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ASYMMETRIC LITHIATION OF FERROCENES*

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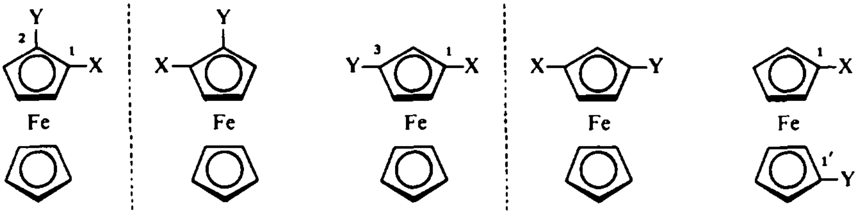
Abstract—Lithiation of isopropylferrocene by means of n-butyllithium-(−)-sparteine complex (**4**) gives dissymmetric 3,1′-dilithio-1-isopropylferrocene (**6**), whose derivatization yields (+)-1,1′-bis(trimethylsilyl)-3-isopropylferrocene (**7a**) or (+)-3-isopropylferrocene-1,1′-dicarboxylic acid (**7c**). The (+)(1*S*)-dicarboxylic acid **7c** has been correlated with (+)(1*S*)-3,1′-dimethylferrocene-1-carboxylic acid (**9a**). Asymmetric lithiation at 2-position is achieved in the metallation of (+)-(N-α-pipecolylmethyl)ferrocene (**11**) with n-butyllithium to afford (1*R*)-2-lithioamine (**12**), which serves as an intermediate for the preparation of chiral 2-trimethylsilyl and 2-bromo substituted ferrocene derivatives (**14c** and **14**) of the known absolute configuration. Finally the absolute configuration of (+)(1*S*, 1′*S*)-2,2′-dimethylbiferrocenyl (**15**) has been established chemically.

Introduction of two different substituents X and Y in ferrocene gives rise to three positional isomers (**1**, **2** and **3**) and both α (**1**) and β derivatives (**2**) can be resolved into optical antipodes (Scheme 1). Schlögl *et al.* have studied the ferrocene chirality to establish the absolute configuration of more than one hundred of such compounds.[2] We now wish to report the asymmetric syntheses of lithioferrocenes (**1** and **2**: X = Li), which would serve as "key intermediates" in establishing the absolute configuration of certain new ferrocene derivatives. The versatile synthetic utility of lithioferrocenes has been well documented.[3]

Scheme 1



1 (α) **2** (β) **3**(hetero)

Asymmetric 3,1′-*dilithiation of isopropylferrocene in the presence of* (−)-*sparteine*

Recently discovered complex of n-butyllithium and N,N,N′,N′-tetramethylethylenediamine (TMEDA) greatly improved the selectivity in lithiation of ferrocene to give the 1,1′-dilithio product exclusively.[4]

(−)-Sparteine[5] as a chiral bidentate ligand gives a modified organolithium (**4**), which has been found to be an asymmetry inducing reagent in the reaction with *gem*-dibromocyclopropanes producing allenes[6a] or in the one with ketones and aldehydes producing carbinols.[6b] Lithiation of isopropylferrocene (**5**) was effected by

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[*] Parts of this paper were published in a preliminary form (Ref. 1).

means of a mixture of n-BuLi and (−)-sparteine (2·5 equivs each) in hexane at −70°* and the resulting mixture was treated with excess trimethylsilyl chloride (Scheme 2). GLC of the product indicated the formation of 1,1′-bis(trimethylsilyl)-3-isopropylferrocene (**7a**, 80%) along with the recovered **5** (15%) and other mono- and bis-trimethylsilyl substituted ferrocenes (total 5%). The distributions are summarized in Table 1, which shows that this procedure is more advantageous than that in diethyl ether[7] in order to obtain 3,1′-dilithio-1-alkylferrocene.

The isolated bis(trimethylsilyl) compound **7a** showed optical activity. The dilithioferrocene **6** was fully carbonated and the product was esterified with diazomethane to give (+)-dimethyl 3-isopropylferrocene-1,1′-dicarboxylate (**7b**), whose hydrolysis gave (+)-diacid (**7c**). The rotations are to be found in Table 2.

SCHEME 2

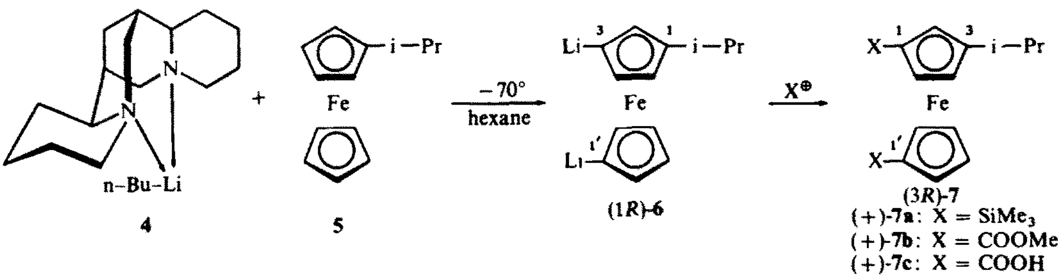

TABLE 1. LITHIATION OF ISOPROPYLFERROCENE

Reagent	Lithiation yield, %	Distribution,[a] % 3	1′	2,1′	3,1′
n-BuLi-(−)-sparteine[b] in hexane	85	2	3	1	94
n-BuLi[c] in diethyl ether	~20	12	28	2	58

[a] Based on GLC analysis (Apiezon L 30%, 240°) of trimethylsilylated products.

[b] Isopropylferrocene was treated with the reagents (2·5 equivts each) at −70° and the mixture was warmed up to room temp during 12 hr.

[c] The reaction was carried out with equimolar n-BuLi at room temp for 30 hr (Ref 7).

TABLE 2. ASYMMETRIC 3,1′-DILITHIATION OF ISOPROPYLFERROCENE

Product[a]	X	$[\alpha]_D$, deg	c, g/100 ml	Yield, %	m.p. (b.p.)
(+)-**7a**	$SiMe_3$	+0·7	5·9 (PhH)	80[b]	(135°/4 mm)
(+)-**7b**	COOMe	+2·5	1·9 (PhH)	58[c]	49–50°
(+)-**7c**	COOH	+3·8	1·3 (MeOH)	53	~180° (dec)

[a] For the racemic modification of these compounds, see Ref. 7. Isopropyl methyl groups were magnetically nonequivalent, cf. Ref. 8. Chemical shift differences (in CCl_4 soln at room temp) were 1·5 Hz for **7a** and 3·0 Hz for **7b** at 60 MHz.

[b] Estimated on GLC (Apiezon L).

[c] Isolated by chromatography on alumina column.

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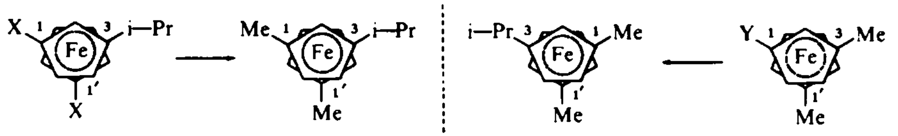
* None of 7 was obtained in optically active form (*vide infra*) when the metallation was carried out at *room temperature.*

Since these compounds have been derivatized from the same dissymmetric 3,1′-dilithio-1-isopropylferrocene **6**, they should have the same absolute configuration and the same optical purity. Among them, (+)(1*S*)-3-isopropylferrocene-1,1′-dicarboxylic acid **7c** is correlated with (+)(1*S*)-3,1′-dimethylferrocene-1-carboxylic acid (**9a**)[9] (Scheme 3) and the optical yield of (1*R*)-**6** is calculated to be *ca* 3%.

The dicarboxylic acid was resolved by means of (−)-phenethylamine salts to give (+)-**7c**, $[\alpha]_D$ +110° (MeOH), which was esterified to dimethyl ester (+)-**7b**, $[\alpha]_D$ +77° (PhH). Reduction of (+)-**7b** with a mixture of LAH and $AlCl_3$ produced (+)-1,1′-dimethyl-3-isopropylferrocene (**8**), b.p. 110°/2 mm, $[\alpha]_D$ +2·0° (cyclohexane). On the other hand, the corresponding enantiomer (−)(1*R*)-**8**, $[\alpha]_D$ −1·0°, was obtained upon similar reduction of (−)(1*S*)-1-(α-hydroxyisopropyl)-3,1′-dimethylferrocene (**9c**), m.p. 49–50°, $[\alpha]_D$ −2·0° (EtOH), which was prepared by the action of two equivalents of methyllithium on (+)(1*S*)-methyl 3,1′-dimethylferrocene-1-carboxylate (**9b**), $[\alpha]_D$ +10° (PhH) or 45% optical purity.

Scheme 3



(+)-**7c**: X = COOH
(+)-**7b**: X = COOMe

(+)-**8**

(−)-**8**

(+)-**9a**: Y = COOH
(+)-**9b**: Y = COOMe
(−)-**9c**: Y = C(OH)Me_2

This assignment was further confirmed by the similarity of ORD spectrum (Fig. 1) of (+)(1*S*)-**7b** to that of (+)(1*S*)-methyl 3-methylferrocene-1-carboxylate (**10**).[9a] It is well known that additional substituent (methoxycarbonyl group in this case) in the second ring exerts no marked influence on the rotation of unsubstituted parent compound.[2]

Asymmetric 2-lithiation of (+)-(N-α-*pipecolylmethyl*) *ferrocene*

Directed lithiation at 2-position of (N,N-dimethylaminomethyl)ferrocene or (N-piperidylmethyl)ferrocene with n-BuLi has been recorded by Hauser *et al.* and the selectivity is ascribed to the intramolecular coordination of nitrogen lone pair to Li atom forming a 5-membered chelate ring.[10] Being interested in the influence of asymmetric ligand in this kind of metallation, we have synthesized (+)(*S*)-(*N*-α-pipecolylmethyl)ferrocene (**11**), m.p. 38–39°, $[\alpha]_D$ +70° (EtOH), by the action of (+)(*S*)-α-pipecoline,[11] $[\alpha]_D$ +33° (neat) or 93% optical purity, on the methiodide of (N,N-dimethylaminomethyl)ferrocene.

This amine (+)-**11** was metallated with n-BuLi in ether–hexane (40:60) at room temperature for 40 hr and the resulting 2-lithioamine (**12**) was treated with an excess of electrophile X[3] to give 2-substituted amine (**13**) (Scheme 4). The methiodide of **13** was allowed to react with a nucleophile Y[12] thoroughly to remove the α-pipecolyl group and the resulting 1,2-disubstituted compound (**14**) was isolated. The results are given in Table 3.

The lithioamine **12** was carbonated to give a lithium salt of amino acid (+)-**13a**, which was quarternized and reduced with sodium amalgam in water. Esterification

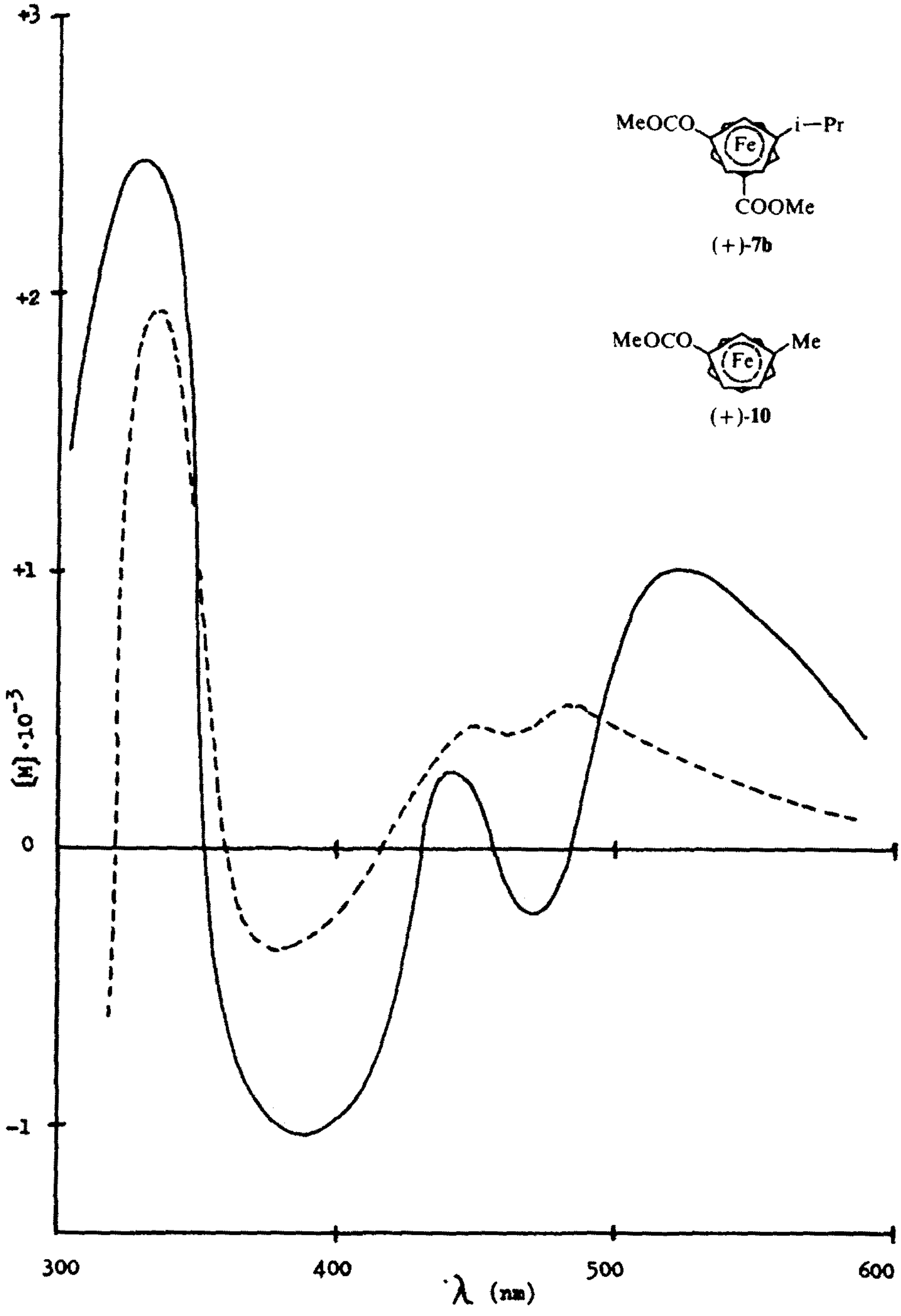
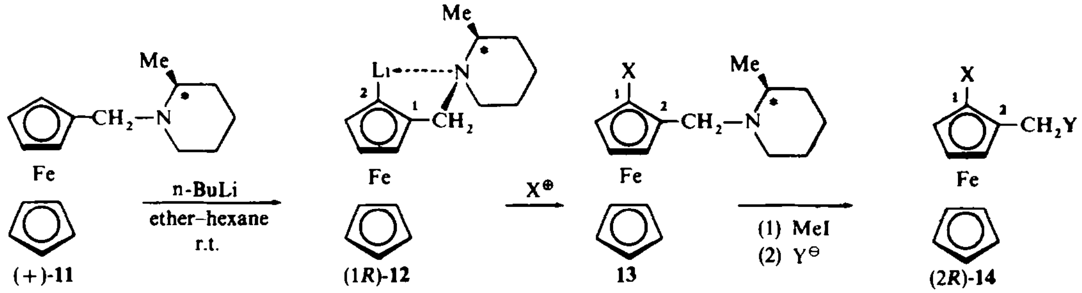


Fig 1. ORD of (+)-**7b** (——) and (+)-**10** (– – –) in ethanol.

SCHEME 4



For X and Y see Table 3

TABLE 3. ASYMMETRIC 2-LITHIATION OF (+)-(N-α-PIPECOLYLMETHYL)FERROCENE (11)[a]

Product[b]	X	CH_2Y	$[\alpha]_D$, deg.	c, g/100 ml	Yield, %	m.p. (b.p.)
(+)-**13a**	COOLi		+56	1·3 (EtOH)	[d]	oil
(−)-**14a₁**	COOMe	CH_3	−10[f]	1·9 (PhH)	24[e]	(125°/1·5 mm)
(−)-**14a₂**	COOMe	CH_2OH	−22	0·81 ($CHCl_3$)	19[e]	oil
(−)-**14b₃**	Me	CHO	−72[c]	0·25 (EtOH)	29[d,e]	solid
(+)-**13c**	$SiMe_3$		+71	1·5 (EtOH)	57[e]	(130°/0·06 mm)
(+)-**14c₁**	$SiMe_3$	CH_3	+3·0	3·6 (PhH)	64	(135°/2 mm)
(+)-**14c₂**	$SiMe_3$	CH_2OH	+1·3	5·2 (PhH)	25	61–62°[j]
(+)-**14c₃**	$SiMe_3$	CHO	+130[c]	0·25 (EtOH)	63	67–70°
(+)-**13d**	$B(OH)_2$		+110	1·2 (EtOH)	[d]	oil
(+)-**13e**	Br		+21	1·3 (EtOH)	37[e]	oil
(+)-**14e₁**	Br	CH_3	+14[c]	2·6 (PhH)	42	65–67°
(+)-**14e₂**	Br	CH_2OH	+6·3	1·9 (PhH)	39	72–73°[g]
(−)-**14e₃**	Br	CHO	−215	0·27 (EtOH)	64	solid[h]

[a] Optical purity was 93 or 96% (Experimental).

[b] All products exhibited NMR and IR spectra consistent with the assigned structures and gave correct elemental analyses.

[c] For optical yields, see text.

[d] Not isolated in pure form.

[e] Based on **11**.

[f] *dl*-Modification, m.p. 63–64° (Ref 14).

[g] *dl*-Modification, m.p. 70–71° (Ref 15).

[h] The semicarbazone, m.p. 207–208° (dec).

with diazomethane followed by chromatography on alumina gave (−)(1*S*)-1-methoxycarbonyl-2-methylferrocene (**14a₁**),[13] $[\alpha]_D$ −10° or 94% optical purity. This means that asymmetric synthesis of **12** of the absolute configuration (1*R*) is achieved in almost quantitative optical yield. The methodide of (+)-**13a** was treated with KOH aq and the resulting 2-hydroxymethylferrocene-1-carboxylic acid was isolated as the methyl ester (−)(1*S*)-**14a₂**.

In contrast, however, a markedly low optical yield was observed in another derivatization. The reaction of **12** with excess methyl iodide gave a crude methiodide of **13b** (X = Me), whose hydrolysis with aq KOH followed by oxidation with active

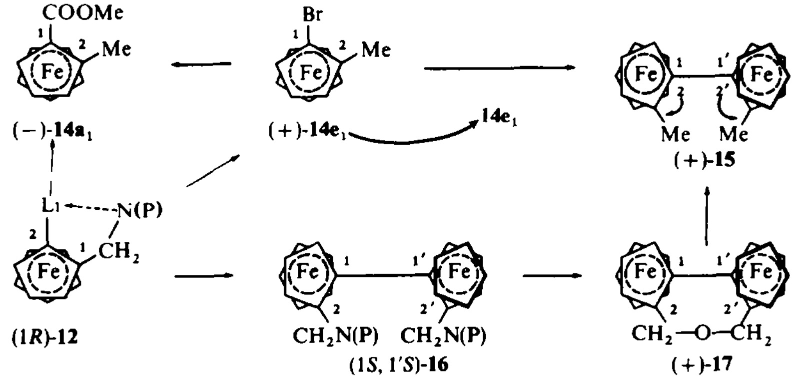
MnO_2 gave (−)(1*S*)-1-methyl-2-formylferrocene (**14b**)[13] contaminated by formylferrocene itself (85:15 ratio by NMR). Calculation based on the rotation of the mixture ($[\alpha]_D$ −61°) indicated that the $[\alpha]_D$ of **$14b_3$** should be 72° (optical purity of 32%). Thus the optical purities of final products **14** were dependent on the reactions by which they were formed.* In any way the predominant formation of (1*R*)-**12** is no doubt and this is verified by further derivatizations.

Optically active 2-trimethylsilyl substituted ferrocenes have been synthesized for the first time. Condensation of **12** with trimethylsilyl chloride gave silyl-amine (+)-**13c**, whose methiodide was reduced with sodium amalgam in water to produce (+)(1*S*)-1-trimethylsilyl-2-methylferrocene (**$14c_1$**).† Hydrolysis of the methiodide in the presence of NaOHaq yielded silyl alcohol (+)-**$14c_2$**, which was oxidized with active MnO_2 to give silyl aldehyde (+)-**$14c_3$**‡

Chiral 2-bromo substituted ferrocenes were prepared as follows. The reaction of **12** with tri-n-butyl borate followed by hydrolysis gave amino boric acid (+)-**13d**, whose treatment with cupric bromide in water gave bromo-amine (+)-**13e**. The methiodide of (+)-**13e** was hydrolysed with KOHaq to give bromo alcohol (+)-**$14e_2$**, which was oxidized with active MnO_2 to bromo aldehyde (−)-**$14e_3$** or reduced with LAH-$AlCl_3$ mixture to (+)(1*R*)-1-bromo-2-methylferrocene (**$14e_1$**).†

The absolute configuration of **$14e_1$** was reconfirmed by the correlation with 2-methylferrocene-1-carboxylic acid[13] (Scheme 5). The bromide (+)(1*R*)-**$14e_1$**, $[\alpha]_D$ +14° (PhH), was subjected to halogen-lithium exchange by means of n-BuLi,[17] the resulting lithioferrocene was carbonated and esterified to give (−)(1*S*)-1-methoxycarbonyl-2-methylferrocene (**$14a_1$**), $[\alpha]_D$ −4·0° (PhH) or 36% optical purity. Calculation based on this correlation indicates that the optically pure **$14e_1$** should have the rotation of 40° in benzene.

SCHEME 5



−N(P) = (*S*)-N-α-pipecolyl

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* This means that the possibility of kinetic effect cannot be excluded during the preparative procedures. To avoid this effect efforts were made to carry out all reactions to completion and to minimize purifications.

† The optical activity of both (+)-**$14c_1$** and (+)-**$14e_1$** is due solely to atomic asymmetry. The ORD observed in the ferrocene band around 450 nm[16] was $[M]_{465}$ + 160° and $[M]_{445}$ + 280°, respectively.

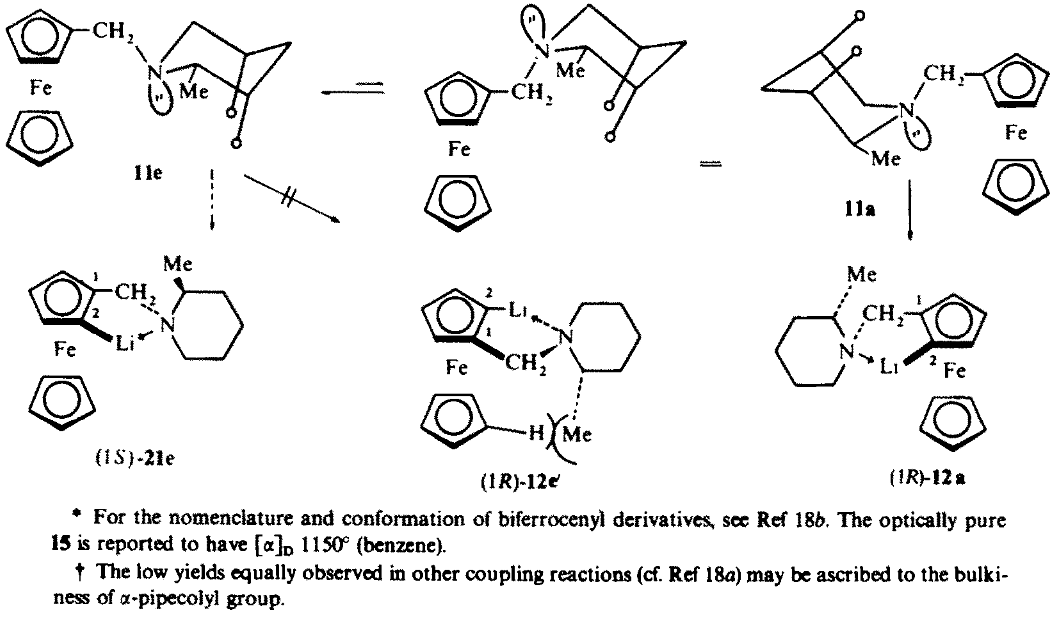
‡ Recently the absolute configuration of (+)(1*S*)-**$14c_3$** was confirmed and the optical purity (67%) was established by G. Gokel, P. Hoffmann, H. Kleimann, H. Klusacek, D. Marquarding and I. Ugi, *Tetrahedron Letters* 1771 (1970)

The synthesis and stereochemistry of 2,2′- and 2,5′-disubstituted biferrocenyl compounds were recently described.[18] We have established the absolute configuration of (+)(1*S*,1′*S*)-2,2′-dimethylbiferrocenyl (**15**)* by direct methods. The Grignard reagent of (+)(1*R*)-**14e**$_1$, $[\alpha]_D$ +12° (PhH) or 30% optical purity, was treated with cobaltous chloride[19] to give a mixture of 2,2′-dimethyl **15** and 2,5′-dimethylbiferrocenyl (55:45 ratio by NMR), which showed $[\alpha]_D$ +340° (PhH). Since 2,5′-isomer is optically inactive, the absolute configuration of (+)-**15** is deduced to be (1*S*,1′*S*). The same conclusion is obtained in another route.

The lithioamine **12** prepared from (+)-**11** of 87% optical purity was subjected to the action of titanium tetrachloride[20] to give a mixture of (1*S*,1′*S*)-biferrocenyl-2,2′-diamine (**16**) and its 2,5′-isomer in low yield.† The dimethiodide of **16** was treated with NaOHaq to give a cyclic ether (+)-**17**, whose reduction with LAH-AlCl$_3$ mixture furnished the desired (+)-**15**, $[\alpha]_D$ +520° (PhH).

Finally the steric aspect in this asymmetric lithiation must be considered (Scheme 6). The most preferred conformer of the amine (*S*)-**11** is presumably **11e**, whose substituents on both nitrogen and carbon are all equatorial.[21] This conformer is expected to give lithioamine (1*S*)-**12e** rather than its diastereomer (1*R*)-**12e**′, as the model inspection shows that there should be a serious interaction between the Me group on α-pipecoline ring and heteroannular aromatic hydrogens which does not favour **12e**′. In contrast to such prediction, the preference for (1*R*) configuration was actually found. This would probably be ascribed to the lithioamine **12a** rather than **12e**′ and accordingly to the intermediacy of the conformer **11a**. The decreased reactivity of **11e** towards the metallation might be explained by assuming that its lone pair is less accessible due to the steric hindrance of axial hydrogens. Flipping on nitrogen gives rise to less preferred conformer **11a**, whose lone pair is appropriately directed to participate in 2-lithiation process leading to (1*R*)-**12a** stereoselectively.

SCHEME 6



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* For the nomenclature and conformation of biferrocenyl derivatives, see Ref 18*b*. The optically pure **15** is reported to have $[\alpha]_D$ 1150° (benzene).

† The low yields equally observed in other coupling reactions (cf. Ref 18*a*) may be ascribed to the bulkiness of α-pipecolyl group.

EXPERIMENTAL

All b.ps and m.ps are uncorrected. Microanalyses were performed at the Elemental Analyses Centre of Kyôto University. IR spectra were obtained in neat liquid films or as KBr pellets on a Shimadzu IR-27-G spectrophotometer. NMR spectra were taken in 10% CCl_4 solns on a JEOL C-60·H spectrometer and chemical shifts are reported in δ values relative to TMS as an internal standard. Optical rotations were measured using a cell of 5 cm length at room temp (20°) and c is given in g/100 ml. ORD spectra were recorded on a JASCO ORD/UV/CD-5 spectropolarimeter in EtOH solns (c in mg/ml) with cells of 1 or 0·2 cm length. Column chromatography was carried out on Sumitomo activated alumina unless otherwise stated. The purity of every product was checked on TLC (Silica Gel G).

Lithiation of isopropylferrocene with n-BuLi-(−)-*sparteine complex and subsequent derivatizations*

(+)(1*S*)-1,1'-*Bis(trimethylsilyl)*-3-*isopropylferrocene* (**7a**). A mixture of n-BuLi (54 mmoles) and (−)-sparteine (11·0 g, 48 mmoles) in hexane (270 ml) was added to a hexane (100 ml) soln of isopropylferrocene (5·0 g, 22 mmoles) at −70° under N_2 in the course of 1 hr. The mixture was stirred for 12 hr under allowing to warm to room temp, then a hexane (100 ml) soln of Me_3SiCl (5·7 g, 53 mmoles) was added at 0° and stirring was continued for 1 hr at room temp. After the reaction mixture was treated with water, the organic layer was washed with HCl aq to remove (−)-sparteine. Evaporation of the solvent gave a dark red oil (8·0 g), which on GLC (Apiezon L 30% 2m, 240°, H_2 40 ml/min, TCD) proved to be a mixture of following components. Substituents on ferrocene, composition and retention time are given in this order: isopropyl-, 15%, 3·3 min; 1-trimethylsilyl-3-isopropyl-, 2%, 5·3 min; 1-trimethylsilyl-1'-isopropyl-, 2%, 5·9 min; 1,1'-bis(trimethylsilyl)-3-isopropyl-, 80%, 8·3 min; and 1,1'-bis(trimethylsilyl)-2-isopropyl-, 1%, 11·0 min. Column chromatography (hexane elution) followed by fractional distillation gave a pure sample of (+)-**7a**, b.p. 134–135°/4 mm, $[\alpha]_D$ + 0·70° (c 5·9, PhH); IR: 3100, 2970, 1250, 1165, 1040, 830 and 755 cm^{-1}; NMR: δ 0·20 (s, 18H), 1·17 (AB-q, $\Delta\nu$ = 1·5 Hz, J = 7·0 Hz, 6H), 2·63 (m, 1H) 3·87 (m, 4H) and 4·13 (m, 3H). (Found: C, 61·5; H, 8·8. $C_{19}H_{32}FeSi_2$ requires: C, 61·3; H, 8·7%).

(+)(1S)-3-*Isopropylferrocene*-1,1'-*dicarboxylic acid* (**7c**) *and its dimethyl ester* (**7b**). A mixture of n-BuLi (54 mmoles) and (−)-sparteine (12·0 g, 51 mmoles) in hexane (120 ml) was added to a hexane (100 ml) soln of isopropylferrocene (5·0 g, 22 mmoles) at −70°. The mixture was warmed under stirring up to room temp in the course of 12 hr, when dry CO_2 gas was bubbled in at 0° and stirring was continued for 2 hr at room temp. The acidic product was taken up in $CHCl_3$. Evaporation of the solvent followed by esterification with diazomethane in ether gave crude **7b**, which was purified by column chromatography (benzene-ether elution) to give a pure sample of (+)-**7b** (4·4 g, 58%), b.p. 135°/0·1 mm or m.p. 49–50°, $[\alpha]_D$ + 2·5° (c 1·9, PhH); IR: 3100, 2950, 1720, 1470, 1370, 1280, 1210, 1190, 1140, 975, 830 and 770 cm^{-1}; NMR: δ 1·25 (AB-q, $\Delta\nu$ = 3·0 Hz, J = 7·0 Hz, 6H), 2·60 (m, 1H), 3·77 (s, 6H), 4·27 (m, 3H) and 4·67 (m, 4H). (Found: C, 59·7; H, 6·1. $C_{17}H_{20}FeO_4$ requires: C, 59·3; H, 5·7%).

A mixture of **7b** (4·5 g, 13 mmoles) and KOH (2·7 g, 48 mmoles) in aqueous MeOH (10%, 54 ml) was heated under reflux for 27 hr. Work-up followed by trituration in aqueous MeOH gave an orange mass of (+)-**7c** (2·2 g, 53%), m.p. ~ 180° (dec), $[\alpha]_D$ + 3·8° (c 1·3, MeOH); IR(KBr): 3200–2400, 1680, 1490, 1300, 1230, 1170, 920, 835 and 750 cm^{-1}. (Found: C, 56·7; H, 5·3. $C_{15}H_{16}FeO_4$ requires: C, 57·0; H, 5·1%).

Chemical correlation of diacid (+)(1S)-**7c** *with monoacid* (+)(1S)-**9a**

Optical resolution of **7c**. A soln of (−)-phenethylamine ($[\alpha]_D$ − 38·7° (neat), 1·7 g, 14 mmoles) in MeOH (20 ml) was added to a soln of (±)-**7c** (2·0 g, 6·3 mmoles) in MeOH (100 ml). Concentration of the reaction mixture gave the salts of (±)-**7c** and 2 moles of (−)-amine (1·2 g, 34%), m.p. 180–191° (dec), $[\alpha]_D$ + 40° (c 3·1, MeOH). (Found: C, 66·5; H, 6·7; N, 5·0. $C_{31}H_{38}FeN_2O_4$ requires: C, 66·8; H, 6·9; N, 5·0%).

Three recrystallizations of this salt from EtOH-MeOH gave a pure sample of single diastereomer (0·32 g, 18%), m.p. 180–196° (dec), $[\alpha]_D$ + 53° (c 2·8, MeOH). Treatment with HCl aq and extraction with $CHCl_3$ afforded (+)-**7c**, m.p. ~ 200° (dec), $[\alpha]_D$ + 112° (c 0·68, MeOH), whose esterification with diazomethane gave dimethyl ester (+)-**7b**, $[\alpha]_D$ + 77° (c 0·78, PhH). The ORD spectrum of (+)-**7b** (c 1·6, EtOH, 1 cm) is reproduced in Fig 1.

(+)(1S)-1,1'-*Dimethyl*-3-*isopropylferrocene* (**8**). A soln of LAH (0·10 g, 2·6 mmoles) and $AlCl_3$ (0·30 g, 2·3 mmoles) in dry THF (10 ml) was added to a soln of (+)-**7b** ($[\alpha]_D$ + 77°, 0·173 g, 0·5 mmole) in THF (5 ml). The mixture was stirred at room temp for 1·5 hr and at reflux temp for 0·5 hr. Work-up followed by column chromatography (hexane elution) gave (+)-**8** (0·092 g, 72%) as a red oil, b.p. 110° (bath)/2 mm, $[\alpha]_D$ + 2·0° (c 1·8, c-C_6H_{12}); IR: 3100, 2950, 1450, 1375, 1300, 1220, 1035, 940, 910 and 810 cm^{-1}; NMR:

δ 1·16 (d, J = 7·0 Hz, 6H), 1·29 (d, 6H), 2·42 (m, 1H) and 3·75 (d, 7H). (Found: C, 70·5; H, 8·5. $C_{15}H_{20}Fe$ requires: C, 70·1; H, 8·2%).

(−)(1S)-1-(α-*Hydroxyisopropyl*)-3,1′-*dimethylferrocene* (**9c**). 3,1′-Dimethylferrocene-1-carboxylic acid (**9a**) was optically resolved by fractional recrystallizations of its (−)-phenethylamine salt from EtOH-ether.[9a] Esterification of (+)(1*S*)-**9a** ($[\alpha]_D$ + 16·0° (*c* 2·2, EtOH) or 45% optical purity based on the reported value 36°) with diazomethane gave methyl ester (+)-**9b**, $[\alpha]_D$ + 10·0° (*c* 2·2, PhH).

An etheral soln of MeLi was prepared by the reaction of MeI (4·7 g, 33 mmoles) with Li (0·7 g, 100 mmoles) in dry ether (100 ml) at − 10°. To an aliquot (25 ml) of this soln an etheral soln of (+)-**9b** (0·44 g, 1·6 mmoles) was added at 0° and the mixture was stirred for 0·5 hr at 0° and further 2 hr at room temp. Work-up gave (−)-**9c** as yellow needles (0·386 g, 88%), m.p. 49–50° (from hexane), $[\alpha]_D$ − 2·0° (*c* 4·3, EtOH); IR: 3300, 3100, 2950, 1455, 1360, 1145, 1040, 955 and 825 cm^{-1}; NMR: δ 1·38 (s, 6H), 1·70 (s, 1H), 1·92 (s, 3H), 1·96 (s, 3H) and 3·75–4·10 (m, 7H). (Found: C, 66·3; H, 7·4. $C_{15}H_{20}FeO$ requires: C, 66·0; H, 7·8%).

(−)(1R)-1,1′-*Dimethyl*-3-*isopropylferrocene* (**8**). To a soln of LAH (0·10 g, 2·6 mmoles) in THF (5 ml) was added a THF (5 ml) soln of (−)-alcohol **9c** ($[\alpha]_D$ − 2·0°, 0·385 g, 1·4 mmoles) and then $AlCl_3$ (0·30 g, 2·3 mmoles) in THF (5 ml). The mixture was stirred for 2 hr at room temp and for 15 min at reflux temp. Work-up followed by column chromatography (hexane elution) and distillation gave (−)-**8** (0·333 g, 92%), $[\alpha]_D$ − 1·0° (*c* 6·6, *c*-C_6H_{12}). The IR and NMR spectra were superimposable on those of (+)-**8** obtained from (+)-**7b**.

Lithiation of (+)-(N-*α-pipecolylmethyl*)*ferrocene and subsequent derivatizations*

(+)(S)-(N-*α-Pipecolylmethyl*)*ferrocene* (**11**). The optical resolution of α-pipecoline was performed by fractional recrystallization of its bitartarate from water.[11a] A mixture of (+)(*S*)-α-pipecoline ($[\alpha]_D$ + 34·7° (neat, d_4^{15} 0·845) or 96% optical purity based on the reported value 36·0°, 20 g, 0·2 mole) and (N,N-dimethylaminomethyl)ferrocene methiodide (24 g, 0·062 mole) in water (20 ml) was stirred under reflux (120°) for 65 hr. Work-up followed by distillation gave (+)-**11** as a dark red oil (16·6 g, 90%), b.p. 130–135°/0·1 mm, $[\alpha]_D$ + 72° (*c* 2·0, EtOH). This sample crystallized on standing as an orange mass, m.p. 38–39°; IR: 1450, 1370, 1320, 1120, 1075, 1000 and 820 cm^{-1}. NMR: δ 1·06 (d, 3H), 0·9–2·9 (m, 9H), 3·44 (AB-q, $\Delta\nu$ = 13 Hz, J = 14 Hz, 2H) and 4·02 (s, 9H); ORD (*c* 1·5): $[M]_{589}$ + 280°, $[M]_{480}$ + 400°, $[M]_{490}$ + 520° and $[M]_{320}$ + 1100°. (Found: C, 68·8; H, 8·0; N, 4·7. $C_{17}H_{23}FeN$ requires: C, 68·7; H, 7·8; N, 4·7%). The picrate was prepared as usual and recrystallized from EtOH, m.p. 156–157° (dec). (Found: C, 52·7; H, 5·0; N, 10·8. $C_{23}H_{26}FeN_4O_7$ requires: C, 52·5; H, 5·0; N, 10·7%).

(−)(1S)-*Methyl* 2-*methylferrocene*-1-*carboxylate* (**14a**$_1$). A hexane soln of n-BuLi (0·75 N, 23 ml, 17 mmoles) was added to a soln of (+)-amine **11** ($[\alpha]_D$ + 70° or 93% optical purity, 1·85 g, 6·2 mmoles) in ether (30 ml) and hexane (30 ml) under N_2 atmosphere. The mixture was stirred at room temp for 42 hr, when excess dry CO_2 gas was bubbled in. After the reaction mixture was treated with water, the aqueous phase was washed with ether and evaporated to dryness to leave a mixture of lithium salts ((+)-**13a**, lithium *n*-valerate and $LiCO_3$) (2·7 g), which showed $[\alpha]_D$ + 56° (*c* 1·3, EtOH). Treatment with excess MeI in MeOH gave a crude methiodide (3·6 g).

An aqueous soln (40 ml) of the crude methiodide (1·8 g) was added to Na-Hg (3·2%, 150 g, 0·22 g atom of Na) and the mixture was heated under reflux for 7 hr. The acidic products were extracted with ether and esterified with diazomethane. Column chromatography (hexane-benzene mixture elution) gave (−)-**14a**$_1$ as a red oil (0·193 g, 24% based on **11**), b.p. 125°(bath)/1·5 mm, $[\alpha]_D$ − 10·0° (*c* 1·9, PhH) or 94% optical purity based on the reported value of 11°;[13] IR: 1720, 1440, 1280, 1210, 1090, 1030, 1000 and 820 cm^{-1}; NMR: δ 2·25 (s, 3H), 3·75 (s, 3H), 4·05 (s, 5H), 4·15 (m, 2H) and 4·60 (m, 1H). (Found: C, 60·3; H, 5·3. Calc. for $C_{13}H_{14}FeO_2$: C, 60·5; H, 5·5%).

(−)(1S)-*Methyl* 2-*hydroxymethylferrocene*-1-*carboxylate* (**14a**$_2$). A mixture of the crude methiodide (1·8 g) obtained above and 5% KOH aq (60 ml, 54 mmoles) was heated under reflux for 26 hr. The acidic products were extracted with ether and esterified with diazomethane. Column chromatography (ether elution) gave (−)-**14a**$_2$ as a red oil (0·162 g, 19% based on **11**), $[\alpha]_D$ − 22° (*c* 0·81, $CHCl_3$); IR: 3450, 1710, 1460, 1290, 1210, 1095, 1000, 820 and 780 cm^{-1}; NMR: δ 3·87 (s, 3H), 4·27 (s) and 4·30–4·83 (m) (total 10 H). The benzoate was prepared as usual and recrystallized from MeOH, m.p. 132°. (Found: C, 63·2; H, 4·8. $C_{20}H_{18}FeO_4$ requires: C, 63·5; H, 4·8%).

Hydrolysis of (−)-**14a**$_2$ gave the free acid, which failed to give γ-lactone on attempted cyclizations.

(−)(1S)-1-*Methyl*-2-*formylferrocene* (**14b**$_3$). A soln of (+)-**11** ($[\alpha]_D$ + 70°, 1·8 g, 6·1 mmoles) in ether (30 ml) and hexane (30 ml) was treated with a hexane soln of n-BuLi (0·55 N, 25 ml, 14 mmoles) at room temp for 42 hr. To an aliquot (65 ml) of this soln MeI (14 g, 100 mmoles) was added. Stirring at room temp for

24 hr and evaporation of the solvents gave a crude methiodide of **13b** (X = Me) (*ca* 2·0 g), which was subjected to the next reaction without further purification. A mixture of the crude methiodide and aq NaOH (4%, 50 ml, 50 mmoles) was heated under reflux for 26 hr. Column chromatography (ether elution) gave a mixture of ferrocenylmethanol and its 2-methylated product **14b**$_2$ (X = Me, $CH_2Y = CH_2OH$) (0·46 g, 46% based on **11**), which was oxidized directly as follows.

A mixture of the alcohols (0·184 g, 0·81 mmole) and active MnO_2 (1·0 g, 12 mmoles) in $CHCl_3$ (5 ml) was stirred overnight at room temp. Column chromatography (benzene elution) gave a mixture of ferrocene-aldehyde and **14b**$_3$ as a red semisolid (0·116 g, 63%), b.p. ~ 140°(bath)/0·15 mm, $[\alpha]_D$ − 61° (*c* 0·25, EtOH). The purity of **14b**$_3$ (85%) was determined by NMR analysis, and the calculated $[\alpha]_D$ of **14b**$_3$ was − 72° or 32% optical purity based on the recorded rotation of 225°;[13] NMR: δ 2·25 (s, 3H), 4·17 (s, 5H), 4·45 (m, 2H), 4·68 (m, 1H) and 10·13 (s, 1H). ORD (*c* 2·5): $[M]_{589}$ − 140°, $[M]_{494}$ − 1250°, $[M]_{450}$ 0°, $[M]_{425}$ + 580°, $[M]_{385}$ + 70°, $[M]_{345}$ + 3000° and $[M]_{324}$ 0°.

α-Trimethylsilyl substituted ferrocenes

(+)-1-*Trimethylsilyl*-2-(N-*α-pipecolylmethyl)ferrocene* (**13c**). A soln of (+)-**11** ($[\alpha]_D$ + 70°, 3·0 g, 10 mmoles) in ether (45 ml) and hexane (45 ml) was treated with a hexane soln of n-BuLi (0·7 N, 35 ml, 25 mmoles) at room temp for 45 hr. To the stirred soln of lithioamine a hexane (30 ml) soln of Me_3SiCl (4·5 g, 41 mmoles) was added at 0° in the course of 30 min. After stirring at room temp for 5 hr, the mixture was heated under reflux for 2 hr. Ether extraction followed by column chromatography (hexane elution) gave (+)-**13c** as a red oil (2·1 g, 57%), b.p. 125–130°/0·06 mm, $[\alpha]_D$ + 71° (*c* 1·5, EtOH); IR: 1240, 1150, 1105, 1080, 1035, 1000, 830 and 750 cm^{-1}; ORD (*c* 1·5): $[M]_{589}$ + 320°, $[M]_{450}$ + 800° and $[M]_{300}$ + 2100°. (Found: C, 65·2; H, 8·7; N, 3·7. $C_{20}H_{31}FeNSi$ requires: C, 65·0; H, 8·5; N, 3·8%). The picrate was prepared as usual and recrystallized from EtOH, m.p. 149–150° (dec). (Found: C, 52·1; H, 5·8; N, 9·4. $C_{26}H_{34}FeN_4O_7Si$ requires: C, 52·2; H, 5·7; N, 9·4%).

(+)(1S)-1-*Trimethylsilyl-2-methylferrocene* (**14c**$_1$). The (+)-silyl-amine **13c** ($[\alpha]_D$ + 71°, 0·39 g, 1·1 mmoles) was quarternized with excess MeI in MeOH. The crude methiodide in water (20 ml) and EtOH (20 ml) was added to Na-Hg (2%, 150 g, 0·13 g atom) and the mixture was heated under reflux for 5 hr. Benzene extraction followed by column chromatography (hexane-benzene mixture elution) gave (+)-**14c**$_1$ as an orange oil (0·183 g, 64%), b.p. 135°(bath)/2 mm, $[\alpha]_D$ + 3·0° (*c* 3·6, PhH); IR: 1240, 1145, 1090, 1070, 1030, 1000, 830 and 750 cm^{-1}; NMR: δ 0·30 (s, 9H), 3·20 (s, 3H), 4·05 (s, 5H) and 4·23 (m, 3H); ORD (*c* 1·5): $[M]_{589}$ + 20°, $[M]_{465}$ + 160°, $[M]_{430}$ + 110°, $[M]_{380}$ + 220° and $[M]_{320}$ + 360°. (Found: C, 61·9; H, 7·5. $C_{14}H_{20}FeSi$ requires: C, 61·8; H, 7·4%).

(+)(1S)-1-*Trimethylsilyl-2-hydroxymethylferrocene* (**14c**$_2$). The crude methiodide of **13c** ($[\alpha]_D$ + 71°, 1·0 g, 2·7 mmoles) was added to 4% NaOH aq (50 ml, 50 mmoles) and the mixture was heated under reflux for 38 hr with stirring. Ether extraction followed by column chromatography (ether elution) gave (+)-**14c**$_2$ (0·262 g, 25%), $[\alpha]_D$ + 1·3° (*c* 5·2, PhH), m.p. 61–62° (from hexane) (*dl*-modification,[14] m.p. 63–64°); IR: 3350, 1240, 1150, 1100, 1075, 1035, 1000, 830 and 750 cm^{-1}; NMR: δ 0·26 (s, 9H), 4·05 (s) and 4·20 (m) (total 10 H). (Found: C, 58·5; H, 7·1. Calc. for $C_{14}H_{20}FeOSi$: C, 58·3; H, 6·9%).

(+)(1S)-1-*Trimethylsilyl-2-formylferrocene* (**14c**$_3$). Active MnO_2 (1·0 g, 12 mmoles) was added to a soln of **14c**$_2$ ($[\alpha]_D$ + 1·3°, 0·167 g, 0·58 mmole) in $CHCl_3$ (5 ml) and the mixture was stirred overnight at room temp. Chloroform extraction followed by column chromatography (benzene elution) gave (+)-**14c**$_3$ as a red solid (0·105 g, 63%), m.p. 67–70°, $[\alpha]_D$ + 130° (*c* 0·25, EtOH); IR: 2950, 1675, 1430, 1330, 1240, 1210, 1150, 1110, 1090, 1040, 1000, 840 and 760 cm^{-1}; NMR ($CDCl_3$): δ 0·32 (s, 9H), 4·25 (s, 5H), 4·54 (m, 1H), 4·70 (m, 1H), 4·96 (m, 1H) and 10·05 (s, 1H); ORD (*c* 2·5): $[M]_{589}$ + 510°, $[M]_{530}$ + 1070°, $[M]_{500}$ 0°, $[M]_{460}$ − 2350°, $[M]_{424}$ 0°, $[M]_{380}$ + 2460°, $[M]_{355}$ 0° and $[M]_{330}$ − 3800°. The semicarbazone was prepared as usual and recrystallized from aq EtOH, m.p. 175–176° (dec). (Found: C, 52·8; H, 6·3; N, 12·2. $C_{15}H_{21}FeN_3OSi$ requires: C, 52·5; H, 6·2; N, 12·2%).

α-Bromo substituted ferrocenes

(+)-2-(N-*α-Pipecolylmethyl)ferrocene-1-boric acid* (**13d**). A soln of (+)-**11** ($[\alpha]_D$ + 72° or 96% optical purity, 8·0 g, 27 mmoles) in ether (90 ml) and hexane (90 ml) was treated with a hexane soln of n-BuLi (1·0 N, 60 ml, 60 mmoles) for 44 hr at room temp. The resulting lithioamine soln was added dropwise to a stirred soln of tri-n-butyl borate (17 g, 74 mmoles) in dry ether (100 ml) at − 70°. The mixture was stirred overnight under allowing to warm up to room temp. Stirring was continued for 24 hr at room temp and for 48 hr at reflux temp (55°). The cooled mixture was treated with water (150 ml) and extracted with ether. Evaporation of the solvents (90°(bath)/2 mm) gave a mixture of (+)-**13d** and the recovered (+)-**11** as a residual red oil (10·6 g), $[\alpha]_D$ + 110° (*c* 1·2, EtOH); IR: 1450, 1340, 1140, 1100, 1080, 1000 and 810 cm^{-1}; ORD (*c* 6·6): $[M]_{589}$ + 750°, $[M]_{475}$ + 2000°, $[M]_{410}$ + 620° and $[M]_{350}$ + 2250°. Attempted purification of (+)-**13d** on column chromatography failed.

(+)-1-*Bromo*-2-(N-*α*-*pipecolylmethyl*)*ferrocene* (**13e**). The crude amino boric acid (+)-**13d** (10·2 g) dissolved in MeOH (50 ml) was added to a stirred soln of $CuBr_2$ (25 g, 110 mmoles) in water (500 ml), and the mixture was heated at 50° for 1·25 hr. Ether extraction followed by column chromatography on silica gel (benzene-ether elution) gave (+)-**13e** as a red oil (3·7 g, 37% based on **11**), $[\alpha]_D$ + 21° (*c* 1·3, EtOH); IR: 1445, 1370, 1100, 1070, 1000, 960 and 820 cm^{-1}; ORD (*c* 7·5): $[M]_{589}$ + 50°, $[M]_{540}$ 0°, $[M]_{490}$ − 125°, $[M]_{475}$ 0°, $[M]_{410}$ + 750° and $[M]_{350}$ + 630°. The picrate was prepared as usual and recrystallized from EtOH, m.p. ~ 183° (dec). (Found: C, 45·8; H, 4·4; N, 9·5. $C_{23}H_{25}BrFeN_4O_7$ requires: C, 45·6; H, 4·2; N, 9·3%).

(+)(1R)-1-*Bromo*-2-*hydroxymethylferrocene* (**14e**$_2$). The reaction of **13e** ($[\alpha]_D$ + 21°, 3·7 g, 9·8 mmoles) with excess MeI (40 g) in MeOH (40 ml) gave a crude methiodide (*ca* 5·1 g). The mixture of crude methiodide and 5·6% KOH aq (160 ml, 160 mmoles) was heated under reflux for 24 hr. Ether extraction followed by column chromatography (benzene-ether elution) gave a crude (+)-**14e**$_2$ as a yellow solid (1·13 g, 39%), $[\alpha]_D$ + 4·1° (*c* 2·1, PhH), which was contaminated by a small amount of hydroxymethylferrocene.

Pure sample of (+)-**14e**$_2$ was obtained by the reduction of **14e**$_3$. An etheral (10 ml) soln of (−)-**14e**$_3$ ($[\alpha]_D$ − 215°, 0·193 g, 0·7 mmole) was added to an ether (10 ml) soln of LAH (0·040 g, 2 mmoles) and the mixture was stirred for 10 min at room temp. Work-up gave (+)-**14e**$_2$ as a yellow solid (0·194 g, 100%), $[\alpha]_D$ + 6·3° (*c* 1·9, PhH) or $[\alpha]_D$ − 3·1° (*c* 1·9, EtOH), m.p. 72–73° (from hexane-ether) (*dl*-modification,[15] m.p. 70–71°); IR: 3200, 1380, 1300, 1245, 1100, 1060, 1000, 975 and 820 cm^{-1}; NMR: δ 1·78 (s, 1H), 4·20 (s, 7H) and 4·48 (s, 3H). (Found: C, 45·4; H, 4·1. Calc. for $C_{11}H_{11}BrFeO$: C, 44·8; H, 3·8%).

(−)(1R)-1-*Bromo*-2-*formylferrocene* (**14e**$_3$). Active MnO_2 (2·5 g, 29 mmoles) was added to a soln of crude (+)-**14e**$_2$ ($[\alpha]_D$ + 4·1°, 0·53 g, 1·8 mmoles) in $CHCl_3$ (30 ml) and the mixture was stirred overnight at 0°. Chloroform extraction followed by column chromatography (hexane-benzene elution) gave a pure sample of (−)-**14e**$_3$ as a red semisolid (0·34 g, 64%), $[\alpha]_D$ − 215° (*c* 0·27, EtOH); IR: 2900, 1690, 1440, 1400, 1370, 1260, 1100, 1020, 1000, 960, 820 and 740 cm^{-1}; NMR: δ 4·28 (s, 5H), 4·47 (m, 1H), 4·73 (m, 2H) and 10·05 (s, 1H); ORD (*c* 4·8): $[M]_{589}$ −700°, $[M]_{514}$ −1860°, $[M]_{466}$ 0°, $[M]_{450}$ +1500°, $[M]_{370}$ 0°, $[M]_{358}$ − 910° and $[M]_{352}$ 0°. The semicarbazone was prepared as usual and recrystallized from aqueous EtOH, m.p. 207–208° (dec). (Found: C, 41·1; H, 3·6; N, 11·8. $C_{12}H_{12}BrFeN_3O$ requires: C, 41·2; H, 3·5; N, 12·0%).

(+)(1R)-1-*Bromo*-2-*methylferrocene* (**14e**$_1$). To a soln of LAH (0·026 g, 0·7 mmole) in ether (10 ml) was added **14e**$_2$ ($[\alpha]_D$ + 5·5° (*c* 2·1, PhH), 0·33 g, 1·1 mmoles) in ether (10 ml) and then $AlCl_3$ (0·072 g, 0·54 mmole). The mixture was stirred for 5 hr at room temp. Ether extraction followed by column chromatography (hexane elution) gave (+)-**14e**$_1$ as orange crystals (0·33 g, 42%), m.p. 65–67°, $[\alpha]_D$ + 14° (*c* 2·6, PhH) or $[\alpha]_D$ + 8·1° (*c* 2·6, EtOH); IR: 1460, 1370, 1355, 1230, 1100, 1060, 1030, 990 and 810 cm^{-1}; NMR: δ 2·05 (s, 3H), 3·90 (m, 2H), 4·08 (s, 5H) and 4·28 (m, 1H); ORD (*c* 12·8): $[M]_{589}$ +33°, $[M]_{500}$ +44°, $[M]_{445}$ +280°, $[M]_{400}$ 0° and $[M]_{320}$ +120°. (Found: C, 47·3; H, 4·4. $C_{11}H_{11}BrFe$ requires: C, 47·4; H, 3·9%).

(−)(1S)-*Methyl* 2-*methylferrocene*-1-*carboxylate* (**14a**$_1$) *from* (+)(1R)-**14e**$_1$. A hexane soln of n-BuLi (1·0 N, 1 ml, 1 mmole) was added to a soln of (+)-**14e**$_1$ ($[\alpha]_D$ + 14·0°, 0·24 g, 0·86 mmole) in dry THF (10 ml) at 0° in the course of 5 min. The resulting red soln was stirred for 30 min at 0°, and dry CO_2 gas was bubbled in. The acidic product was extracted with ether and esterified with diazomethane. Work-up followed by column chromatography (hexane-benzene elution) gave (−)-**14a**$_1$ as a red oil (0·035 g, 16%), $[\alpha]_D$ − 4·0° (*c* 0·7, PhH) or 36% optical purity based on the highest rotation of 11°.[13] The IR and NMR spectra were superimposable on those of authentic sample.

α,α,′-Disubstituted biferrocenyls

(+)(1S,1′S)-2,2′-*Dimethylbiferrocenyl* (**15**) *from* (+)(1R)-**14e**$_1$. To Mg turnings (0·15 g, 6·3 mg atoms) activated with a drop of MeI under N_2 was added a soln of (+)-**14e**$_1$ ($[\alpha]_D$ + 12·0°, 0·30 g, 1·1 mmoles) and ethylene bromide (0·25 g, 1·3 mmoles) in dry THF (10 ml) at 30° in the course of 30 min. After the mixture was stirred for 2·5 hr at 40°, anhydrous $CoCl_2$ (0·10 g, 0·8 mmole) was added all at once at 0°. The mixture was allowed to stand overnight at room temp and decomposed with HCl aq. Ether extraction followed by column chromatography (hexane elution) gave a mixture of active biferrocenyl (+)-**15** and inactive *meso*-2,5′dimethylbiferrocenyl as an orange mass (0·090 g, 43%), which showed $[\alpha]_D$ + 340° (*c* 1·8, PhH). The composition ratio of the mixture was determined on the basis of NMR analysis:[18b] Me signal of 2,2′-isomer **15** appeared at δ 1·82 (55%) whereas that of 2,5′-isomer at δ 2·28 (45%). (Found: C, 66·0; H, 6·0. Calc. for $C_{22}H_{22}Fe_2$: C, 66·4; H, 5·5%).

(+)(1S,1′S)-2,2′-(*β*-*Oxapropylene*)*biferrocenyl* (**17**) *and* (+)(1S,1′S)-**15**. A soln of (+)-**11** ($[\alpha]_D$ +65° or

87% optical purity, 10 g, 34 mmoles) in ether (90 ml) and hexane (95 ml) was treated with a hexane soln of n-BuLi (0·58 N, 85 ml, 49 mmoles) at room temp for 44 hr. $TiCl_4$ (8·0 g, 42 mmoles) was added to an aliquot (120 ml) of this soln at −70° and the mixture was stirred overnight under allowing to warm to room temp. Stirring was continued for 48 hr at room temp and finally for 6 hr at reflux temp. Work-up gave a red oil (3·0 g), which contained a small amount of **16**. A mixture of dimethiodide (*ca* 5 g) of this crude diamine and Na-Hg (5·6%, 180 g, 0·44 g atom) in water (100 ml) was heated at 130° for 2·5 hr. Work-up followed by column chromatography gave two kinds of products. Hexane eluted methylferrocene (0·21 g) containing a trace amount of (+)-**15**. Benzene eluted a mixture of bis(ferrocenylmethyl) ether[22] and (+)-**17**, which formed an orange solid (0·11 g) showing $[\alpha]_D$ +30° (*c* 1·0, PhH). The composition ratio of (+)-**17** (12%) was determined as follows and the calculated chemical yield of **17** was 0·5% based on **11**.

The crude cyclic ether (+)-**17** (0·090 g, 0·22 mmole) in ether (2 ml) was added to a suspension of LAH (0·060 g, 1·6 mmoles) and $AlCl_3$ (0·080 g, 0·6 mmole) in ether (5 ml). The mixture was heated at reflux temp for 5 hr under stirring. Work-up followed by column chromatography (hexane elution) gave methylferrocene (0·066 g, 88%) and (+)-**15** (9 mg, 12%), which showed $[\alpha]_D$ +520° (*c* 0·18, PhH). The IR and NMR spectra were identical with those reported.[18]

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