatives and additional bibliographic information for known compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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