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Alkoxymethylation of ferrocenylalkenes *

Andreas Ketter and Rudolf Herrmann *

Organisch-Chemisches Institut der Technischen Universität München, Lichtenbergstr. 4, D-8046 Garching (F.R.G.)

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Abstract

The reaction of ferrocenylalkenes with chloromethyl alkyl ethers catalyzed by Lewis acids gives 3-alkoxy-1-ferrocenyl carbocations, which can be trapped by nucleophiles to give 1,3-disubstituted ferrocenylalkane derivatives. The application of this reaction to the preparation of chiral 3-hydroxy-1-ferrocenylalkylamines is described; their structures and conformations have been elucidated by NMR spectroscopy. The stereochemical course of the alkoxymethylation reaction involves "*exo*" attack of the chloromethyl ether at the β carbon of the double bond relative to the ferrocene, and subsequent "*exo*" attack of the nucleophile at the carbocationic centre formed in the first step.

Introduction

Whereas much is known about alkylferrocene derivatives with one functional group, particularly α to the ferrocene, there are only a few reports on compounds containing two (or more) different functional groups separated by two or more carbon atoms [e.g. 1–3]. Such ferrocene derivatives can be expected to behave as interesting chelating ligands in metal complexes, and if they can be prepared in optically active form, they should be able to catalyze asymmetrically a variety of organic reactions. We have described a method for synthesising substituted ferrocenylethyl methyl ethers [4], in which the two functional groups are separated by two carbon atoms, and we now report a simple and quite general method for the construction of substituted ferrocenylpropyl alkyl ethers in which the two functional groups are separated by three carbon atoms. The method involves alkylation of ferrocenylalkenes with chloromethyl alkyl ethers in the presence of Lewis acids. Alkylation of ferrocenylalkenes has not been carried out previously although the addition of chloroalkyl ethers to alkenes has many applications in the synthesis of 3-alkoxy-1-chloroalkenes [5,6].

* Dedicated to Prof. Dr. Karl Schlögl on the occasion of his 65th birthday.

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Results and discussion

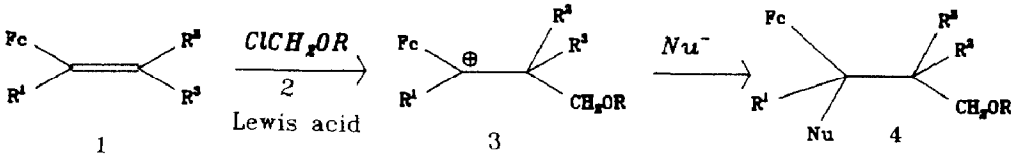
In contrast to the alkoxyalkylation of conventional alkenes, in which the intermediate carbocations cannot be isolated, but are trapped in situ by the halogenide, the extraordinary ability of the ferrocene system to stabilize positive charges [7] leads to the formation of carbocations **3**, that are stable under the reaction conditions. These ions react in a subsequent step with nucleophiles to form the desired 1,3-disubstituted ferrocenylalkyl derivatives **4** (Fig. 1).

The alkoxymethylation reaction seems to be quite general for many ferrocenylalkenes, although some limitations should be noted. First, the simplest compound, vinylferrocene, does not give monomeric products, but undergoes oligo- and polymerisation. Second, ferrocenylalkenes having aromatic rings conjugated with the double bond are completely unreactive; the reason for this is not obvious.

The choice of the Lewis acid is crucial for the success of the reaction. $TiCl_4$ and $SnCl_4$ act as oxidizing agents, destroying the ferrocene system. Better results were obtained with $ZnCl_2$, but the Lewis acid of choice is $TiCl_2(O\text{-}i\text{-}Pr)_2$, prepared in situ by mixing equivalents of $TiCl_4$ and $Ti(O\text{-}i\text{-}Pr)_4$. Since it is a liquid, this compound can be used in a homogeneous reaction and this leads to highly reproducible results, whereas the yields with less soluble solid Lewis acids (e.g. $ZnCl_2$ and $AlCl_3$) vary greatly (see Table 1).

The structures of the products of the alkoxymethylation reactions were determined by NMR techniques (Table 2) and confirmed by mass and IR spectra (Table 3).

Mixtures of diastereoisomers are formed when the double bond bears four different substituents. The diastereomeric ratio depends on the substituent R in the chloromethyl ether, lower diastereoselectivity being observed with the bulkier benzyl group. It was not possible to assign (*R,R/S,S*) and (*R,S/S,R*) isomers. If unhindered rotation around the ferrocene–alkylidene bond is assumed, a ratio close to 1 could be expected. However, the alkene **1a**, which is a derivative of enantiomerically pure (−)-menthone [8], gives a enantiomerically pure azide **4g** (see Fig. 2). The introduction of the very large menthyl substituent hinders the rotation around the ferrocene–methylidene bond and fixes the conformation of the ferrocene in such a manner that the sterically less cumbersome part of the menthyl moiety points down ("*endo*") towards the unsubstituted cyclopentadienyl ring, and the main part of the molecule remains above the plane of the substituted cyclopentadienyl ring, as shown in Fig. 2. It is well known from an X-ray structural study of the amine obtained by protonation of the alkene **1a** and subsequent azide substitution that the protonation occurs from the "*exo*" side of the ferrocene in this most



R = CH_3, CH_2Ph

Fig. 1. Alkoxymethylation of ferrocenylalkenes.

(*continued on p. 246*)

Table 1

Amines and azides obtained by alkoxymethylation of ferrocenylalkenes

Alkene 1			$ClCH_2OR$	nucleophile	Lewis acid	Temperature	Time	Product	Yield (%)	Remarks
R^1	R^2	R^3	R:			(°C)	(h)	**4**		
H	H	H	Me	N_3	$ZnCl_2$	20	17		0	polymer
H	H	H	Me	N_3	$SnCl_4$	−30	17		0	oxidation
H	H	H	Me	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−30	17		0	polymer
H	Me	Me	Me	N_3	$ZnCl_2$	20	20	**4a**	60	
H	Me	Me	Me	N_3	$AlCl_3$	−30	20	**4a**	15	[a]
H	Me	Me	Me	$HNMe_2$	$HgCl_2$	0	18	**4b**	5	[b]
H	Me	Me	Me	N_3	$TiCl_4$	−30	17		0	oxidation
H	Me	Me	Me	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	20	20	**4a**	68	
H	Me	Me	Me	$HNMe_2$	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	20	**4b**	86	
H	Me	Me	Me	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	20	**4a**	67	
H	Me	Me	CH_2Ph	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	20	**4e**	51	
Me	Me	Me	Me	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−30	20		0	[c]
H	Me	Pr	Me	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	20	**4c**	76	[d]
H	Me	Pr	Me	$HNMe_2$	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	20	**4d**	79	[d]
H	Me	Pr	CH_2Ph	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	20	**4d**	45	[e]
H	Me	Ph	Me	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−30	17		0	[f]
Ph	H	Ph	CH_2Ph	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−30	17		0	[f]
CH_2Ph	H	Ph	CH_2Ph	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−30	17		0	[f]
$(CH_2)_4$		H	CH_2Ph	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	20		0	[g]
Me	H	$CH{=}CH_2$	CH_2Ph	N_3	$TiCl_2(O\text{-}i\text{-}Pr)_2$	−35	17		0	[h]

[a] Low conversion. [b] Many by-products. [c] The product was 2-ferrocenyl-3,3-dimethyl-4-methoxy-1-butene (45%). [d] Mixture of diastereoisomers, ratio 2.2. [e] Mixture of diastereoisomers, ratio 1.2. [f] No reaction. [g] Complex mixture of products. [h] Only dimers and trimers of the diene were formed.

Table 2

NMR spectra of the compounds **4**, δ-values in ppm, solvent $CDCl_3$

Compound	C/H	Cp (unsubst.)	Cp (subst.)	α(CH)	β(C)	$\gamma(CH_2)$	R^2	R^3	R	X
4a	H	4.23	4.14	4.35(s)	–	2.96, 3.14 (d, 8.9 Hz)	0.71, 0.80 (2s, 3H each)		3.34 (s, 3H)	–
	C	68.6	67.0, 67.2 67.4, 87.6	66.9	40.6	68.8	20.9, 21.4		58.7	–
4b	H	4.15	4.05 (2H), 4.10 (2H)	3.45(s)	–	2.93, 3.32 (d, 8.5 Hz)	0.94, 1.02 (2s, 3H each)		3.34 (s, 3H)	2.33 (s, 6H)
	C	68.9	66.5, 66.8, 67.8, 86.3	66.1	41.7	70.0	21.8, 24.0		58.7	44.3
4c	H	4.22	4.01–4.14	4.37(s)	–	2.90, 3.07 (d, 9.0 Hz)	0.67(s)	0.77–1.55 (m, 7H)	3.27	–
other diast.				4.38(s)	–	3.07, 3.17 (d, 8.9 Hz)	0.64(s)		3.32	–
	C	68.6	67.3, 67.4, 87.7	66.9	43.0	69.0	17.7	14.9, 16.8, 36.6	58.6	–
other diast.			87.8	67.0		69.3	17.9	15.0, 16.9, 37.0		–

4d	H	4.14	4.06–4.11	3.42(s)	–	2.87, 3.00 (d, 8.8 Hz)	0.70–0.90 (6H) 1.10–1.50 (m, 4H)		3.25	2.28(s)
other diast.				3.48(s)	–	3.16, 3.28 (d, 8.8 Hz)			3.31	2.43(s)
	C	68.2	65.9–67.5, 86.4	65.2	40.6	69.5	17.2	14.9, 16.7, 36.9	57.9	44.9
other diast.		68.3	86.5	65.3		69.9	17.4	15.2, 16.9, 38.0		44.6
4e	H	4.20	4.13	4.41(s)	–	3.04, 3.25 (d, 8.8 Hz)	0.72, 0.80(2s, 3H each)		4.47, 4.52 (d, 12.0 Hz), 7.35 (m, 5H)	–
	C	68.7	66.9, 67.0, 67.5, 87.8	67.2	40.7	73.2		20.9, 21.5	68.9, 127.6, 127.7, 128.4, 138.5	–
4f	H	4.22	4.10–4.13	4.71(s)	–	3.08, 3.25 (d, 9.0 Hz)	0.67 (tr, 3H) 0.78–1.43 (m, 7H)		4.48 (s, 2H), 7.37 (m)	–
other diast.				4.73(s)	–	3.18, 3.33 (d, 9.1 Hz)			4.51 (s, 2H)	–
	C	68.7	67.3–67.4, 87.9	67.0	43.3	73.1	17.9	14.8, 16.8, 36.6	69.3, 127.6, 127.7, 128.2, 138.5	
other diast.					43.1			14.9, 16.9, 36.9		–

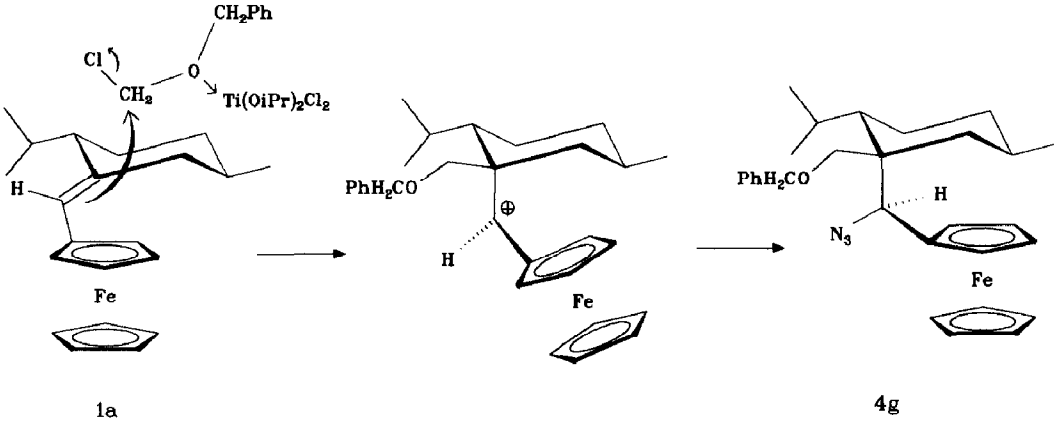
Table 3

Properties of the compounds obtained by alkoxymethylation of ferrocenylalkenes and subsequent reactions

Compound	R^1	R^2	R^3	R	X	Yield (%)	MS	Others [a]
4a	H	Me	Me	Me	N_3	86	327 (M^+, 100%)	IR 2090 cm^{-1}
4b	H	Me	Me	Me	NMe_2	67	329 (M^+) 242 (100%)	–
4c	H	Me	Pr	Me	N_3	76	355 (M^+, 100%)	IR 2095 cm^{-1}
4d	H	Me	Pr	Me	NMe_2	79	357 (M^+) 242 (100%)	–
4e	H	Me	Me	CH_2Ph	N_3	51	403 (M^+, 100%)	IR 2100 cm^{-1}
4f	H	Me	Pr	CH_2Ph	N_3	45	431 (M^+, 100%)	IR 2095 cm^{-1}
5a	H	Me	Me	Me	NH_2	78	301 (M^+) 214 (100%)	–
5b	H	Me	Pr	Me	NH_2	86	329 (M^+) 214 (100%)	–
5c	H	Me	Me	CH_2Ph	NH_2	59	377 (M^+) 214 (100%)	–
5d	H	Me	Pr	CH_2Ph	NH_2	62	405 (M^+) 214 (100%)	–
6a	H	Me	Me	H	NH_2	42	287 (M^+) 214 (100%)	m.p. 92–93 °C

[a] Compounds for which no melting points are given were oils.

stable conformation [9]. To determine the side-selectivity of the alkoxymethylation, we studied the products by NMR spectroscopy. For convenience we used the aminoalcohol obtained from the original azide **4g** by reduction of the azide and the benzyl group, because this gave less overlap in the ^1H NMR signals of the aliphatic region. With too much overlap, NOE experiments would become unreliable. The spectral data for **4g**, of the product of the azide reduction **5e**, and for the aminoalcohol **6b**, are listed in the Tables 4 and 5. For identification of all signals, COSY, DEPT, and inverse C–H correlation [10,11] were necessary. The particularly difficult assignments of the ^{13}C signals of the CH_2 groups in all three compounds were based on the combination of COSY (which shows the coupling between the



1a 4g

Fig. 2. Benzyloxymethylation of the chiral ferrocenylalkene **1a**.

Table 4

^{1}H NMR data for the compounds obtained by benzyloxymethylation of **1a** and subsequent reactions, δ-values in $CDCl_3$

Compound proton(s)	**4g**	**5e**	**6b**
1′	4.25	4.14	4.18
2–5	4.16 (4H)	4.11 (2H), 4.18 (2H)	4.48 (1H), 4.16 (1H), 4.20 (2H)
6	4.65	4.08	4.27
8	1.40 (dq, 3.4, 14.0 Hz)	1.44 (dq, 4.0, 12.5 Hz)	1.42 (dq, 3.5, 12.6 Hz)
9	1.07 (tr, 14.0 Hz), 1.10 (m)	0.93 (tr, 14.0 Hz), 1.05 (dtr, 3.1, 14.0 Hz)	0.12 (ax, tr, 13.6 Hz), 0.85 (eq, m, 13.6 Hz)
10	0.87 (m), 1.78 (m)	0.84 (m, 12.5 Hz), 1.74 (m, 12.5 Hz)	0.78 (eq, m), 1.76 (ax, m, 13.6 Hz)
11	0.90	0.98	0.99
12	1.53 (m), 1.63 (m)	1.56 (m), 1.60 (m)	1.48 (m), 1.62 (m)
13	2.30	2.31 (6.8 Hz)	2.98 (7.4 Hz)
14, 15	0.90 (7.0 Hz), 0.91 (6.5 Hz)	0.93, 0.99	1.00, 1.02
16	0.75 (6.5 Hz)	0.70 (6.5 Hz)	0.68 (6.5 Hz)
17	2.89, 3.62 (8.2 Hz)	3.11, 3.81 (9.4 Hz)	3.24 (1.5, 10.4 Hz), 3.64 (10.4 Hz)
R, X	4.36 (s), 7.26 (m, 5H)	1.83 (br), 4.39 (d), 4.43 (d, 12.2 Hz), 7.28 (m, 5H)	1.37, 3.40 (br)

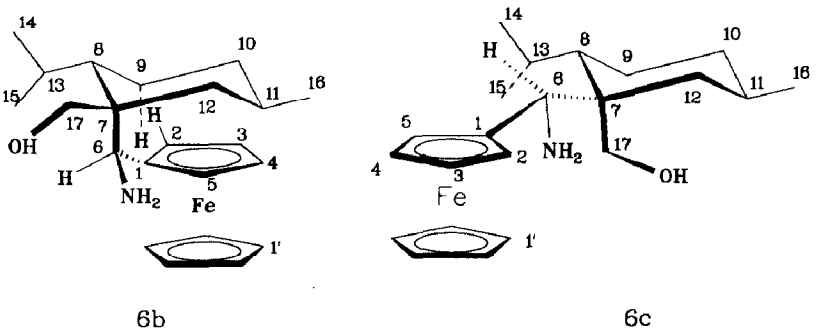
protons at C(9) and C(10)) and C–H correlation, and conform the somewhat unexpected chemical shifts of C(12) (e.g., δ 22.8 ppm in **6b**).

Two structures, **6b** and **6c**, can a priori be expected for the reduction products of the azide, resulting from "*exo*" (for **6b**) or "*endo*" (for **6c**) attack (relative to ferrocene) of the alkoxymethylation reagent at the β carbon of the double bond

Table 5

^{13}C NMR data for the compounds obtained by benzyloxymethylation of **1a** and subsequent reactions, δ-values in $CDCl_3$.

Compound C atom (s)	**4g**	**5e**	**6b**
1′	69.0	68.7	68.4
1	89.7	94.7	93.1
2–5	67.0, 67.4, 67.7, 68.0	66.4, 66.8, 67.1, 68.3	66.4, 66.7, 67.7, 68.8
6	63.2	47.2	52.2
7	46.6	44.5	42.3
8	46.5	50.7	53.7
9	41.9	42.9	44.0
10	35.8	35.9	35.7
11	27.9	27.7	27.8
12	22.7	22.6	22.8
13	25.5	25.3	26.0
14, 15	18.9, 25.7	19.2, 25.7	19.3, 26.2
16	22.3	22.4	22.3
17	73.5	73.3	74.3
R, X	71.8, 127.2, 127.4 128.1, 138.8	73.2, 127.1, 127.3 128.1, 139.1	– –



6b 6c

Fig. 3. Assignment of NMR signals; and configuration and conformation in the chiral aminoalcohol **6**.

(compare Fig. 3). The configuration at the carbocationic centre is thus determined by the donating and stabilizing influence of the ferrocene [7], and attack of the nucleophile at the cation has been shown generally to take place at the "*exo*" side, to give retention of the configuration at this carbon atom [12].

The decision as to whether the compound obtained is **6b** or **6c**, was based on NOE measurements. We used the rotating frame technique (ROESY) [13–16]. A characteristic interaction between the axial H(9) (δ 0.12 ppm) and a proton of the substituted cyclopentadienyl ring at δ 4.48 ppm pointed to close vicinity, which is possible only if the ferrocenylmethyl substituent is in an axial position at the cyclohexane ring. Thus, the compound must be **6b**, and not **6c**, which implies that the stereochemistry of alkoxymethylation is very similar to that of protonation, the initial attack of the chloromethyl ether being "*exo*" relative ferrocene. The unusual chemical shift of the axial H(9) (δ 0.12 ppm) compared with that of its equatorial counterpart (δ 0.85 ppm) may be accounted for in terms of the shielding effect of the cyclopentadienyl ring current, confirming that the compound adopts a conformation in which the ferrocene lies (at least partly) "under" the cyclohexane ring. Other NOE effects between protons not directly coupled (equatorial H(9) and H(13); H(8) and H(17)) and the absence of an NOE effect between H(6) and H(8) confirm this model. A conformation which is in accord with the observed NOE effects is shown in Fig. 3.

The chemical behaviour of the azides obtained from chloromethyl benzyl ether is unique in respect of attempted catalytic hydrogenation, which should cleave off both the azide and benzyl functions. Under the usual conditions (room temperature, Pd/C catalyst, low H_2 pressure) neither the azide nor the benzyl group react. The resistance of ferrocenylalkyl azides to catalytic hydrogenation is a general phenomenon, but the influence on the benzyl group separated from the ferrocene by four atoms is unexpected. Only after reduction of the azide by lithium aluminium hydride could the benzyl group be removed, to give the amino alcohols.

The new products are of interest as chelating ligands for metal ions with potential to catalytic applications. The *N*-tosylate of the chiral amino alcohol **6b** is currently being tested as a ligand for the preparation of chiral Lewis acids to be used as catalysts for a variety of asymmetrically catalyzed organic reactions, e.g. the Diels–Alder reaction. Other chiral ligands that can be prepared by this technique may have applications in many catalytic asymmetric reactions, such as hydrogenations.

Table 6. NMR data for the compounds **5a–5d** and **6a**, δ-values in $CDCl_3$.

Compound	C/H	Cp (unsubst.)	Cp (subst.)	α(CH)	β(C)	γ(CH_2)	R^2	R^3	R	X(NH_2)
5a	H	4.14	4.11	3.62(s)	–	2.95 3.13 (d, 8.9 Hz)	0.66, 0.67 (2s, 3H each)		3.19(s)	2.00 (br, 2H)
	C	68.2	66.0, 66.7 67.0, 92.3	56.1	38.4	69.4		21.1, 22.2	59.0	–
5b	H	4.15	4.08–4.11	3.63(s)	–	2.91 3.07 (d, 8.8 Hz)	0.65(s)	0.86 (tr, 3H)	3.26(s) 1.08–1.41 (m, 4H)	2.45 (br, 2H)
other diast.				3.69(s)	–	3.01 3.17 (d, 9.0 Hz)	0.76(s)		3.28(s)	
	C	68.2	66.1–66.9 92.2	55.9	44.1	69.2	18.4	14.9, 16.6, 36.7	58.7	–
other diast.			92.5		44.2	69.4	18.5	16.7, 37.4	58.8	–
5c	H	4.15	4.08–4.11	3.68(s)	–	3.07 3.23 (d, 8.9 Hz)	0.80, 0.83 (2s, 3H each)		4.45, 4.50 (d, 12.2 Hz), 7.30 (m)	2.29 (br, 2H)
	C	68.3	66.7, 67.0 92.3	56.2	38.5	73.2		21.2, 22.4	69.4, 127.4, 128.3, 138.7	–
5d	H	4.15	4.11	3.67(s)	–	3.04 3.18 (d, 9.0 Hz)	0.66(s)	0.81–1.42 (m, 7H)	4.42 (s, 2H) (m), 7.30 (m)	1.95 (br, 2H)
other diast.				3.75(s)	–	3.12 3.26 (d, 9.1 Hz)	0.78(s)		4.45 (s, 2H)	
	C	68.3	66.3, 66.7 66.8, 67.0, 92.5	56.0	40.8	73.2	18.6	15.0, 16.8, 36.7	69.4, 127.4, 127.5, 128.3, 138.7	
other diast.			92.8	56.0	40.9	73.2		16.9, 37.5	69.6	
6a	H	4.16	4.12	3.57(s)	–	3.23 3.47 (d, 10.7 Hz)	0.64, 1.02 (2s, 3H each)		3.25 (br, 1H)	3.71 (br, 2H)
	C	68.3	67.1, 67.3 67.5, 91.1	60.2	37.7	69.6		21.2, 23.7	–	–

Experimental

NMR spectra were recorded on a Bruker AM 360 spectrometer, IR spectra on a Perkin Elmer 157 spectrophotometer, and mass spectra on a Varian CH 5 instrument. (Chloromethyl)-methyl and -benzyl ether were prepared by known procedures [17,18]. All reactions involving ferrocenyl carbocations were performed under nitrogen. The starting alkenes were made from ferrocene and carbonyl compounds [8,9,19,20], or from acetylferrocene by the Wittig reaction [21,22] or by Grignard reaction followed by dehydration under acidic conditions [23]. Vinylferrocene was prepared as previously described [24].

General method for the alkoxymethylation of ferrocenylalkenes

To a solution of the alkene **1** (50 mmol) in dichloromethane (100 ml) were added the chloromethyl alkyl ether **2** (60 mmol) and the Lewis acid (60 mmol), under the conditions specified in Table 1, and the mixture was stirred for the time indicated. For the preparation of azides, the solution of the carbocation was added dropwise to a saturated solution of LiN_3 [25] in methanol (100 ml) containing triethylamine

Table 7

Microanalytical data for new compounds

Compound	Formula	Mol. weight	Analysis (found (calcd.) (%))		
			C	H	N
4a	$C_{16}H_{21}FeN_3O$	327.21	58.4 (58.7)	6.1 (6.4)	13.0 (12.8)
4b	$C_{18}H_{27}FeNO$	329.26	66.1 (65.7)	8.0 (8.3)	4.1 (4.3)
4c	$C_{18}H_{25}FeN_3O$	355.26	61.3 (60.9)	7.1 (7.1)	11.6 (11.8)
4d	$C_{20}H_{31}FeNO$	357.32	67.0 (67.2)	8.3 (8.7)	3.6 (3.9)
4e	$C_{22}H_{25}FeN_3O$	403.31	65.1 (65.5)	6.4 (6.3)	10.6 (10.4)
4f	$C_{24}H_{29}FeN_3O$	431.36	66.6 (66.8)	7.0 (6.8)	10.0 (9.7)
4g	$C_{29}H_{37}FeN_3O$	499.48	70.1 (69.7)	7.4 (7.5)	8.3 (8.4)
5a	$C_{16}H_{23}FeNO$	301.21	64.2 (63.8)	7.6 (7.7)	4.6 (4.7)
5b	$C_{18}H_{27}FeNO$	329.26	65.3 (65.7)	8.1 (8.3)	4.2 (4.3)
5c	$C_{22}H_{27}FeNO$	377.31	69.7 (70.0)	7.1 (7.2)	3.6 (3.7)
5d	$C_{24}H_{31}FeNO$	405.36	70.9 (71.1)	7.9 (7.7)	3.6 (3.5)
5e	$C_{29}H_{39}FeNO$	473.48	73.5 (73.6)	8.2 (8.3)	3.0 (3.0)
6a	$C_{15}H_{21}FeNO$	287.18	63.0 (62.7)	7.1 (7.4)	5.0 (4.9)
6b	$C_{22}H_{33}FeNO$	383.36	68.8 (68.9)	8.9 (8.7)	3.6 (3.7)

(150 mmol), at −40 °C. The mixture was then allowed to warm to room temperature, water (300 ml) was added, and the mixture was extracted three times with ether (200 ml). The extracts were dried (Na_2SO_4) and the solvent evaporated. The residue was purified by chromatography (silica gel/hexane).

In the preparations of the dimethylamine derivatives, the solution of the carbocations was added dropwise with very efficient stirring to a solution of dimethylamine (200 mmol) in 2-propanol (100 ml) at −70 °C. Work-up was as described for the azides. The products were purified by chromatography (silica gel/dichloromethane). The yields and properties of the compounds are given in Table 1. Their NMR data are listed in Tables 2, 4 and 5, other spectroscopic data in Table 3, and microanalyses in Table 7.

*1-{Azido[(1R,2S,5R)-1-phenylmethoxymethyl-2-isopropyl-5-methylcyclohexyl]-(S)-methyl}ferrocene (**4g**).* Yield: 40%, m.p. 109–110 °C, IR (KBr): 2100 cm^{-1}, MS: 499 (M^+, 100%), $[\alpha]_D^{22}$ + 83.8° (*c* 0.6, $CHCl_3$).

The reduction of the azido group to the amine by $LiAlH_4$ follows standard procedures [8,9,20]. The yields and properties of the products are shown in Table 3, their NMR spectra in the Tables 4,5 and 6, and microanalyses are found in Table 7.

*1-{Amino[(1R,2S,5R)-1-phenylmethoxymethyl-2-isopropyl-5-methylcyclohexyl]-(S)-methyl}-ferrocene (**5e**).* Yield: 69%, oil, MS: 473 (M^+) and 214 (100%), $[\alpha]_D^{22}$ + 60.9° (*c* 0.9, $CHCl_3$).

Catalytic hydrogenation of the aminobenzyl ethers

To a solution of the benzyl ether **5** (10 mmol) in methanol (50 ml) were added 100 mg of Pd on charcoal (10%), and hydrogenation was performed at 1.1 bar. The hydrogen uptake was complete after about 20 h. The solution was filtered, the solvent evaporated and the residue purified by recrystallization from hexane or by chromatography (silica gel/hexane). The yields and properties of the products are listed in Table 3, their NMR data in the Tables 4, 5 and 6, and the microanalyses in Table 7.

*1-{Amino[(1R,2S,5R)-1-hydroxymethyl-2-isopropyl-5-methylcyclohexyl]-(S)-methyl}ferrocene (**6b**):* Yield: 49%, m.p. 137–139 °C, MS: 383 (M^+) and 214 (100%), $[\alpha]_D^{22}$ + 47.3° (*c* 0.4, $CHCl_3$).

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